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4 **Does digital finance foster industrial and green**
5
6 **transformation in China?**
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9

10 **Abstract**
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12 Purpose

13 This paper study the role of digital finance in driving industrial and green transformation by
14 considering regional heterogeneity. The result aim to provide insights for policymakers and
15 practitioners to develop targeted strategies for promoting sustainable industrial development
16 through the leveraging of digital finance and technological innovation.
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19 Design/methodology/approach

20 This paper examines how digital finance affects the industrial and green transformation in
21 China, considering its heterogeneity across various aspects and dimensions. It uses panel data
22 from 31 provinces and municipalities in China during 2011-2020 to analyse the relationship
23 between digital finance and industrial transformation, with technological innovation as a
24 mediating factor. The findings are robust and tested by using various robust and endogeneity
25 approaches.
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30 Findings

31 The results show that digital finance has a positive and significant impact on the advancement,
32 efficiency, and green aspects of industrial transformation, which is mediated by technological
33 innovation. As the levels of digital finance development and technological innovation improve,
34 the incentive effect of digital finance strengthens. Additionally, the positive impact of digital
35 finance on the efficiency of industrial transformation is only observed in the eastern regions,
36 while in the central and western regions, digital finance primarily influences the advancement
37 and green aspects of industrial transformation.
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42 Originality/value

43 This paper introduces the digital finance and ecological indicators into the analysis of industrial
44 structure transformation, presenting a unique contribution to existing literature. To our
45 knowledge, this is one of the first papers to include digital finance, technological innovation
46 and green transformation of industrial structure within the same research framework.
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50 This paper examines how digital finance affect the industrial and green transformation in China,
51 taking into account its heterogeneity across various aspects and dimensions. The paper uses
52 panel data from 31 provinces and municipalities during 2011-2020 to analyse the relationship.
53 The result presents that digital finance has positive and significant impact on the development
54 of the advancement, efficiency and green aspects of industrial transformation, mediated by
55 technological innovation. As the levels of digital finance development and technological
56 innovation continue to improve, the incentive effect of digital finance strengthens. Moreover,
57 the positive impact of digital finance on the efficiency of industrial transformation is only
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Keywords: digital finance; technology innovation; industrial transformation, green transformation; innovation

JEL: L16; P25; O53

1. Introduction

The transformation of the industrial structure has been a key aspect of China's economic development strategy since the late 20th century. As China's economy continues to grow, its industrial structure is constantly being optimized and improved. The evolution has progressed from a rapid industrialization to an efficiency transformation which focuses on knowledge-based, high-tech industries and services. However, this extensive economic development model has resulted in the excessive consumption of energy resources and has caused serious concerns for the ecological environment. To tackle these challenges, and to align with the global community's collective objective of transitioning towards a sustainable, low-carbon and environmentally friendly economy, China has the ambition of "striving to reach a carbon peak by 2030 and achieving carbon neutrality by 2060", which emphasizes the importance of actively fostering high-quality, intelligent, and green industrial transformation.

However, achieving high-quality green economic development requires significant investments, innovations, and collaborations between various stakeholders. This is where digital finance can play a crucial role. Digital finance refers to a variety of innovative financial products, financial services, financial software, and new means of customer communication and interaction provided by financial technology companies and various financial service providers (Gomber et al., 2018). As an emerging industry uniting digital technology and traditional finance, digital finance can effectively make up for the shortcomings of traditional finance and provide opportunities for industrial green transformation (Li et al., 2022). Examples of innovations include mobile banking, online payment systems, digital currencies, and Fintech or other financial technologies that use digital platforms and data analytics to provide financial services (Ozili, 2018). Digital finance is using various innovative technologies such as big data, cloud computing, and artificial intelligence to transform the traditional financial service model to a more efficient, accessible, and affordable business model. It helps to address traditional financial challenges, such as information asymmetry and adverse selection, by enhancing the efficiency and transparency of financial markets, providing easy access to funding sources, encouraging innovation, and fostering collaboration and coordination across sectors (Jefferson et al., 2012; Gomber et al., 2018; Demertzis et al., 2018). For example, digital finance based on the Internet and other digital means-based online financing improves the success rate of business financing (Mollick 2014).

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It also improves corporate investment by increasing the level of cash holdings and cutting debt financing costs of technology-based companies (Zhang & Chang, 2020). Digital finance also helps to improve the traditional financial system by reducing transaction costs in foreign trade (Ghosh & Chaudhury, 2020). Given its pivotal role in modern financial development, can digital finance serve as a new driving force to foster industrial and green transformation in China? What are the mechanisms and impacts of this process?

To answer these questions, this paper aims to investigate the underlying mechanism and the heterogeneity of the impact of digital finance on the industrial structure transformation. It employs a two-way fixed effect model to analyze the regional panel data from 31 provinces and municipalities in China between 2011 and 2020. Mediation effect and panel threshold models are applied to explore the underlying mechanism of the effect and introduce technological innovation as the transmission channel.

Our main contribution is to extend the existing literature by incorporating the green transformation dimension to enhance our comprehensive understanding of the industrial transformation and its efficiency, as well as enriching existing theories of the relationship between digital finance and economic development by considering nonlinear effects. These extensions provide a more comprehensive insight into the role of digital finance in industrial and green transformation. Our main result suggests that digital finance has a positive and significant impact on the development of the advancement, efficiency and green aspects of industrial transformation. This impact is mediated by technological innovation. As levels of digital finance development and technological innovation continue to improve, the incentive effect of digital finance on transformation strengthens. In addition, there is observable heterogeneity in the impact. Among the various sub-dimensions of digital finance, the depth of the adoption of digital finance has the most positive impact, followed by the digitalization degree and the coverage. In regional heterogeneity, the positive impact of digital finance of efficiency is only observed in the eastern regions. In the central and western regions of China, digital finance mainly influences the advancement and green aspects of industrial transformation. These outcomes contribute to the literature by providing empirical evidence and theoretical insights on the role of digital finance in sustainable industrial development.

This paper is structured as follows. Section 2 reviews the literature regarding the relationship between digital finance and industrial transformation, and proposes theoretical hypotheses. The research design is presented in section 3, followed by the empirical results in Section 4. Section 5 presents further studies on the heterogeneity and dynamics of the relationships between digital finance and industrial transformation.

2. Literature Review and Hypotheses

2.1. *The impact of digital finance on industrial transformation*

Through the application of digital technology, digital finance can help to address some of the traditional financial challenges that hinder industrial transformation. For example, digital finance can reduce information asymmetry and adverse selection problems by improving the credit information of enterprises. It helps to improve the credit support rate of enterprises from banks and other financial institutions and enables them to invest more in innovation and productivity (Jefferson et al., 2012; Gomber et al. 2018; Demertzis et al., 2018).

Digital finance can also provide tools for the traditional financial sector to innovate and to improve its risk management capabilities, allowing them to better serve the technological innovation activities of enterprises (Norden et al., 2014; Jagtiani & Lemieux, 2018; Rao et al., 2022). For instance, digital finance can help banks and other financial institutions to monitor and evaluate the risks and performance of their borrowers, and to offer more customized and flexible financial products and services to enterprises. Digital technology can strengthen the information and data processing capabilities of financial markets to efficiently carry out risk identification and green capital allocation (Feng et al., 2022), reducing the target bias of traditional financial services.

