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Research on the Impact of Green Digital Finance on the Industrial Green Transformation of Resource-Based Cities in China

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Abstract

China possesses abundant natural resources, and resource-based cities have played a vital role in driving rapid national economic growth. However, these cities commonly exhibit industrial systems characterized by high emissions, high pollution, and high energy consumption. Their over-reliance on resource extraction is unsustainable, making green transition a critical issue. Green digital finance, an innovative service model integrating green finance and digital finance, plays a significant role in promoting the industrial green transition of resource-based cities. This study aims to examine whether green digital finance can influence this transition and analyze its mechanisms and effects, providing theoretical and empirical support for making policy. Based on a literature review and theoretical analysis, the study first defines key concepts, summarizes current developments and challenges, and explores potential mechanisms. Using panel data from 111 Chinese resource-based cities (2013–2023), it employs the EBM model to measure industrial green transition levels and econometric models to assess the impact of green digital finance. Results show that green digital finance significantly promotes the transition, mainly through enhancing human capital, alleviating financing constraints, and advancing industrial structure. Heterogeneity analysis reveals varying effects across city types, income levels, and geographical regions. Policy recommendations include: actively developing green digital finance to provide targeted green funding; leveraging its technological and inclusive features to ease corporate financing constraints; utilizing its mechanisms to enhance human capital and industrial upgrading; and implementing differentiated policies based on city-specific characteristics.

Keywords

Green Digital Finance; Resource-based Cities; Industrial Green Transition.

1. Introduction

In the context of global efforts to address climate change and promote sustainable development, resource-based cities have become a key challenge and main battlefield for achieving the "dual carbon" goals and high-quality development in China and around the world, due to their industrial structures characterized by high energy consumption, high emissions, and high pollution. At the same time, digital technologies such as big data, artificial intelligence, and the Internet of Things are reshaping the economic landscape with unprecedented breadth and depth.

This study focuses on the green digital economy,a new paradigm emerging from the deep integration and systemic coupling of the green economy and the digital economy. This paradigm is not merely a simple combination of the two but rather leverages the empowerment of digital technologies to achieve precise allocation, transparent management, and enhanced

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efficiency of green elements, such as clean energy and circular economy. This gives rise to more efficient, intelligent, and sustainable production and consumption models. Applying this paradigm to the industrial green transformation of resource-based cities holds profound necessity and urgent strategic value.

Therefore, based on city-level panel data from 2013 to 2023, this study adopts green total factor productivity measured via the EBM model as an indicator for evaluating the green economic development level of resource-based cities. The core explanatory variable is the green digital finance index. Furthermore, an econometric model is constructed to analyze the impact effects and transmission mechanisms of green digital finance on the economic green transformation of resource-based cities in China. Robustness tests are conducted to ensure the reliability of the results, while heterogeneity analysis is carried out to reveal differential effects under varying contextual conditions. Finally, based on the empirical findings, policy recommendations are proposed to support the economic green transformation of resource-based cities in China.

2. Background and Literature Review

2.1. Research on the Industrial Economic Transformation of Resource-based Cities

In the evaluation research on industrial green transformation, the academic community has largely followed the measurement approaches used for economic green development or environmental performance, forming three main categories of measurement methods. The first category focuses on constructing multi-indicator comprehensive evaluation systems. Examples include the Resource and Environmental Performance Index (REPI) proposed by the Sustainable Development Strategy Research Group of the Chinese Academy of Sciences, the Green Development Index developed by Li et al.(2014)[1], and the comprehensive indicator system established by Liu et al. (2017)[2] across three dimensions: green products, green industries, and green production. Wu et al.(2017)[3] employed an improved entropy weight method to systematically assess the green development performance of urban agglomerations in the middle reaches of the Yangtze River from four aspects: resource utilization, environmental governance, growth quality, and green living. The second category primarily employs Stochastic Frontier Analysis (SFA). For instance, Kuang et al. (2012)[4] measured provincial environmental efficiency in China, while Feng et al.(2013)[5] estimated the total factor productivity of large and medium-sized industrial enterprises across different regions. The third category relies on Data Envelopment Analysis (DEA). Representative studies include Li et al.(2013)[6], who measured the green total factor productivity of 36 industrial sectors in China by incorporating industrial CO_2 emissions and energy consumption as input variables. Huang(2016)[7] and Zhang et al.(2018)[8] further constructed super-efficiency SBM models to systematically evaluate China’s green economic efficiency.

In measuring the level of industrial green transformation, two main methodological approaches have been adopted in academia, both building on the three aforementioned evaluation techniques. One approach focuses on the theoretical connotations of industrial green transformation, constructing multi-dimensional comprehensive evaluation systems to capture its dynamic evolution. For example, Peng et al.(2016)[9] established an evaluation indicator system for provincial industrial green transformation in China across four dimensions: structural optimization, green technological innovation, transformation of development modes, and energy conservation with emission reduction. Deng et al.(2019)[10] developed an indicator framework centered on pollution reduction, sustainable development, productivity improvement, industrial structure upgrading, and efficient utilization of energy resources, using the entropy method to systematically assess the quality of industrial green transformation at the provincial level in China.

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The other approach directly employs industrial green development levels or industrial green total factor productivity as proxy indicators. For instance, Shen et al.(2018)[11] and Xiao et al.(2019)[12] used the super-efficiency SBM model to measure the industrial environmental efficiency of Chinese provinces and the industrial green development efficiency of 108 resource-based cities, respectively, treating these as primary measures of industrial green transformation in the corresponding regions.

In summary, within existing academic research, Data Envelopment Analysis (DEA) is widely adopted for its ability to incorporate undesired outputs into efficiency evaluation frameworks. Meanwhile, green total factor productivity has become a mainstream measurement indicator in empirical analysis due to its advantages in decomposability and comparability. These methodological characteristics provide an important reference for the scientific measurement of industrial green transformation levels in this study

2.2. Research on Green Digital Finance

While China's green finance sector has been developing rapidly, it still faces the challenge of regional imbalance. Wang(2022)[13] points out that such regional disparities have become a significant constraint on the improvement of the green financial system. Wang(2020)[14] indicates that the development of green finance continues to grapple with insufficient endogenous momentum. Huang(2023)[15] further highlights that the inclusivity of current green finance practices remains inadequate and needs strengthening.