Moreover, the increased synergy between technology and finance can effectively improve the efficiency of corporate financing and corporate investment across sectors (Zhang & Chang, 2020). It can increase the accessibility and affordability of finance opportunities for enterprises. For example, it helps enterprises to access alternative sources of financing, such as online platforms, digital currencies, and crowdfunding, and lowers transaction costs and information barriers, allowing them to invest more in innovation and transformation. Easing liquidity constraints and improving the accessibility of payment systems also effectively promotes the income and consumption of growth households, helps them to save, borrow and transfer money more easily and securely, and allows them to access a wider range of financial products and services (Yi & Zhou, 2018). This can increase the income and consumption of households, which stimulates demand for services and the development of the service industry, which is a key component of industrial transformation. Therefore, we propose:

Hypothesis 1: *Digital finance has an impact on industrial transformation.*

However, digital finance fosters industrial transformation in various ways, depending on the dimensions, regions, and dynamic factors involved. For example, there is a ‘structural effect’ on enterprise technological innovation, with digital finance prompting more significant technological innovation in the regions with a poor financial development level compared with rich regions (Tang et al., 2020). Tian et al., (2021) presented empirical evidence on the endogeneity effect of digital finance in

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3 terms of the coverage breadth, application depth and digitization degree on easing the
4 capital mismatch across regions. Bruhn and Love (2014) investigated Mexican banks
5 and came to a similar conclusion. They found that strengthening digital financial
6 services and enhancing the rational flow of funds between industries benefits the
7 adjustment of industrial structure for low-income groups. Moreover, Li et al. (2020)
8 found that digital finance facilitates residents' consumption, by using mobile networks,
9 and plays a significant role in promoting the consumption expenditure of low- and
10 middle-income families. Yang and Wang (2021) also found that the level of economic
11 development heterogeneously influences the impact of digital finance on technological
12 innovation, entrepreneurship and human capital. In addition, the literature indicates the
13 nonlinear effect of digital economy on the traditional manufacturing industry. For
14 instance, Liu and Hui (2021) provide empirical evidence of the nonlinear effect of
15 digital economy on the traditional manufacturing industry by using threshold analysis
16 and observing provincial panel data in China from 2006 to 2018. Liu et al. (2023)
17 come to a similar conclusion by using digital economy scale and green financial
18 development support as threshold variables. It is important to understand the
19 heterogeneity of the impact of digital finance on industrial transformation, and to
20 identify the key factors that influence this relationship.
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28 **Hypothesis 2:** *Digital finance has heterogeneous effect on industrial transformation in*
29 *terms of dimensions, regions, and dynamic factors.*
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32 **2.2. The mediating effect of the technological innovation**

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34 Digital finance affects the industrial transformation through various channels and
35 pathways. One of the transmission channels is by promoting technological innovation.
36 Some studies have found that digital finance increases the efficiency of industries by
37 supporting innovation bodies and operational process. For example, Brown et al. (2012)
38 found that digital finance reduces the production costs of enterprises by promoting their
39 R&D innovation. Similar results in finance sectors were obtained by Pierrakis and
40 Collins (2013). They investigated the efficiency of financing and suggested that
41 financial costs are reduced after increasing technological innovation in the finance
42 process. Digital finance uses dynamic data from consumer platforms for credit and risk
43 precision assessment, alleviating the problems of high risk and high search costs arising
44 from information asymmetry and helping to optimize the allocation of financial
45 resources (Asongu et al., 2019). In manufacturing sectors, Chen and Zhang (2021)
46 found that enhancing the intensity of innovation and the degree of digitization facilitates
47 the servitization of manufacturing industry. In addition, Yin (2018) also found that
48 digital finance has a significant positive effect on China's industrial structure efficiency,
49 advancement and intra-industrial evolution by promoting digital innovation in payment
50 systems.
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57 There are some related studies in the literature on understanding the mediating role of
58 technological innovation on the impact of digital finance. Chihiro et al. (2018) analyzed
59 the path of digital finance's effect on structural industrial transformation and suggest
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3 that technological innovation can be considered as a transmission mechanism.
4 Reviewing examples from China, similar results are obtained in Yang and Wang (2021)
5 and Liu et al. (2021). Other researchers also studied the impact of digital finance
6 development on industrial structure transformation from the perspective of the
7 threshold effect (Tang et al., 2019; Ge & Zhang, 2021) and the spatial spillover effect
8 (He et al., 2020), using innovation as the mediating variable.
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12 **Hypothesis 3:** *Digital finance affects industrial transformation through promoting*
13 *technological innovation.*
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15 16 **2.3. The three aspects of Industrial transformation**

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18 Various approaches have been applied in previous literature to understand industrial
19 transformation in the traditional settings. In a single country study, Chenery and
20 Syrquin (1975) derived a normative model that uses population and national income
21 per capita as exogenous variables to determine the level of development of a country's
22 industrial structure. More aspects of industrial transformation are considered in sub-
23 dimensional levels across multiple countries, including industrial structure variation
24 (Krugman 1991), industrial structure efficiency and advancement (Xu & Zhang 2016;
25 Romano & Traù, 2017), upgrading of technology, product and process (Kailan et al.,
26 2019), and the magnitude, quality and pathway of industry adjustment (Huang et al.,
27 2013). Yu (2015) studied industrial transformation by emphasizing the structure's
28 transition from labor-intensive sectors to technology and knowledge-intensive sectors.
29 These are defined as Advancement aspects of industrial transformation in this paper.
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35 Zhou (1992) made an initial assessment of industrial structure transformation in China
36 based on a comparison of the output value and employment share of each industry,
37 aiming to understand the allocation of resources across industries. To understand the
38 level of industrial transformation under the evolution law of China's economic
39 structure, industrial transformation in China is further classified into industrial structure
40 efficiency and upgrading (Li & Hu, 2008; Han, 2016; Li & Deng, 2017). The Efficiency
41 aspect of industrial transformation is characterized by the effective coordination
42 between the inputs and outputs within each industry.
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47 Moreover, digital finance potentially accelerates the green transformation in industry.
48 Guo and Xie (2021) found that digital finance improves the efficiency of enterprises
49 with high pollution more significantly compared to green enterprises. To provide a
50 reference for establishing an industrial structure optimization judgment under
51 environmental uncertainty, and aid understanding of the impact of industrial
52 development on the environment, some recent studies considered factors relating to the
53 ecological environment. Yang and Shao (2018) incorporated environmental impact into
54 the evaluation index system to estimate the degree of optimization and upgrading of
55 China's industrial structure. Murillo-Zamorano (2005) and Ji et al. (2014) consider
56 energy consumption in their studies. To include the quality of water resources, Ren et
57 al. (2013) constructed a stochastic linear fractional programming model based on the
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3 uncertainty of the water environment.
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6 **Hypothesis 4:** *Digital finance has a positive impact on industrial transformation in*
7 *terms of Advancement, Efficiency and Green transformation.*
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10 **3. Research Design**

11 **3.1. Variable selection and calculation**

12 **3.1.1. Explained variables**

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16 The industrial transformation refers to the transformative process wherein the industrial
17 framework transitions from a low-level configuration, characterized by outdated
18 production patterns, to a more advanced form that comes with enhanced efficiency and
19 sustainability. For example, from a production-dominated manufacturing economy to a
20 service- and knowledge-based economy. Instead of considering the transformation in a
21 specific industry, we study the industry transformation at the macro level in each region.
22 Therefore, all the measurements in this paper are at the regional level. This paper
23 examines the impact of digital finance on industrial transformation by considering three
24 aspects: *Advancement (SH)*, *Efficiency (SR)*, and *Green (SE)*.
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29 Advancement (SH) denotes the industrial transformation characterized by a shift from
30 labor-intensive sectors to technology and knowledge-intensive sectors. It can be
31 indicated by the continuous flow of production factors from secondary industry towards
32 tertiary industries. Secondary industry refers to manufacturing sectors such as
33 automobile manufacturing, electronics production, machinery production, etc., while
34 tertiary industry represents the service sector, including a range of low-cost and high-
35 value industries such as retail, banking, healthcare, education, professional services and
36 so on. Following Yu (2015), Advancement is measured as the ratio of the added value
37 of the tertiary industry to the secondary industry. The larger the ratio, the higher the
38 level of Advancement. The added value is measured as the sum of the values produced
39 by those industries. With the equation:
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$$45 \text{SH} = Y_3 / Y_2$$

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47 Y_3 denotes the sum of values produced in tertiary industry while Y_2 represent the sum
48 of the values produced in secondary industry.
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51 Efficiency (SR) measures the efficient allocation of resources, including labor and
52 capital, across industries. This process ensures that the inputs and outputs of each
53 industry are effectively coordinated with one another. The industrial structure equality
54 (SR) is expressed by the Thiel Index:
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$$58 \text{SR} = \sum_{i=1}^n \left(\frac{Y_i}{Y} \right) \ln \left(\frac{Y_i / L_i}{Y / L} \right)$$

where, Y represents GDP of the region, L represents the total number of employees, Y_i/Y denotes the ratio of the added value of the i th industry to GDP, and L_i is the employment of the i th industry. i represents 2 or 3, which are Secondary or Tertiary industry. The larger the SR , the less efficient the industrial structure. In this paper, the reciprocal $1/SR$ is used to measure the efficiency degree of production factors across various industries. The larger the $1/SR$, the higher the level of industrial structure efficiency.

The Green (SE) index serves as a measure of the green performance of the industrial structure in terms of two aspects: energy utilization efficiency and pollution emission intensity. The energy utilization efficiency index is determined by the ratio of GDP to total energy consumption, while the pollution discharge intensity is calculated as the ratio of regional GDP to regional levels of wastewater, waste gas and industrial solid waste. To derive the Green index, the entropy weight method is employed to determine the weight of each indicator. A higher Green index value corresponds to improved energy efficiency and reduced pollution intensity. The detailed calculation process is as follows:

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| Data standardization processing: | $X_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})}$ |
| Weighting of sample indicator values: | $Y_{ij} = \frac{X_{ij}}{\sum_{i=1}^n X_{ij}}$ |
| Information entropy of each indicator: | $e_j = -\frac{1}{\ln(n)} \sum_{i=1}^n Y_{ij} \ln(Y_{ij})$ |
| Weights of each indicator: | $W_j = \frac{1 - e_j}{m - \sum_{j=1}^m e_j}$ |
| Composite score: | $S_i = \sum_{j=1}^m W_j \times X_{ij}$ |

where X_{ij} is the i th sample value of indicator j , n is the number of years, and m is the number of indicators. Finally, the composite index representing the Green level is obtained by summing up the composite scores of each indicator, and for convenience of analysis, the indicator is multiplied by 100.

3.1.2. Explanatory variables

Our core explanatory variable, Digital Inclusive Finance Index, is the regional digital financial index, which measures the development level of digital finance in each

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3 province of China. This index system is developed by the Institute of Digital Finance
4 at Peking University. It is a commonly used index in measuring digital finance in China
5 (Zhang and Lu, 2007, Yi and Zhou, 2018, and Zheng, Zhao, and Fan, 2021. It is a
6 comprehensive consolidated index with multiple indicators. It constructed using Ant
7 Financials' extensive database on digital inclusive finance, which includes data on
8 trading accounts and other relevant information. The compilation process involves
9 employing techniques such as the coefficient of variation method and analytic hierarchy
10 process. For a detailed explanation of the specific compilation process and
11 comprehensive index description, please refer to Guo et al. (2020).
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16 In this paper, we consider the total digital finance development index (DFI) and its three
17 sub-dimensions, which are: coverage breadth (DFC), application depth (DFD) and
18 digitization degree (DFS).
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21 *3.1.3. Mediating variable*

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24 Technological innovation (PJS) is adopted as the chosen mediating variable because
25 industrial transformation heavily relies on technological innovation. To ascertain the
26 level of technological innovation, various approaches are reviewed, including input
27 methods such as research and development (R&D) input intensity, and output methods
28 such as the number of patents granted. To capture the direct impact of R&D on
29 industrial transformation, this paper uses the number of patent applications granted per
30 10,000 people to measure technological innovation.
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34 *3.1.4. Control variables*

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37 (1) Level of economic development. The level of economic development in a certain
38 region reflects the living standard of residents, to a certain extent. In order to meet the
39 growing diversified needs of the people, relevant industries develop rapidly, and the
40 level of regional economic development is an important influencing factor for industrial
41 restructuring. This paper uses the logarithmic form of per capita GDP ($\ln(\text{PGDP})$) to
42 represent the level of economic development.
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46 (2) Foreign direct investment. The technology spillover and competition effects brought
47 by foreign direct investment have an impact on industrial transformation. However, the
48 economic growth stimulated by this influx of foreign capital may accelerate energy
49 consumption and environmental pollution in China, and its impact on industrial
50 transformation needs further verification. This paper uses the logarithmic form of the
51 per capita actual utilization of foreign direct investment ($\ln(\text{FDI})$) to represent the level
52 of foreign direct investment.
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56 (3) Degree of government intervention. In the process of continuous evolution of
57 industrial structure, government involvement through fiscal intervention will affect the
58 rational allocation of production factors and resources, thereby impacting regional
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economic development and the transformation of the industrial structure. This paper selects the proportion of fiscal expenditure to regional GDP as an indicator of the degree of government intervention (CZ).

(4) Level of consumption. Consumption is one of the three driving forces of economic development and plays a guiding role in production. Changes in consumption levels can lead to changes in consumption patterns, which in turn can cause changes in the structure of final products and further guide industrial restructuring. This paper measures the level of consumption (ln(PRC)) using the logarithmic form of per capita consumer expenditure.

3.2. Database

This study uses regional data which covers 31 provinces in China, with the time period spanning from 2011 till 2020, prior to the global pandemic. We collected data from various databases. The regional digital finance data is obtained from the Peking University Digital Inclusive Finance Index (2011-2020), while total energy consumption data is sourced from the China Energy Statistical Yearbook and Provincial Statistical Yearbooks. The industrial solid waste data is obtained from the China Environmental Statistical Yearbook. For the robust analysis, the output value of the six energy-consuming industries is from the China Industrial Statistics Yearbook and the Fourth Economic Census. The data on patent applications and authorizations is extracted from the China Science and Technology Statistical Yearbook. Other data is obtained from the National Bureau of Statistics, the China Statistical Yearbook, Provincial Statistical Yearbooks and Statistical Bulletins. The data relating to Tibet is obtained from Wind¹. The descriptive statistics and the correlations of the main variables are presented in Table 1 and Table 2.

Table 1 Descriptive Statistics

| Variable | Obs | Mean | Std. Dev. | Min | Max | VIF |
|----------|-----|---------|-----------|-------|---------|------|
| ind | 310 | 11.019 | 13.268 | 1.531 | 122.56 | |
| dfi | 310 | 216.235 | 97.03 | 16.22 | 431.928 | 2.78 |
| lngdp | 310 | 9.695 | 1 | 6.416 | 11.619 | 3.95 |
| lnfdi | 310 | 4.563 | 1.328 | .547 | 7.292 | 1.78 |
| cz | 310 | .297 | .21 | .12 | 1.354 | 3.36 |
| lnrc | 310 | 9.639 | .427 | 8.53 | 12.654 | 3.20 |

Table 2 Matrix of correlations

| Variables | (1) | (2) | (3) | (4) | (5) | (6) |
|-----------|-------|-----|-----|-----|-----|-----|
| (1) ind | 1.000 | | | | | |

¹ Wind is a financial information database and research platform widely used in China.