Inclusive finance primarily aims to reduce service costs and expand coverage. However, Chen et al.(2023)[16] note that current inclusive financial services pay insufficient attention to the green attributes of beneficiaries and, to some extent, still support high-energy-consuming and high-polluting industries. This has led to a paradox where inclusive finance lacks sufficient green focus, and green finance lacks adequate inclusivity. Research by Fang et al.(2023)[17] further reveals that the integration of these two faces multiple constraints, including relatively high credit risks in green-inclusive businesses, insufficient motivation for financial institutions to engage in related activities, and inadequate data support due to weak information infrastructure.

Regarding solutions, scholars generally agree that digital technologies offer a potential breakthrough. Research by Huang et al.(2018)[18] shows that, as an extension of inclusive finance, digital inclusive finance can reach a broader range of underserved groups by lowering service barriers and costs. Wu and Wen(2023)[19] further propose that by introducing digital technologies such as big data and blockchain, green finance can innovate its service models, thereby enhancing coverage and accessibility for disadvantaged groups.

Existing research primarily revolves around four main directions: Zhang(2022)[20] analyzes the current challenges in the integrated development of green finance and inclusive finance based on practical cases from pilot reform zones and proposes digital solutions; Zou (2022)[21] explores the necessity and feasibility of their integrated development from a theoretical perspective; in empirical research, Huang and Wang (2022)[22] find that digital finance improves the efficiency of financial institutions, Zhong et al. (2023)[23] emphasize its role in enhancing risk prevention capabilities for green projects, and Liang et al. (2022)[24] point out that it alleviates information asymmetry, collectively promoting the development of green finance; Wang and Zhan (2023)[25] study the pathways for their synergistic development from the perspectives of high-quality economic growth and common prosperity, respectively.

Although existing research has made significant progress, most studies conduct empirical analysis from the perspective of how digital inclusive finance influences green finance, without delving deeply into the factors affecting their integrated development or the pathways to achieve it. This leaves valuable space for further exploration in subsequent research.

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2.3. The Impact of Green Digital Finance on the Economic Green Transformation of Resource-based Cities

Numerous studies have confirmed that financial development can prevent or reverse the resource curse (Guo, 2017[26]; Zhang, 2020[27]). These studies explore the potential of financial development to mitigate the "resource curse" effect and emphasize its critical role in this process. However, some attempts to alleviate the "resource curse" by reducing financial development have found that this approach may instead exacerbate the phenomenon. Additionally, green financial instruments have played a positive role in promoting the transition of resource-based cities toward more sustainable development models. Research by Xian(2022)[28] and Yang et al. (2023)[29] shows that green finance effectively reduces carbon emission intensity by improving environmental governance and resource utilization efficiency, which not only significantly advances high-quality urban development but also generates positive spatial spillover effects on neighboring cities. Furthermore, GONG Q (2023)[30] notes that both green finance and green environmental innovations in the renewable energy sector can drive economic growth, with green finance playing a particularly significant role in this regard. Pengand Li(2016)[31], in their analysis of environmental regulation categories, point out that green finance, as an economically incentivized environmental policy, provides sustained motivation for enterprises to adopt clean production technologies and encourages green technology research and development, thereby promoting industrial green transformation. Ren et al. (2016)[32] also argue that green finance, as a market-based environmental regulation policy, strengthens policy intensity and contributes to China's industrial structural transformation. Ghisetti et al. (2015)[33] further emphasize that if green finance development lags, it may hinder green technological innovation and its application in energy conservation and emission reduction, thereby impeding industrial transformation.

Many scholars have paid significant attention to the role of digital finance in promoting industrial green transformation. Li et al. (2023)[34] empirically test the spatial spillover effects of digital finance on the green transformation of the manufacturing industry using a spatial Durbin model, finding a significant positive promoting effect. Fang et al. (2023)[35] note that digital inclusive finance has become a crucial force in advancing green development in industrial sectors, and their spatial econometric model confirms its positive spatial spillover effects on industrial green transformation. Zhu and Zhang(2022)[36] further demonstrate that digital finance can promote the transition of urban economies toward green and low-carbon development by enhancing technological innovation capabilities and alleviating financing constraints. Li (2023)[37] finds that digital finance significantly promotes economic growth in resource-based cities, with stimulating household consumption being an important channel for this effect.

At the enterprise level, numerous studies have shown that digital finance can effectively promote corporate green technology innovation, thereby advancing industrial green transformation and overall industrial green development. Chen et al. (2022)[38], by analyzing the pathways through which digital finance influences corporate green technology innovation, identifies three main mechanisms: increasing innovation investment, reducing operational risks, and improving governance levels. Other research suggests that digital finance can facilitate industrial green transformation by reducing pollution emissions and enhancing resource utilization efficiency. For example, Chen(2024)[39] points out that digital inclusive finance can alleviate the ecological burden accumulated in the oil and gas sector, injecting resilience into industrial sustainability through green operations, emission reduction, and performance optimization. Another study argues that this financial model can significantly accelerate the green transformation of industries and improve green total factor productivity by catalyzing technological leaps and industrial upgrading. Lan(2023)[40] also believes that

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digital finance can stimulate corporate green technology research and development by improving green innovation efficiency, thereby driving the overall greening of industries.

These studies indicate that digital finance plays a vital role in the economic green transformation of resource-based cities, promoting green innovation and sustainable development through multiple mechanisms and pathways. The radiating effects of digital finance can reshape capital flows, facilitate cross-regional factor mobility, accelerate the dissemination and implementation of green achievements, and open new growth opportunities for resource-based cities during transitional phases.