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|-----------|--------|--------|--------|--------|--------|-------|
| (2) dfi | 0.377 | 1.000 | | | | |
| (3) lngdp | 0.314 | 0.373 | 1.000 | | | |
| (4) lnfdi | 0.504 | 0.171 | 0.530 | 1.000 | | |
| (5) cz | -0.228 | -0.110 | -0.805 | -0.481 | 1.000 | |
| (6) lnrc | 0.794 | 0.725 | 0.501 | 0.504 | -0.356 | 1.000 |

3.3. Model specification

This paper uses a bidirectional fixed-effects model for the baseline regression analysis. The model is as follows:

$$ISR_{it} = \alpha_0 + \alpha_1 DFI_{it} + \alpha_2 \ln(PGDP_{it}) + \alpha_3 \ln(FDI_{it}) + \alpha_4 CZ_{it} + \alpha_5 \ln(PRC_{it}) + \lambda_i + \eta_t + \varepsilon_{it} \quad (1)$$

The explanatory variable ISR is the level of industrial transformation in province i in year t , specifically Advancement (SH), Efficiency (SR) and Green (SE). The core explanatory variable DFI is the digital financial index in province i in year t . $PGDP$, FDI , CZ and PRC are control variables that may affect industrial transformation, namely, the level of economic development, foreign direct investment, the degree of government intervention and the level of consumption. λ denotes an individual fixed effect, η represents a time fixed effect and ε is a random disturbance term.

To further understand the mechanism of influence of digital finance on industrial transformation in China, and to examine whether technological innovation plays a mediating role, a mediating effect model is developed as follows:

$$PJS_{it} = \beta_0 + \beta_1 DFI_{it} + \beta_2 \ln(PGDP_{it}) + \beta_3 \ln(FDI_{it}) + \beta_4 CZ_{it} + \beta_5 \ln(PRC_{it}) + \lambda_i + \eta_t + \varepsilon_{it} \quad (2)$$

$$ISR_{it} = \zeta_0 + \zeta_1 DFI_{it} + \zeta_2 PJS_{it} + \zeta_3 \ln(PGDP_{it}) + \zeta_4 \ln(FDI_{it}) + \zeta_5 CZ_{it} + \zeta_6 \ln(PRC_{it}) + \lambda_i + \eta_t + \varepsilon_{it} \quad (3)$$

where PJS represents the mediating variable, which is the level of technological innovation.

Prior to conducting the regression analysis, the variance inflation factor (VIF) was computed and it is below 5. This indicates that the models do not suffer from multicollinear issues and are reasonable.

4. Empirical Results

4.1. Benchmark regression analysis

Based on the results of the Hausman test (Hahn, Hausman, and Kuersteiner 2007), this paper uses a panel bidirectional fixed-effects model to test the impact of digital finance on industrial transformation. Table 3 shows the results of the benchmark regressions based on equation (1).

Table 3 Regression results of the benchmark model

| Variables | (1) Advancement | (2) Efficiency | (3) Green |
|------------------|----------------------|----------------------|----------------------|
| Digital finance | 0.559*** (4.87) | 0.186*** (4.90) | 0.298*** (7.99) |
| GDP | -0.806*** (-4.72) | -0.249*** (-4.41) | -0.122** (-2.205) |
| FDI | -0.021 (-1.05) | -0.062 (-0.94) | 0.033* (1.81) |
| Gov Intervention | 1.876*** (4.57) | 0.151 (1.12) | -0.185 (-1.39) |
| Consumption | -0.118** (-2.09) | 0.310*** (16.53) | -0.050*** (-2.73) |
| Constant | 9.867*** (5.41) | -0.275* (-1.91) | 1.678*** (2.84) |
| Region effects | yes | yes | yes |
| Time effects | yes | yes | yes |
| Observed values | 310 | 310 | 310 |
| R ² | 0.776 | 0.641 | 0.751 |

Note: ***, **, * denote significance levels at 1%, 5% and 10% respectively, with *t*-values in brackets, as in the following tables.

According to Table 3, after controlling for region and time fixed effects, all coefficients of digital finance exhibit significant positive effects at the 1% significance level. Digital finance has the most significant impact on the Advancement aspects of industrial transformation. A one standard deviation increase in Advancement is associated with 55.9% change in digital finance, while Efficiency experiences 18.6% increase, and Green transformation sees 19.8% increase. These results indicate that digital finance plays an important role in promoting industrial transformation, in particular in the advancement progress. It suggests that the current development of digital finance effectively fosters the regional growth of high-tech industries, green industries and other emerging sectors by alleviating financing constraints, optimizing resource allocation efficiency and improving risk management practices. Consequently, these factors highly incentivize industrial transformation.

Regarding control variables, economic development exhibits significant negative effects in all three models. It suggests that traditional economic development has yet to undergo intensive transformation. The economic growth of China continues to rely on labor-intensive and resource-intensive industries, hindering industrial transformation. Furthermore, imbalances in economic development have exacerbated regional disparities, further slowing down industrial structure transformation. Foreign direct investment has a negative but insignificant effect on the Advancement and Efficiency of transformation, while demonstrating a positive and significant effect on Green transformation. This suggests that the introduction and efficient utilization of foreign investment drives a technological spillover effect that enhances green production

efficiency. In addition, government intervention exhibits a significant positive effect on Advancement and a positive but insignificant effect on Efficiency. However, it demonstrates a negative but insignificant impact on the Green transformation. These findings indicate that the government places greater emphasis on the advancement of the industrial structure and provides stronger support for the tertiary industry. As for the consumption level, it reveals that consumption has a negative impact on the Advancement and Green transformation and a positive impact on the Efficiency of industrial transformation. This suggests that the consumption level remains imbalanced, posing challenges for transforming the industrial structure.

4.2. Mediating effect test

In this study, a stepwise test of mediating effect is employed to examine the potential role of technological innovation as a mediating channel in facilitating industrial transformation through digital finance. The results are shown in Table 4.

Table 4 Regression results of mediating effect test

| Variables | (1) Innovation | (2) Advancement | (3) Efficiency | (4) Green |
|------------------|-----------------------|----------------------|----------------------|----------------------|
| Digital Finance | 0.393*** (11.48) | 0.330** (2.38) | 0.067 (1.49) | 0.079** (2.02) |
| Innovation | | 0.583*** (2.86) | 0.303*** (4.61) | 0.056*** (9.64) |
| GDP | -21.510*** (-4.23) | -0.681*** (-3.91) | -0.184*** (-3.27) | -0.002 (-0.04) |
| FDI | -0.035 (-0.06) | -0.021 (-1.06) | -0.007 (-0.96) | 0.004 (0.63) |
| Gov Intervention | -16.920 (-1.38) | 1.975*** (4.86) | 0.203 (1.54) | -0.091 (-0.79) |
| Consumption | -0.460 (-0.27) | -0.116** (-2.07) | 0.311*** (17.23) | -0.048*** (-3.00) |
| Constant | 222.8*** (4.11) | 8.569*** (4.62) | -0.949 (-1.59) | 0.439 (0.83) |
| Region effects | yes | yes | yes | yes |
| Time effects | yes | yes | yes | yes |
| Observed values | 310 | 310 | 310 | 310 |
| R ² | 0.704 | 0.782 | 0.667 | 0.668 |
| Sobel Z | - | 2.777 | 4.277 | 7.385 |

The first column in Table 4 shows that the coefficient representing the impact of digital finance on technological innovation is significantly positive. This implies a notable positive impact of digital finance on technological innovation, with a one standard

deviation increase in technological innovation is associated with 39.3% increase in digital finance. After introducing the mediating variable of the technological innovation index to the benchmark model, all estimated coefficients related to technological innovation display significant positive effects, while the impact of digital finance on Efficiency becomes insignificant. The coefficients for Advancement and Green transformation remain significantly positive, with a one standard deviation increase associated with a 33% and 7.9% rise in digital finance. However, these values have decreased compared to the benchmark results, which were 55.9% and 19.8%. This indicates that a partial mediation effect exists between digital finance and industrial advancement and green development. There is a full mediation effect between digital finance and Efficiency development. These findings suggest that digital finance influences industrial transformation through promoting technological innovation, such as by providing support for innovation subjects and activities.

4.3 Instrumental Variable Method

To address the potential endogeneity issue, this paper employs the instrumental variable method for endogeneity. The level of Internet development is closely related to the development of digital finance, and the development of the Internet is driven by long-term economic development and technological progress, which is not directly related to the upgrading of industrial structure, and meets the exogenous requirement of instrumental variables. Therefore, with reference to Xie et al. (2018), the level of Internet development is adopted as an instrumental variable, while drawing on Huang et al.'s (2019) idea of constructing an Internet development index to represent the level of Internet development. This paper standardizes the four indicators, namely, the penetration rate of mobile telephones, the number of employees in the field of information transmission and computers, the number of Internet broadband access ports, and the total amount of per capita telecommunication services. An entropy method is used to use the Internet development index (HLW) to measure the level of Internet development in each province, which is estimated by the two-stage least squares (2SLS) method. The one-stage equation is as follows:

$$DF_{it} = \chi_0 + \chi_1 HLW_{it} + \chi_2 \ln PGDP_{it} + \chi_3 \ln FDI_{it} + \chi_4 CZ_{it} + \chi_5 \ln PRC_{it} + \lambda_t + \eta_t + \varepsilon_{it}$$

To verify whether the level of Internet development is a valid IV for digital finance, the "non-identifiable" test and the weak instrumental variable test are conducted. According to Table 5, the Kleibergen-Paap rk LM statistic is 17.126, which passes the "non-identifiable" test at 1% significance level, indicating that the level of Internet development as an instrumental variable is identifiable. The Cragg-Donald Wald F statistic is 34.904 and Kleibergen-Paap rk Wald F statistic is 21.903, which are greater than the F-critical value of 16.38 at the 10% level, and the hypothesis of weak instrumental variables is rejected. In addition, the instrumental variables are exactly identified due to the equal number of endogenous and instrumental variables. The first-stage regression shows that the coefficient of the Internet development index is 0.76, which is significantly positive, indicating that there is a significant positive correlation between the level of Internet development and digital finance, reflecting the validity of

the instrumental variables selected in this paper. The results of the two-stage regression show that after using the instrumental variables, the positive impact of digital finance on the industrial structure advancement, efficiency and green development remain significant and are all consistent with the results of the benchmark regression in the previous section.

Table 5 Regression results of instrumental variables

| variables | One-stage regression | Two-stage regression | | |
|-------------------------------------|----------------------|----------------------|----------------------|---------------------|
| | DFI | SH | SR | SE |
| HLW | 0.760*** (5.91) | | | |
| DFI | | 1.061** (3.13) | 0.709*** (4.99) | 0.572*** (4.90) |
| lnPGDP | 0.288*** (3.40) | -0.936*** (-4.90) | -0.384*** (-4.81) | -0.193** (-2.93) |
| lnFDI | 0.022** (2.22) | -0.038* (-1.67) | -0.024** (-2.53) | -0.006 (-0.78) |
| CZ | 0.200 (0.96) | 1.843*** (4.44) | 0.117 (0.67) | -0.203 (-1.42) |
| lnPRC | 0.052* (1.83) | -0.147** (-2.45) | 0.280*** (11.19) | -0.066** (-3.18) |
| Region effect | yes | yes | yes | yes |
| Time effect | yes | yes | yes | yes |
| Kleibergen-Paap rk LM statistic | 17.126*** | | | |
| Cragg-Donald Wald F statistic | 34.904** | | | |
| Kleibergen-Paap rk Wald F statistic | 21.903*** | | | |
| Observations | 310 | 310 | 310 | 310 |
| R ² | - | 0.759 | 0.383 | 0.459 |

4.4. Robustness tests

4.4.1. Substitution of explanatory variables

To assess the robustness of our findings, we conducted additional analyzes by reconstructing three explanatory variables. Advancement is represented by the proportion and weights of the three industrial output values, while Efficiency is measured using the structural deviation index. In addition, the Green transformation was evaluated through the proportion of sales output value from polluting industries to regional GDP, with polluting industries represented by the six high-energy-consuming

industries in the National Economic Classification. The results presented in Table 6 are consistent with the baseline model, indicating that digital finance maintains a significant positive effect across all three models.

Table 6 Regression results of substitute explained variables

| Variables | (1) Advancement II | (2) Efficiency II | (3) Green II |
|------------------|-----------------------|----------------------|----------------------|
| Digital Finance | 0.045** (2.48) | 0.066*** (4.31) | -0.108* (-1.84) |
| GDP | -0.151*** (-5.61) | -0.043* (-1.87) | 0.527*** (6.04) |
| FDI | 0.003 (1.03) | 5.56e-05 (0.02) | -0.006 (-0.57) |
| Gov Intervention | 0.108* (1.68) | -0.019 (-0.36) | 0.912*** (4.35) |
| Consumption | 0.007 (0.80) | -0.008 (-1.06) | 0.003 (0.11) |
| Constant | 3.766*** (13.15) | 0.531** (2.19) | -5.133*** (-5.52) |
| Region effects | yes | yes | yes |
| Time effects | yes | yes | yes |
| Observed values | 310 | 310 | 310 |
| R ² | 0.861 | 0.202 | 0.593 |

4.4.2. Exclusion of municipalities

Inequality in economic development and variances in resource endowments across different regions in China may influence the effect of digital finance on industrial transformation. Being centrally-administered municipalities, Beijing, Tianjin, Shanghai and Chongqing stand out as regions with substantial political and economic advantages compared with other regions. In order to ensure the accuracy of the results, the data from these four municipalities is excluded from the total sample. The estimated results presented in Table 7 show that the coefficients and significance remain consistent with previous findings.

Table 7 Regression results excluding municipalities

| Variables | (1) Advancement | (2) Efficiency | (3) Green |
|-----------------|--------------------|--------------------|--------------------|
| Digital Finance | 0.338*** (3.36) | 0.184*** (4.27) | 0.175*** (8.13) |
| GDP | -0.209 | -0.213*** | -0.059* |

| | | | |
|------------------|----------------------|---------------------|--------------------|
| | (-1.28) | (-3.03) | (-1.68) |
| FDI | -0.059*** (-3.41) | -0.009 (-1.20) | -0.004 (-1.12) |
| Gov Intervention | 2.934*** (7.36) | 0.220 (1.29) | -0.158* (-1.85) |
| Consumption | -0.032 (-0.67) | 0.316*** (15.68) | -0.009 (-0.90) |
| Constant | 2.773* (1.78) | -0.719 (-0.95) | 0.701* (1.86) |
| Region effects | yes | yes | yes |
| Time effects | yes | yes | yes |
| Observed values | 270 | 270 | 270 |
| R ² | 0.833 | 0.650 | 0.732 |

4.4.3. Adjustment of the sample interval

The year 2013, marked by the birth of Yu'E Bao, is widely considered to be the beginning of China's digital financial development. Given the substantial growth of digital finance in China since 2013, we reset the starting point of the study to 2013 and shorten the sample interval to 2013-2020 as part of the robustness test. As shown in Table 8, all estimated coefficients are consistent with the results of the benchmark regression, which confirms the reliability of our results.