3. Mechanism Analysis

3.1. Direct Impacts

At present, China's resource-based cities are at a critical stage of transitioning their development models. Their traditional economic growth has heavily relied on resource extraction and heavy chemical industries, facing multiple challenges such as tightening resource constraints, increasing ecological and environmental pressures, and a monolithic industrial structure. Meanwhile, the advancement of the national dual-carbon strategic goals imposes rigid constraints on high-carbon emission industrial systems. However, the transformation process faces deep-seated constraints: the high-carbon asset system and technological path dependency lead to persistent market failures in green investment, including difficulties in internalizing positive externalities, maturity mismatches in financing, and severe information asymmetry. This results in a dual dilemma of insufficient incentives for green technological innovation and a financing gap for transformation.

The core role of green digital finance lies in effectively mitigating these market failures through technological empowerment. In terms of resource allocation, the digital technology system built on the Internet of Things, blockchain, and big data enables real-time monitoring, accurate accounting, and credible tracing of environmental benefits, transforming the externalities of green projects into tradable digital assets or credit instruments. This mechanism allows funds to be directed with higher precision and transparency into key areas such as clean energy, energy-saving retrofits, and ecological restoration, guiding capital flow from traditional high-carbon industries to green and low-carbon industries, thereby driving fundamental optimization of the industrial structure.

In the dimension of risk management, green digital finance enables the quantitative identification and dynamic early warning of climate transition risks and physical risks by constructing environmental big data analysis platforms and intelligent risk assessment models. An ESG evaluation system based on corporate carbon accounts and lifecycle environmental performance provides differentiated pricing benchmarks for the climate resilience of assets to financial institutions. By establishing market-based adjustment mechanisms such as preferential interest rates for green credit and risk premiums for brown assets, it effectively guides enterprises to reduce carbon emissions and avoid environmental compliance risks.

In terms of service efficiency, digital technology significantly enhances the inclusivity and penetration of green finance. Small and medium-sized enterprises in resource-based cities and distributed green projects, which are often underserved by traditional financial services, can gain access to precise financing support through digital tools such as big data credit assessment and supply chain fintech. Simultaneously, digital platforms can integrate multidimensional resources such as policy guidance, technical solutions, capital matching, and market channels, providing systematic solutions for transformation entities and reducing the overall costs of green technology application and industrial upgrading.

In summary, by establishing a targeted, market-based, and inclusive financial support system, green digital finance not only alleviates the short-term financing constraints faced by resource-

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based cities in their green transformation but also fosters their endogenous growth drivers in the medium to long term. It represents a vital pathway for aligning ecological and environmental protection with the achievement of high-quality economic development.

Based on the above mechanisms, research hypothesis 1 is proposed: green digital finance can promote the industrial green transformation of resource-based cities in China.

3.2. Indirect Impacts

3.2.1. Human Capital Enhancement Effect

Currently, China is undergoing a critical transition from relying on demographic dividends to harnessing talent dividends. This macro-demographic shift has profound implications for advancing the green and low-carbon transformation of resource-based cities, requiring them to place greater emphasis on attracting, cultivating, and effectively deploying high-quality talent during the processes of industrial upgrading and technological innovation. Enhancing the quality of human capital serves as a pivotal pathway for driving industrial green transformation in these cities. Green digital finance, as a deep integration of green finance and digital finance, retains the inclusive characteristics of traditional finance while reinforcing targeted support for green development.

At the green finance level, it provides specialized financing support for environmental projects and green technology training through instruments such as green credit and green bonds. At the digital finance level, it leverages internet platforms and big data risk control to achieve efficient outreach and precise pricing of financial services. This dual advantage enables green digital finance to offer convenient financing for green skill training to residents of resource-based cities, facilitating access to environmental education and green technology learning opportunities. Simultaneously, digital platforms foster collaboration within green industry communities, enhancing the cooperative capacity of human capital through the sharing of environmental information and exchanges of green technologies. Moreover, green digital finance promotes the green literacy of human capital through digital tools such as green consumer finance and the dissemination of ecological culture.

Resource-based cities have long exhibited path dependence on natural resource development, with their economic growth often constrained by declining resource reserves and increasing environmental pressures. In the industrial green transformation of these cities, the green skill level of the workforce is crucial for driving the transition. On the one hand, as green transformation deepens, the demand for environmental management and green technology professionals rises significantly. Environmental education and specialized training supported by green digital finance can effectively alleviate the shortage of green-skilled talent. High-quality human capital helps resource-based cities develop environmental protection and green technology industries, gradually reducing their reliance on traditional high-pollution sectors. On the other hand, workers equipped with green digital literacy can more effectively apply environmentally friendly technologies and digital tool systems, thereby driving the intensive improvement of production processes and the systematic enhancement of resource utilization efficiency. During the green transition, these high-caliber professionals not only improve corporate environmental performance but also promote green upgrading across entire industries through knowledge spillover effects. Additionally, a workforce with green digital skills can integrate sustainability principles with digital technologies, fostering the greening of traditional industries.

Thus, green digital finance offers a novel pathway for enhancing human capital through its unique "green + digital" dual attributes. It continues the green finance tradition of supporting environmentally friendly initiatives while leveraging the inclusive advantages of digital finance, collectively contributing to the overall improvement of human capital levels in resource-based cities.

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Based on the above mechanisms, research hypothesis 2 is proposed: green digital finance can promote the industrial green transformation of resource-based cities in China by enhancing the level of human capital.

3.2.2. Alleviation of Financing Constraints

The sustainable operation and green transformation of industrial enterprises in resource-based cities often heavily rely on stable and continuous capital investment. However, in reality, such enterprises commonly face significant financing constraints. Limited by insufficient capital supply, a considerable number of enterprises struggle to effectively advance green technology research, development, and application. This structural contradiction has become a key bottleneck hindering the overall transition of regional industries toward green and low-carbon development.

From a macroeconomic perspective, the operational logic of capital markets inherently favors investment areas with higher returns. Influenced by information asymmetry in the traditional financial system, the relatively monolithic industrial composition of resource-based cities is often perceived as high-risk, creating structural barriers for local industrial enterprises in accessing external funding. For small and medium-sized enterprises, such financing constraints are particularly pronounced.