Table 8 Regression results of the shortened sample interval

| Variables | (1) Advancement | (2) Efficiency | (3) Green |
|------------------|----------------------|----------------------|---------------------|
| Digital Finance | 0.359*** (3.02) | 0.194*** (4.60) | 0.259*** (5.64) |
| GDP | -0.807*** (-3.85) | -0.263*** (-3.53) | -0.138* (-1.70) |
| FDI | -0.025 (-1.26) | -0.007 (-0.97) | 0.003 (0.35) |
| Gov Intervention | 1.785*** (4.49) | 0.152 (1.08) | -0.182 (-1.19) |
| Consumption | -0.065 (-1.29) | 0.295*** (16.53) | -0.041** (-2.09) |
| Constant | 9.351*** (4.18) | -0.222 (-0.28) | 1.519* (1.76) |
| Region effects | yes | yes | yes |
| Time effects | yes | yes | yes |
| Observed values | 248 | 248 | 248 |
| R ² | 0.758 | 0.688 | 0.502 |

5. Further analysis

5.1. Digital finance by dimensions

To further understand the implication of digital finance to industry transformation, we examined three sub-dimensions of its development: Digital Finance coverage (DFC), Digital Finance Depth (DFD) and Digital Finance Scale (DFS). DFC measures the extent to which digital financial services are accessible to the population. DFD represents the level of digital financial service usage by the population, while DFS measures the degree of financial digitization. As seen in Table 9, 10 and 11, the three sub-dimensions demonstrate varying results. According to Table 9, digital finance coverage has a significant positive effect on advancement transformation, while its impact on efficiency and green transformation is not statistically significant.

Table 9 Regression results of digital finance coverage

| Variables | (1) Advancement | (2) Efficiency | (3) Green |
|------------------|----------------------|----------------------|-------------------|
| DF Coverage | 0.332* (1.83) | 0.074 (1.24) | -0.052 (-0.82) |
| GDP | -0.786*** (-4.20) | -0.229*** (-3.69) | -0.026 (-0.40) |
| FDI | -0.087 (-0.42) | -0.014 (-0.20) | 0.015** (2.05) |
| Gov Intervention | 1.865*** (4.37) | 0.153 (1.08) | -0.158 (-1.06) |
| Consumption | -0.105* (-1.78) | 0.316*** (16.08) | -0.031 (-1.49) |
| Constant | 9.598*** (4.78) | -0.515 (-0.77) | 0.578 (0.83) |
| Region effects | yes | yes | yes |
| Time effects | yes | yes | yes |
| Observed values | 310 | 310 | 310 |
| R ² | 0.610 | 0.759 | 0.444 |

Table 10 shows that digital finance depth has a positive effect on all aspects of the industrial transformation at the 1% significance level. One standard deviation increase in Advancement, Efficiency and Green transformation, associates with 22.5%, 6.3% and 15.1% increase in digital finance depth, respectively. In terms of the magnitude of the coefficients, digital finance depth contributes the most to advancement, followed by green and efficiency transformation. Similar results are obtained in Table 11. The digital finance scale drives the industrial transformation overall. These results suggest

that the convenience and low cost of digital financial services attract innovative and entrepreneurial entities and digital finance plays a significant role in optimizing resource allocation for industrial transformation.

Table 10 Regression results of digital finance depth

| Variables | (1) Advancement | (2) Efficiency | (3) Green |
|------------------|----------------------|----------------------|---------------------|
| DF Depth | 0.225*** (3.79) | 0.063*** (3.20) | 0.151*** (7.95) |
| GDP | -0.690*** (-4.03) | -0.209*** (-3.67) | -0.064 (-1.17) |
| FDI | -0.009 (-0.43) | -0.002 (-0.26) | 0.009 (1.40) |
| Gov Intervention | 1.894*** (4.54) | 0.158 (1.14) | -0.178 (-1.33) |
| Consumption | -0.099* (-1.73) | 0.317*** (16.58) | -0.042** (-2.27) |
| Constant | 8.539*** (4.69) | -0.733* (-1.81) | 1.017* (1.75) |
| Region effects | yes | yes | yes |
| Time effects | yes | yes | yes |
| Observed values | 310 | 310 | 310 |
| R ² | 0.768 | 0.623 | 0.550 |

Table 11 Regression results of digital finance scale

| Variables | (1) Advancement | (2) Efficiency | (3) Green |
|------------------|----------------------|----------------------|---------------------|
| DF Scale | 0.164*** (4.07) | 0.070*** (5.40) | 0.100*** (7.71) |
| GDP | -0.681*** (-3.99) | -0.209*** (-3.80) | -0.057 (-1.03) |
| FDI | -0.015 (-0.77) | -0.006 (-0.88) | 0.006 (0.80) |
| Gov Intervention | 1.950*** (4.69) | 0.180 (1.34) | -0.143 (-1.06) |
| Consumption | -0.098* (-1.72) | 0.315*** (17.09) | -0.040** (-2.18) |
| Constant | 8.475*** (4.67) | -0.711 (-1.21) | 0.958* (1.68) |

| | | | |
|-----------------|-------|-------|-------|
| Region effects | yes | yes | yes |
| Time effects | yes | yes | yes |
| Observed values | 310 | 310 | 310 |
| R ² | 0.770 | 0.647 | 0.545 |

The comprehensive analysis of three sub-dimensions of digital finance on various aspects of industrial transformation shows that the application depth of digital finance yields the most positive impact on industrial transformation, followed by the digitalization scale, and finally the coverage. This implies that digital finance drives industrial transformation overall, but mostly through its depth and scale. To drive industrial transformation further, in particular Green and Efficiency measures, the accessibility of digital finance to the population needs to be further explored.

5.2. Digital finance by regions

Taking into account the variations in resource endowments and levels of economic and social development between regions in China, there exists possible regional heterogeneity regarding the impact of digital finance on industrial transformation. In this paper, the total sample is divided into two parts: the eastern region and the central and western regions. Regional heterogeneity is then analyzed using a sub-sample regression approach, with the empirical results presented in Table 12.

The Advancement and Green elements of industrial transformation are significantly positive in both the eastern and the central and western regions. However, Efficiency is only significantly positive in the eastern region, while is not statistically significant in the central and western regions, despite indicating a positive effect. This suggests that, in the eastern region, digital finance facilitates the optimization and transformation of all aspects of the industrial structure, while in the central and western regions, it primarily exhibits a more prominent effect on high-tech industries and environmentally-friendly industries. From the aspects of general effect, the impact of digital finance is relatively weaker in the central and western regions compared to the eastern regions. This regional heterogeneity can be attributed to several factors. The eastern regions of China have the first-mover advantages in terms of talent, technology and location, along with superior financial facilities. These advantages contribute to the rapid development of digital finance and accelerate the provision of digital financial services for industrial transformation. Conversely, the central and western regions exhibit lower levels of economic development. Their economy relies on labor-intensive industries, such as mining and agriculture. Limitations in infrastructure, talent availability and technological innovation restrict the employment of digital finance.