Compared to traditional financial models, green digital finance demonstrates significant structural advantages due to its inherent technological embeddedness and ecological orientation, particularly in alleviating information asymmetry and reducing adverse selection risks. This holds substantial practical value for addressing the financing constraints of industrial enterprises, especially those in resource-based cities, and for activating green innovation momentum. Specifically, leveraging digital technologies such as big data and blockchain, green digital finance enhances the credit identification and risk assessment capabilities of financial institutions. By establishing cross-entity information-sharing mechanisms, it improves the visualization of risks, enabling a more comprehensive and dynamic understanding of enterprises' actual operational conditions and risk profiles. This process not only reduces the information disclosure burden on enterprises during financing but also curbs potential opportunistic behavior through technological constraints, thereby enhancing financing efficiency while improving the precision and sustainability of financial resource allocation.

Simultaneously, the green digital finance system opens up more diverse and flexible financing pathways for industrial enterprises in resource-based cities. Leveraging the extensive coverage and efficient connectivity of internet platforms, it effectively aggregates dispersed social funds, precisely matching the diverse financing needs of enterprises at different development stages and under varying environmental conditions. This innovative model not only alleviates financing constraints but also provides critical support for green technological innovation. On the other hand, green digital finance optimizes the allocation of financial resources, directing capital toward green enterprises with development potential and innovative capabilities. With the aid of digital technologies, financial institutions can more accurately assess the potential value and risk characteristics of projects, enabling precise capital allocation. This mechanism enhances the efficiency of financial capital utilization while promoting the healthy development of regional industrial economies.

Based on the above mechanisms, research hypothesis 3 is proposed: green digital finance can promote the industrial green transformation of resource-based cities in China by alleviating financing constraints.

3.2.3. Enhancement Effect of Industrial Structure Advancement

Industrial structure advancement serves as a critical transmission pathway linking green digital finance with industrial green transformation. Resource-based cities have long relied on

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traditional industrial structures characterized by high consumption and high emissions. This rigid industrial framework not only locks in technological pathways but also solidifies pollution patterns, leaving green transformation without the necessary industrial foundations and market space. Without profound adjustments to the industrial structure, the capital supply from green digital finance may become trapped within the existing high-carbon industrial chains, making it difficult to trigger systemic green change.

The driving force of green digital finance in advancing industrial structure lies in its ability to accurately identify and support green industrial activities. By leveraging digital technologies such as big data and artificial intelligence, green digital finance can establish a multi-dimensional green identification system to precisely assess the environmental benefits and transformation potential of projects. This capability enables it to channel capital toward the clean transformation of traditional industries, circular economy projects, and strategic emerging industries such as new energy and energy conservation, providing targeted financial support for the transition of industrial structures toward green and low-carbon development.

More importantly, green digital finance offers sustained momentum for industrial structure advancement through innovative financial products and services. It can develop differentiated pricing products linked to carbon footprints and environmental performance, as well as design comprehensive green financial solutions covering entire industrial chains. Such deep integration not only reduces the financing costs of green transformation but also enhances the enthusiasm of enterprises for green innovation, thereby fostering a virtuous cycle of green industrial agglomeration and development.

Once industrial structure advancement is achieved, it creates an endogenous driving mechanism for industrial green transformation. When green industries become the dominant sectors of the economy, clean production technologies, environmental protection technologies, and resource recycling technologies will gain greater application space and market demand. This technological evolution and market-scale effect driven by industrial structure upgrading can significantly enhance total factor productivity, reduce resource consumption and pollution emissions per unit of output, and gradually decouple economic growth from environmental impact.

Based on the above mechanisms, research hypothesis 4 is proposed: green digital finance can promote the industrial green transformation of resource-based cities in China by advancing the industrial structure.

4. Data Sources and Scale Design

4.1. Data Source and Sample Study

The data for the green finance indicators selected in this paper are sourced from the Wind database, while the Digital Inclusive Finance Index is derived from the corresponding index published by the Peking University Digital Finance Research Center. Given the availability of prefecture-level city data, the study utilizes panel data from 111 prefecture-level cities in China between 2013 and 2023 as the analysis sample. City-level data are primarily obtained from the China Regional Economic Statistical Yearbook, China Statistical Yearbook, China Environmental Statistical Yearbook, the China Research Data Service Platform (CNRDS), and the Wind database. Missing values are partially supplemented using interpolation methods. To mitigate potential estimation bias caused by heteroskedasticity, all variables except the financing constraint and internet penetration rate variables are logarithmically transformed.

4.2. Variable Selection and Scale Design

The explained variable is the industrial green transformation of resource-based cities(GTFP), measured by Green Total Factor Productivity. Drawing on the research framework of Ma Jie

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(2023) and other scholars, this study incorporates the impact of environmental pollution and adopts the EBM model to calculate the industrial green total factor productivity of resource-based cities as a key indicator of their industrial green transformation.Following the economic implications of total factor productivity and existing literature, the input indicators selected for the model include labor, capital, and resource factors. The industrial gross output of resource-based cities is taken as the desired output, while the emissions of wastewater, exhaust gases, and dust generated during industrial production are included as undesired outputs.

The explanatory variable in this study is Green Digital Finance, which is measured by the coupling coordination index between green finance and digital inclusive finance. This index captures the level of synergistic development between the two components. The calculation method follows the approach proposed by Wang et al. (2021) and is summarized as follows.

$$C_{it} = \frac{2\sqrt{U_1 U_2}}{U_1 + U_2}$$

$$T_{it} = aU_1 + bU_2$$

$$D_{it} = \sqrt{C_{it} \times T_{it}}$$

In the equation,U_1 denotes the level of green finance development, U_2 denotes the level of digital inclusive finance development, D_{it} represents the coupling degree between the two, C_{it} indicates the coupling coordination degree between green finance and digital inclusive finance, and T_{it} characterizes the degree of positive interaction between the subsystems. The parameters α and β signify the relative importance of each subsystem within the coordination system, subject to the condition α + β = 1. This study assumes that both subsystems are equally important, and thus sets α = β = 0.5.