Table 12 Results of regional heterogeneity

| Variables | Eastern Regions | | | Central and Western Regions | | |
|-----------|--------------------|-------------------|--------------|-----------------------------|-------------------|--------------|
| | (1) Advancement | (2) Efficiency | (3) Green | (1) Advancement | (2) Efficiency | (3) Green |

| | | | | | | |
|------------------|---------------------|---------------------|------------------------|---------------------|--------------------|----------------------|
| Digital Finance | 0.706** (2.51) | 0.235** (2.11) | 0.440** * (4.27) | 0.170*** (5.29) | 0.038 (1.43) | 0.053* (1.96) |
| GDP | -0.557** (-1.12) | -0.077 (-0.39) | -0.202 (-1.11) | -0.103** (-2.12) | 0.05 (1.25) | 0.087** (2.11) |
| FDI | 0.031 (0.50) | -0.137 (-0.56) | 0.044* (1.96) | 0.557 (1.46) | -0.528* (-1.68) | -0.269 (-0.83) |
| Gov Intervention | 0.422 (0.29) | 0.881 (1.51) | -0.648 (-1.20) | 0.235*** (2.83) | 0.268*** (3.92) | -0.064 (-0.91) |
| Consumption | -0.095 (-1.26) | 0.320*** (10.75) | -0.046* (-1.68) | -0.128** (-2.50) | -0.077* (-1.77) | -0.200*** (-4.58) |
| Constant | 7.515* (1.86) | -2.282* (-1.78) | 2.272 (1.56) | 4.341*** (10.61) | 0.123 (0.37) | 0.966*** (2.78) |
| Region effects | yes | yes | yes | yes | yes | yes |
| Time effects | yes | yes | yes | yes | yes | yes |
| Observed values | 110 | 110 | 110 | 200 | 200 | 200 |
| R ² | 0.786 | 0.721 | 0.650 | 0.859 | 0.474 | 0.717 |

5.3. Threshold effect analysis

The preceding analysis provides empirical evidence on the nonlinear dynamic effects of digital finance in promoting industrial transformation through the enhancement of technological innovation. Digital finance increases the level of technological innovation, which, in turn, influences the development of digital finance as well. Furthermore, as science and technology continue to be effectively integrated with financial services, the rapid development of digital finance is expected to further enhance its influence on industrial transformation. To examine the nonlinear dynamics of the relationship between these variables, a panel threshold model is employed. The Total Digital Finance Index and the level of technological innovation are considered as “threshold variables”. We follow Hansen (2000)’s threshold model, an example of the single threshold model, as follows:

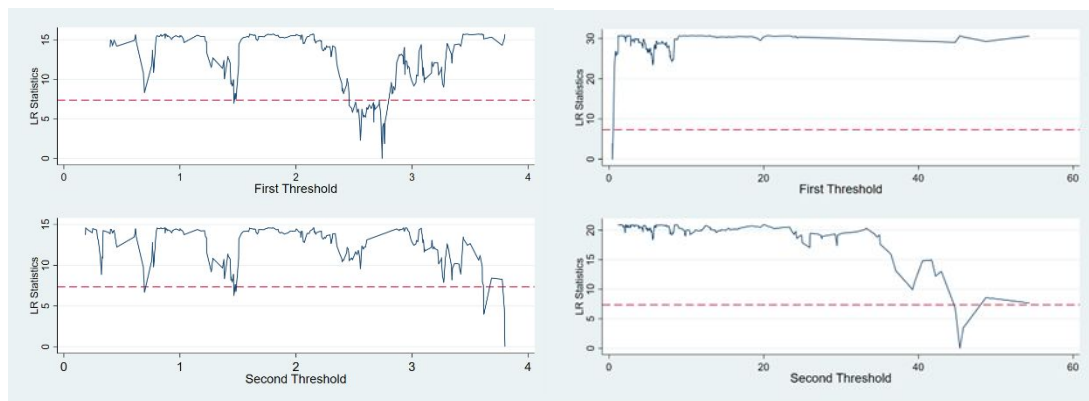
$$\begin{aligned}
 ISR_{it} = & \phi_0 + \phi_1 DFI_{it} \times I(q_{it} \leq \gamma) + \phi_2 DFI_{it} \times I(q_{it} > \gamma) + \phi_3 \ln(PGDP_{it}) \\
 & + \phi_4 \ln(FDI_{it}) + \phi_5 CZ_{it} + \phi_6 \ln(PRC_{it}) + \lambda_t + \eta_t + \varepsilon_{it}
 \end{aligned}$$

where q is the threshold variable, and $I(\mathbf{Q})$ is an indicator function which takes the value 1 or 0: 1 if the conditions in the brackets are met, otherwise it takes 0. γ is a specific threshold value.

Before carrying out threshold estimation, it is necessary to test whether there is a threshold effect. The threshold test results are shown in Table 13. A multiple threshold self-sampling test is employed. The results indicate that the incentive effect of digital finance in all aspects of industrial transformation exhibits a single threshold characteristic, which is determined by the levels of digital financial development and technological innovation.

Table 13 Threshold test results

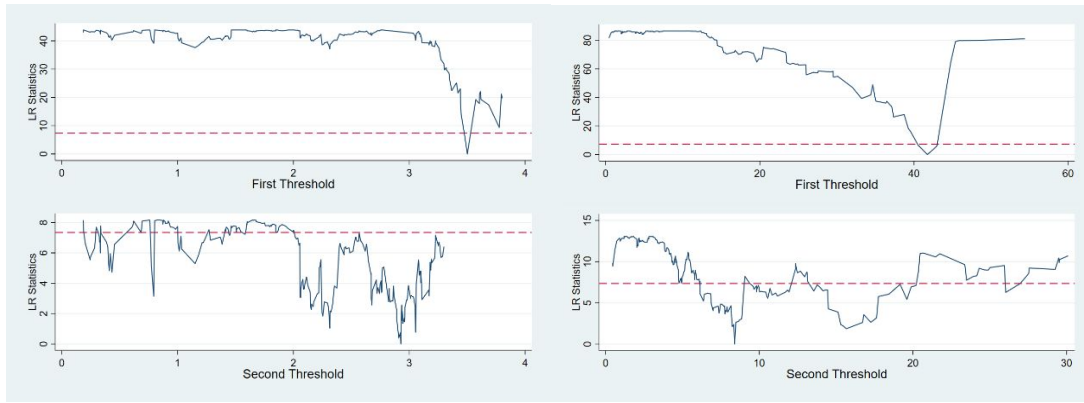
| Explained variable | Threshold variable | Threshold type | Threshold value | <i>p</i> -value | 95% confidence interval |
|--------------------|--------------------|------------------|-----------------|-----------------|-------------------------|
| Advancement | Digital finance | Single threshold | 2.743 | 0.0800 | [2.5297, 2.7608] |
| | Innovation | Single threshold | 41.732 | 0.0033 | [40.0401, 42.2284] |
| Efficiency | Digital finance | Single threshold | 3.303 | 0.0800 | [3.2642, 3.3192] |
| | Innovation | Single threshold | 0.460 | 0.0667 | [0.4492, 0.6000] |
| Green | Digital finance | Single threshold | 3.288 | 0.0667 | [3.1869, 3.2994] |
| | Innovation | Single threshold | 45.372 | 0.000 | [44.7595, 45.8214] |



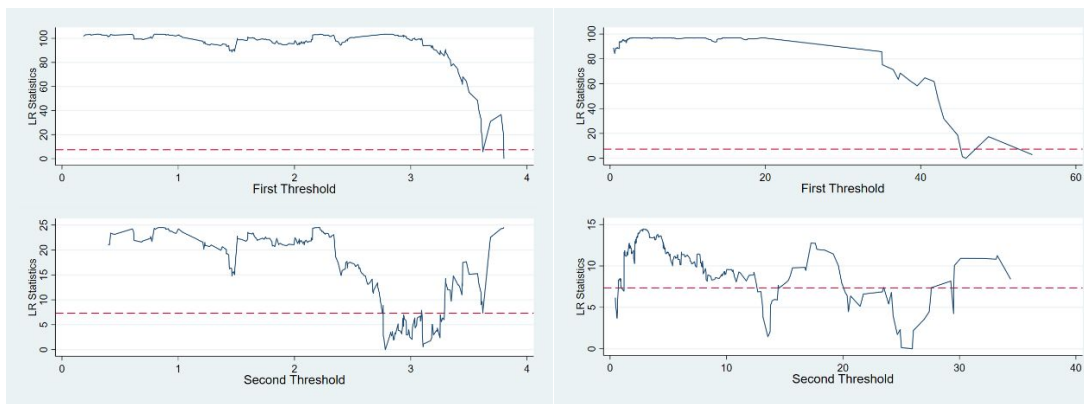
a) Digital financial development

b) Technological innovation

Fig. 1 LR diagram of threshold variable (industrial advancement transformation)



a) Level of digital financial development b) Level of technological innovation
 Fig. 2 LR diagram of threshold variable (industrial efficiency transformation)



a) Level of digital financial development b) Level of technological innovation
 Fig. 3 LR diagram of threshold variable (industrial green transformation)

Figures 1, 2, and 3 present the LR diagrams illustrating the threshold variables of the digital financial development level and technological innovation level for the Advancement, Efficiency and Green level of the industrial transformation. These diagrams provide a more intuitive representation of a single threshold effect.