The mechanism variables in this study are defined as follows: (1)Human Capital Level (HC) is measured by the ratio of the number of students enrolled in regular undergraduate and specialized higher education institutions to the total resident population at the end of the year, serving as an indicator of the regional human capital development level. (2)Financing Constraints (SA)are proxied by the ratio of the year-end balance of loans from financial institutions to the year-end balance of deposits, following established practices in the literature.(3)Industrial Upgrading (INDINDEX)is quantified using a composite index based on the proportion of value added by the primary, secondary, and tertiary industries in GDP. The index is calculated by assigning weights of 1, 2, and 3 to the primary, secondary, and tertiary industries, respectively, and then summing the weighted proportions. This approach ensures a systematic and theoretically grounded measurement of the key mechanisms under investigation.

In consideration of the potential influence of other urban characteristic factors on GTFP, and in reference to existing literature, this study incorporates a set of city-level control variables, including foreign investment level (FDI), proxied by the logarithm of the ratio of foreign direct investment to regional GDP; government intervention intensity (REV), measured as the share of general budget expenditure in regional GDP to reflect the role of macro-regulation in shaping resource allocation and industrial evolution; urbanization rate (UR), represented by the proportion of non-agricultural population to registered household population, which captures both the agglomeration dividends and the possible “lock-in effect” of extensive expansion in China's resource-based cities; economic development level (LGDP), measured by the logarithm of per capita GDP to account for the channels of capital supply, technological accessibility, and demand upgrading; and population size (LPOP), represented by the logarithm of registered

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household population, which reflects both local market expansion and potential structural shifts toward service-oriented economies.

4.3. Modeling

The benchmarking model constructed in this study is specified as follows:

$$GTFP_{it} = \alpha_0 + \alpha_1 GDFO_{it} + \sum \alpha_j \, Control_{it}^j + \theta_i + \mu_t + \varepsilon_{it}$$

The equation examines the impact of green digital finance on the economic green transformation of resource-based cities. Here, i denotes the city and t denotes the year. GTFP represents the level of industrial green transformation in resource-based cities. GDFO denotes green digital finance. $Control_j$ refers to all control variables included in the model. The constant term is represented by α_0, while α_1 and α_j are coefficients to be estimated. ε_{it} denotes the error term. To account for unobserved heterogeneity and potential endogeneity at both individual and temporal dimensions, individual fixed effects (θ_i) and time fixed effects (μ_t) are incorporated into the model.

To systematically analyze the underlying mechanisms through which green digital finance influences the industrial green transformation of resource-based cities, this study incorporates human capital level (HC), financing constraints (SA), and industrial upgrading (INDINDEX) into the analytical framework as key variables for examining mediating or moderating effects.

To test Hypothesis 2, which explores whether green digital finance can promote the industrial green transformation of resource-based cities through the human capital mechanism, this study first introduces the human capital (HC) variable into the baseline modelto analyze its direct relationship with industrial green transformation (GTFP):

$$GTFP_{it} = \alpha_0 + \alpha_1 HC_{it} + \sum \alpha_j \, Control_{it}^j + \theta_i + \mu_t + \varepsilon_{it}$$

$$GTFP_{it} = \alpha_0 + \alpha_1 HC_{it} + \alpha_2 GDFO_{it} + \sum \alpha_j \, Control_{it}^j + \theta_i + \mu_t + \varepsilon_{it}$$

$$GTFP_{it} = \alpha_0 + \alpha_1 HC_{it} + \alpha_2 GDFO_{it} + \alpha_3 GDFO_{it} \times HC_{it} + \sum \alpha_j \, Control_{it}^j + \theta_i + \mu_t + \varepsilon_{it}$$

Subsequently, green digital finance (GDFO) is incorporated into this model to form an extended model, allowing for further examination of the influence of green digital finance:

$$GTFP_{it} = \alpha_0 + \alpha_1 SA_{it} + \sum \alpha_j \, Control_{it}^j + \theta_i + \mu_t + \varepsilon_{it}$$

$$GTFP_{it} = \alpha_0 + \alpha_1 SA_{it} + \alpha_2 GDFO_{it} + \sum \alpha_j \, Control_{it}^j + \theta_i + \mu_t + \varepsilon_{it}$$

$$GTFP_{it} = \alpha_0 + \alpha_1 SA_{it} + \alpha_2 GDFO_{it} + \alpha_3 GDFO_{it} \times SA_{it} + \sum \alpha_j \, Control_{it}^j + \theta_i + \mu_t + \varepsilon_{it}$$

Finally, by adding the interaction term between green digital finance and human capital (GDFO×HC), model is constructed to identify the moderating effect of their synergistic interaction on the transformation process:

$$GTFP_{it} = \alpha_0 + \alpha_1 INDINDEX_{it} + \sum \alpha_j \, Control_{it}^j + \theta_i + \mu_t + \varepsilon_{it}$$

$$GTFP_{it} = \alpha_0 + \alpha_1 INDINDEX_{it} + \alpha_2 GDFO_{it} + \sum \alpha_j \, Control_{it}^j + \theta_i + \mu_t + \varepsilon_{it}$$

$$GTFP_{it} = \alpha_0 + \alpha_1 INDINDEX_{it} + \alpha_2 GDFO_{it} + \alpha_3 GDFO_{it} \times INDINDEX_{it} + \sum \alpha_j \, Control_{it}^j + \theta_i + \mu_t + \varepsilon_{it}$$

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4.4. Descriptive Statistics

Table 1 presents the descriptive statistics of the main variables, including MEAN, SD, and MINMAX, to illustrate the central tendency and dispersion of the sample data and to provide a reference for the distribution characteristics in subsequent empirical tests. According to the statistical results, the foreign investment level (FDI), economic development level (LGDP), population size (LPOP), and internet penetration rate (INTERNET) exhibit larger gaps between their maximum and minimum values compared to other variables. This indicates that the levels of foreign investment, economic development scale, population size, and internet penetration vary significantly across resource-based cities in China, reflecting regional disparities and heterogeneity.

Table 1. Descriptive Statistics

	COUNT	MEAN	SD	MIN	MAX
GTFP	1221	0.780	0.041	0.680	0.963
GDFO	1221	1.131	0.121	0.520	1.361
FDI	1221	-7.305	1.867	-17.522	-3.979
REV	1221	0.231	0.106	0.044	0.741
UR	1221	0.385	0.210	0.075	1.000
LGDP	1221	10.701	0.567	9.085	12.883
LPOP	1221	5.389	0.944	2.249	7.302
HC	1221	-4.711	0.852	-11.108	-2.304
SA	1221	0.677	0.218	0.200	5.613
INDINDEX	1221	-0.043	0.452	-1.574	1.324
INTERNET	1221	2.572	1.398	0.259	14.713

5. Empirical Analyses

5.1. Benchmark Regression Results

Table 2 presents the regression analysis results of the relationship between green digital finance development and the industrial green transformation of resource-based cities. The data indicate a significant positive correlation between them: in column (1), the estimated coefficient of green digital finance is 0.05, which is statistically significant at the 5% level. After gradually introducing various control variables, the coefficient remains at 0.0519 and continues to be significant in column (6), further confirming the sustained promoting effect of green digital finance on industrial green transformation. The underlying reasons are as follows: green digital finance guides resources toward green enterprises through policy incentives and leverages digital technologies to precisely alleviate financing constraints and break information barriers for enterprises, thereby optimizing resource allocation and driving industrial green transformation. Relying on digital technologies such as big data, green digital finance enables accurate identification and risk assessment of green projects, reducing barriers to financial services and effectively channeling social capital toward environmentally friendly sectors such as clean production and energy conservation, thereby advancing the process of industrial green transformation.

Table 2 presents the analytical results of the relationships between various variables and the industrial green transformation of resource-based cities. The results from models (3) to (6) consistently show that the coefficients of urbanization level (UR) and economic development level (LGDP) are significantly positive. This finding aligns closely with theoretical expectations, highlighting the indispensable supportive roles of both factors in the process of industrial green transformation. The promoting effect of urbanization (UR) primarily stems from two

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dimensions. First, urbanization is often accompanied by the optimization and upgrading of industrial structures. Resource-based cities typically exhibit excessive reliance on traditional heavy industries, while urbanization creates broad development opportunities for green and low-carbon industries such as services and high-tech sectors, facilitating the transition of urban economic structures from resource dependence to innovation-driven growth. Second, urbanization contributes to the widespread enhancement of residents' environmental awareness. As populations concentrate in urban areas, public demand for improved living environments intensifies, creating an external pressure mechanism that encourages enterprises to adopt more environmentally friendly production methods, thereby driving industrial green transformation from the demand side.

The significantly positive influence of economic development level (LGDP) reflects the supportive role of economic foundations in green technological innovation. Higher levels of economic development often provide local governments and enterprises with more substantial financial resources and funding capacity, which can be allocated to support independent research and development, introduction, and application of environmental technologies. Meanwhile, a favorable economic environment also offers mature markets and financing channels for green industries, making business models such as clean production and circular economy commercially viable, thereby injecting sustained momentum into industrial green transformation.

Among the analytical results, the unconventional relationships observed for government intervention (REV) and foreign investment (FDI) warrant deeper investigation. The effect of government intervention (REV) exhibits notable fluctuations across different models. When other variables are not adequately controlled (models 2 and 3), its coefficient is significantly negative, consistent with existing literature suggesting that excessive government intervention may suppress market vitality through a "crowding-out effect." Specifically, excessive government protection and subsidies for specific industries or state-owned enterprises may distort resource allocation, allowing inefficient polluting enterprises to persist while weakening the competitive advantage and innovation incentives of green enterprises, leading them into a "subsidy trap" rather than committing to long-term green technology innovation. However, after incorporating more comprehensive control variables such as economic development and population size (models 4 and 5), the coefficient of REV turns significantly positive. This shift suggests that the role of government intervention is not simply linear suppression but may operate within an "optimal range." In the early stages of transformation, effective government planning, stringent environmental standards, and targeted support for green industries—such as R&D subsidies and tax incentives—can effectively address market failures and guide resources toward green sectors, thereby playing a positive driving role.

More unexpectedly, the effect of foreign investment (FDI) is consistently negative across all models, reaching statistical significance in models (4) to (6). This result contradicts the conventional view that "foreign investment brings advanced technology and management experience" but provides evidence supporting the "pollution haven" hypothesis in the context of China's resource-based cities. It may indicate that a portion of FDI flowing into these cities is concentrated in resource extraction, primary processing, and other high-consumption, high-pollution segments of the industrial chain. Foreign enterprises leverage relatively lenient environmental regulations and abundant natural resources in these regions, treating them as "pollution havens" rather than introducing globally advanced green production technologies. While such investments may stimulate short-term economic growth, they reinforce traditional and unsustainable development patterns in the long run, thereby inhibiting industrial green transformation.

The models show that the coefficient of population size (LPOP) is significantly negative. This indicates that, for resource-based cities, population growth may manifest more as

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environmental pressure than as human capital dividends. Larger population sizes imply greater demand for resources such as energy, water, and land, while also generating increased domestic pollution and carbon emissions, imposing severe challenges on urban environmental carrying capacity and pollution management capabilities, thereby hindering the improvement of industrial green total factor productivity.