The threshold regression results in Table 14 show that when the level of digital finance development surpasses the threshold of 2.743, the coefficient representing its effect on the industrial structure advancement significantly increases from 0.51 to 0.543. This indicates that as digital finance development continues to improve, its positive contribution to the industrial structure advancement becomes more obvious. Similarly, when the development level of digital finance crosses the threshold of 3.303 and 3.288 respectively, its significant positive effect on the Efficiency and Green elements of industrial structure progressively strengthens. It implies that digital finance development plays a non-linear moderating role in its effect on the Efficiency and Green elements of industrial structure.

Table 14 Regression results of threshold of digital financial development level

| Variable | (1) Advancement | (2) Efficiency | (3) Green |
|-------------------------|----------------------|----------------------|----------------------|
| DFI (DFI $\leq\gamma$) | 0.510*** (4.43) | | |
| DFI (DFI $>\gamma$) | 0.543*** (4.77) | | |
| DFI (DFI $\leq\gamma$) | | 0.083* (1.70) | |
| DFI (DFI $>\gamma$) | | 0.095** (2.05) | |
| DFI (DFI $\leq\gamma$) | | | 0.192*** (4.07) |
| DFI (DFI $>\gamma$) | | | 0.205*** (4.56) |
| GDP | -0.830*** (-4.90) | -0.232*** (-4.17) | -0.106* (-1.94) |
| FDI | -0.023 (-1.14) | -0.006 (-0.85) | 0.004 (0.57) |
| Gov Intervention | 1.775*** (4.34) | 0.138 (1.03) | -0.209 (-1.60) |
| Consumption | -0.112** (-2.00) | 0.313*** (16.98) | -0.047*** (-2.61) |
| Constant | 10.115*** (5.60) | -0.437 (-0.74) | 1.532*** (2.64) |
| Region effects | yes | yes | yes |
| Time effects | yes | yes | yes |
| Observed values | 310 | 310 | 310 |
| R ² | 0.781 | 0.654 | 0.571 |

The threshold regression results in Table 15 show that the coefficient of digital finance significantly decreases from 1.016 to 0.609 when the level of technological innovation crosses the threshold of 41.732. It indicates a non-linear effect of digital finance on the Advancement of industrial structure. The facilitative effect is strongest when the level of technological innovation begins to rise. As the level of technological innovation continues to rise, the facilitative effect slightly diminishes, but the overall effect remains strong. Regarding Efficiency, it is only when the level of technological innovation exceeds the threshold of 0.46 that digital finance exhibits a significant positive impact on Efficiency. This indicates that the continuous improvement in technological innovation contributes to the development of digital finance, which drives the efficiency of industrial transformation. Finally, for the coefficient of Green, when the level of technological innovation crosses the threshold of 45.372, the coefficient of digital finance rises significantly from 0.159 to 0.197. This implies that as the level of technological innovation continues to increase, digital finance plays an

increasing role in promoting the Green transformation.

These results show that the positive effect of digital finance on industrial transformation is strengthened with the improvement of digital finance and technological innovation. This indicates that development of digital finance exhibits a non-linear effect on industrial transformation. It also provides empirical support for the rationale behind choosing the level of technological innovation as the mediating variable in this paper.

Table 15 Regression results of threshold of technological innovation

| Variable | (1) Advancement | (2) Efficiency | (3) Green |
|-------------------------|----------------------|----------------------|----------------------|
| DFI (PJS $\leq\gamma$) | 1.016*** (7.35) | | |
| DFI (PJS $>\gamma$) | 0.609*** (5.56) | | |
| DFI (PJS $\leq\gamma$) | | 0.035 (0.94) | |
| DFI (PJS $>\gamma$) | | 0.070* (1.92) | |
| DFI (PJS $\leq\gamma$) | | | 0.159*** (4.52) |
| DFI (PJS $>\gamma$) | | | 0.197*** (5.85) |
| GDP | -0.622*** (-3.75) | -0.154*** (-2.99) | -0.024 (-0.49) |
| FDI | -0.038** (-2.00) | -0.006 (-1.02) | 0.002 (0.32) |
| Gov Intervention | 2.255*** (5.68) | 0.199* (1.65) | -0.100 (-0.87) |
| Consumption | -0.106* (-1.96) | 0.295*** (17.68) | -0.074*** (-4.63) |
| Constant | 7.781*** (4.38) | -1.090** (-2.01) | 0.922* (1.79) |
| Region effects | yes | yes | yes |
| Time effects | yes | yes | yes |
| Observed values | 310 | 310 | 310 |
| R ² | 0.798 | 0.718 | 0.668 |

6. Conclusion

This paper examines the driving forces of digital finance in terms of their impact on industrial transformation by using regional data which covers 31 provinces in China.

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There are several key findings. Firstly, digital finance significantly contributes to the development of the advancement, efficiency and green aspects of industrial transformation. Among them, the impact on Advancement is the greatest, followed by Green and Efficiency measures. In addition, technological innovation emerges as a vital pathway for digital finance to drive industrial transformation and its impact demonstrates nonlinear effect. As the levels of digital finance development and technological innovation continue to improve, the incentive effect of digital finance on transformation strengthens. Moreover, among the various sub-dimensions of digital finance, the depth of the adoption of digital finance has the most positive impact, followed by the digitalization degree and the coverage. Furthermore, regional heterogeneity is observed. In the eastern regions, the positive impact of digital finance is significant to all observed aspects of industrial transformation. However, in the central and western regions, digital finance primarily influences the Advancement and Green aspects of industrial transformation.

Based on the findings, several recommendations can be made. Firstly, there is a need to accelerate the development of digital finance through various means. This includes investing in the construction of digital infrastructure to support the expansion and accessibility of digital financial services. Financial institutions should adopt digital transformation quickly in order to effectively facilitate the landscape of digital finance. Additionally, cultivating and attracting talents in the field of digital finance will be beneficial. Moreover, it is crucial to ensure balanced development across different regions, particularly between eastern and central-western regions. Finally, promoting innovation in digital financial services models and tools and improving technological innovation support for service industries can further drive the structural transformation of these sectors.

Notwithstanding the contributions of this paper, there are several areas for further refinement and future research. Firstly, this paper uses the Digital Inclusive Finance Index provided by the Digital Finance Research Centre of Peking University to measure the digital finance. Future research could consider incorporating data from multiple sources, such as digital development indicators and information from large financial institutions, to enhance the objectivity and accuracy of the measure of digital finance. Secondly, this paper primarily focuses on the provincial level. A micro-level study could be applied, from the perspective of prefecture-level cities and industries. Thirdly, we acknowledge that technological innovation is not exclusive to digital finance. To separate the effects of digital finance from other factors, in the future, we could employ difference-in-differences (DID) by comparing industrial transformation before and after a particular policy that promotes digital finance. It would allow us to separate the causal impact of digital finance on industrial transformation, controlling for other variables. Finally, given the significant impact of the COVID-19 pandemic on the Chinese economy in 2021, we only investigated the 10-year time frame up until 2020. Incorporating data from the pandemic period and analyzing its effects on digital finance and industrial transformation would be valuable perspectives for future research.

Statements and Declarations

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