Table 2. Benchmark regression results

	(1)	(2)	(3)	(4)	(5)	(6)
	GTFP	GTFP	GTFP	GTFP	GTFP	GTFP
GDFO	0.0500**	0.0500**	0.0490**	0.0545**	0.0501**	0.0519**
	(2.136)	(2.137)	(2.097)	(2.348)	(2.200)	(2.292)
FDI		-0.0008	-0.0009	-0.0010	-0.0015**	-0.0013*
		(-1.231)	(-1.347)	(-1.424)	(-2.280)	(-1.936)
REV			-0.0281*	-0.0366**	0.0475**	0.0411**
			(-1.693)	(-2.205)	(2.294)	(1.992)
UR				0.0590***	0.0424***	0.0321**
				(4.408)	(3.167)	(2.365)
LGDP					0.0357***	0.0376***
					(6.564)	(6.934)
LPOP						-0.0748***
						(-3.909)
_cons	0.7177***	0.7120***	0.7184***	0.6933***	0.3082***	0.6959***
	(28.812)	(28.127)	(28.096)	(26.678)	(4.818)	(5.908)
N	1221	1221	1221	1221	1221	1221
R^2	0.2596	0.2599	0.2612	0.2734	0.3003	0.3093
F	49.8852	45.8757	42.6392	41.6470	43.2362	42.0179
Year FE	YES	YES	YES	YES	YES	YES
City FE	YES	YES	YES	YES	YES	YES

Notes: ***p<0.001, **p<0.01, *p<0.05

5.2. Mechanism Verification

To further examine the hypothesized mechanisms through which green digital finance influences the industrial green transformation of resource-based cities in China, this study conducts empirical analysis to investigate whether it exerts a positive impact on the transformation process by promoting human capital accumulation, alleviating financing constraints, and advancing industrial structure upgrading.

To further investigate the underlying mechanisms through which green digital finance influences the industrial green transformation of resource-based cities, this study examines the potential moderating role of human capital. Table 3 presents the test results for the moderating effect of human capital.

Model (2), which includes the green digital finance variable alongside control variables, shows a coefficient of 0.0497 that is significantly positive at the 5% level. This robustly confirms the independent promoting effect of green digital finance on the industrial green transformation of resource-based cities.

In Model (3), after introducing the interaction term between green digital finance and human capital, the regression results reveal insightful changes. First, the coefficient of the interaction term is 0.0303 and is highly significant at the 1% statistical level. Simultaneously, the coefficient of green digital finance increases substantially from 0.0497 to 0.1819, with its significance level also improving. This outcome directly demonstrates a significant positive moderating effect of

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human capital in the process through which green digital finance influences industrial green transformation. In other words, a higher level of human capital strengthens the marginal promoting effect of green digital finance on industrial green transformation.

Table 3. Regression Results on the Human Capital Enhancement Effect

	(1)	(2)	(3)
HC	-0.0002	-0.0002	0.0324***
	(-0.128)	(-0.120)	(2.828)
GDFO		0.0497**	0.1819***
		(2.194)	(3.559)
GDFOxHC			0.0303***
			(2.883)
REV	0.0401*	0.0401*	0.0399*
	(1.908)	(1.911)	(1.910)
UR	0.0301**	0.0316**	0.0329**
	(2.225)	(2.338)	(2.442)
LGDP	0.0384***	0.0381***	0.0395***
	(6.940)	(6.895)	(7.147)
LPOP	-0.0740***	-0.0747***	-0.0739***
	(-3.841)	(-3.885)	(-3.856)
_cons	0.7428***	0.6966***	0.6866***
	(6.310)	(5.836)	(5.768)
N	1210.0000	1210.0000	1210.0000
R^2	0.3007	0.3032	0.3078
F	40.3688	38.4109	36.9840

Year FE	YES	YES	YES	YES	YES	YES
City FE	YES	YES	YES	YES	YES	YES

Notes: ***p<0.001, **p<0.01, *p<0.05

To examine whether green digital finance promotes industrial green transformation through alleviating corporate financing constraints, this study constructs an interaction term between financing constraints and green digital finance for mechanism testing. The empirical results are presented in Table 4.

In Model (2), after introducing the core explanatory variable, its coefficient is 0.051 and significant at the 5% level, once again confirming its direct promoting effect on industrial green transformation.

When the interaction term between green digital finance and financing constraints is incorporated, the regression results undergo fundamental changes, providing strong support for the existence of the financing constraint alleviation mechanism. First, the coefficient of financing constraints shifts from being insignificant to -0.104, which is highly significant at the 1% level. This significantly negative coefficient clearly indicates that, after accounting for the moderating role of green digital finance, financing constraints exhibit a notable inhibitory effect on the industrial green transformation of resource-based cities. Green digital finance effectively mitigates the adverse effects caused by financing constraints. Specifically, in situations where financing constraints are severe, green digital finance leverages its digital credit assessment, efficient risk pricing, and diversified inclusive financial services to precisely channel financial resources to industrial enterprises with green transformation potential that are hindered by capital shortages, thereby breaking the financing bottlenecks they face.

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Table 4. Regression Results on the Financing Constraint Alleviation Effect

	(1)	(2)	(3)
SA	0.001	0.001	-0.104***
	(0.35)	(0.34)	(-2.60)
GDFO		0.051**	0.054**
		(2.26)	(2.37)
GDFOxSA			0.101***
			(2.65)
FDI	-0.001*	-0.001*	-0.001*
	(-1.95)	(-1.94)	(-1.79)
REV	0.041**	0.041**	0.042**
	(1.99)	(1.98)	(2.04)
UR	0.031**	0.032**	0.034**
	(2.27)	(2.39)	(2.51)
LGDP	0.038***	0.038***	0.038***
	(6.97)	(6.92)	(7.02)
LPOP	-0.073***	-0.074***	-0.065***
	(-3.80)	(-3.86)	(-3.32)
_cons	0.738***	0.692***	0.634***
	(6.31)	(5.83)	(5.27)
N	1220.000	1220.000	1220.000
R^2	0.303	0.306	0.309
F	41.002	39.035	37.459
Year FE	YES	YES	YES
City FE	YES	YES	YES

Notes: ***p<0.001, **p<0.01, *p<0.05

Table 5. Regression Results on the Industrial Advancement Effect

	(1)	(2)	(3)
INDINDEX	0.0196***	0.0201***	0.0950***
	(5.392)	(5.538)	(4.507)
GDFO		0.0585***	0.0595***
		(2.616)	(2.672)
GDFOxINDINDEX			0.0678***
			(3.609)
FDI	-0.0015**	-0.0015**	-0.0016**
	(-2.260)	(-2.257)	(-2.375)
REV	0.0327	0.0322	0.0207
	(1.597)	(1.575)	(1.006)
UR	0.0311**	0.0329**	0.0274**
	(2.320)	(2.463)	(2.048)
LGDP	0.0288***	0.0282***	0.0286***
	(5.118)	(5.017)	(5.122)
LPOP	-0.0759***	-0.0769***	-0.0811***
	(-4.012)	(-4.077)	(-4.311)
_cons	0.8416***	0.7909***	0.8128***
	(7.244)	(6.732)	(6.947)
N	1221.0000	1221.0000	1221.0000
R^2	0.3239	0.3275	0.3348
F	44.4098	42.4231	41.2305
Year FE	YES	YES	YES
City FE	YES	YES	YES

Notes: ***p<0.001, **p<0.01, *p<0.05

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This empirical analysis aims to examine the mechanism role of industrial structure advancement in the relationship between green digital finance and industrial green transformation. Table 5 presents the results of the stepwise regression tests, providing systematic evidence for the existence of the mechanism pathway.

Model (1), the baseline regression, shows that industrial structure advancement has a significantly positive impact on industrial green transformation, with a coefficient of 0.0196. This preliminarily verifies the fundamental role of industrial structure optimization in driving green development.

Model (2) introduces the digital infrastructure variable while controlling for industrial structure. The results indicate that digital infrastructure has a significantly positive effect on industrial green transformation, with a coefficient of 0.0585. This suggests that the construction of digital infrastructure independently contributes to green transformation.

Model (3) further incorporates the interaction term between digital infrastructure and industrial structure advancement. The results reveal that the coefficient of the interaction term is significantly positive at 0.0678. This confirms that industrial structure advancement plays a significant positive moderating role in the process through which digital infrastructure influences industrial green transformation. Additionally, the significant positive coefficient of the interaction term indicates that the promoting effect of digital infrastructure on industrial green transformation strengthens as the level of industrial structure advancement increases, reflecting the synergistic effect between digital technology and industrial upgrading.

5.3. Robust Test

To further enhance the credibility and robustness of the econometric model estimation results, this study employs robustness tests such as the GMM model, alternative econometric specifications, and substitution of explanatory and dependent variables. The specific results are presented in Table 6.

(1) GMM Model

Given potential issues such as heteroskedasticity in the error term, this study applies the Generalized Method of Moments (GMM) for robustness testing. Specifically, the one-period lag of the industrial green transformation index is used as an instrumental variable, and the System GMM (SYS-GMM) method is adopted for re-estimation. The SYS-GMM results show that green digital finance (GDFO) has a significant positive effect on industrial green total factor productivity (GTFP), with a coefficient of 0.065 (significant at the 1% level). This implies that a one-unit increase in green digital finance development raises industrial GTFP by 6.5%. The model passes all diagnostic tests: the AR(1) test p-value is 0.000 (confirming first-order autocorrelation), the AR(2) test p-value is 0.122 (supporting no second-order autocorrelation), and the Hansen over-identification test p-value is 0.380 (validating the instrument set). The coefficient of the one-period lag of GTFP is 0.809, indicating strong path dependence in industrial green transformation. Overall, the model is well-specified and the results are reliable, providing robust evidence that green digital finance promotes industrial green transformation.

(2) Alternative Econometric Model

Ordinary Least Squares (OLS) is used as an alternative estimation method. The results show a coefficient of 0.0142 for green digital finance, significant at the 1% level. This aligns closely with the baseline regression, confirming the robustness of the original estimates.

(3) One-Period Lag of the Explanatory Variable

To account for possible time lags in the effect of green digital finance, the one-period lag of the green digital finance index (L.GDFO) is included as the core explanatory variable. The lagged term remains statistically significant, and its magnitude is consistent with the baseline results, further supporting the robustness of the findings.

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Table 6. Regression results of robustness test.

	(1)	(2)	(3)	(4)	(5)
L.GTFP	0.771***				
	(14.54)				
GDFO	0.1243***	0.046***		0.1278*	0.0451***
	(5.25)	(4.99)		(1.909)	(4.499)
L.GDFO			0.047***		
			(4.77)		
_cons	-0.071	0.729***		0.9108***	
	(-1.07)	(15.48)		(2.617)	
N	1110	1221	1110	1221	1110
R^2		0.278	0.312	0.0945	0.1759
F		33.486	41.915	15.8336	17.0080
AR1	0.000				
AR2	0.122				
Hansen	0.380				
Control	YES	YES	YES	YES	YES
Year FE			YES	YES	YES
City FE			YES	YES	YES

Notes: ***p<0.001, **p<0.01, *p<0.05

(4) Alternative Dependent Variable

The dependent variable is replaced by industrial green total factor productivity measured with the SBM_eff method. SBM_eff is a widely used DEA model that directly accounts for slacks and provides more precise, non-radial efficiency estimates. The regression shows that the coefficient of green digital finance (GDFO) remains positive and significant at the 10% level, indicating that the core conclusion holds under a different measure of green transformation efficiency.

(5) One-Period Lag of the Dependent Variable

To examine potential delayed and cumulative effects, the core explanatory variable is replaced with its one-period lag (L.GDFO). The coefficient of L.GDFO stays positive and statistically significant, with a magnitude and significance level similar to the baseline estimates. This confirms that the promoting effect of green digital finance on industrial green transformation is persistent and robust.

5.4. Heterogeneity Test

Based on differences in resource security capacity and socio-economic sustainable development levels, resource-based cities can be categorized into four types: growing, mature, declining, and regenerating. To examine the heterogeneity of environmental decentralization's impact on the green transformation of industries across different types of cities, this study conducts baseline regression analyses on the four sub-samples separately. The specific results are presented in Table 7.

As shown in the regression results in Table 7, the impact of green digital finance on industrial green transformation exhibits significant heterogeneity across different types of resource-based cities, with its effectiveness closely linked to the city's lifecycle stage.

First, for regenerating and mature cities, the promoting effect of digital infrastructure is most significant, with coefficients significantly positive at the 10% level. This finding carries profound policy implications. Regenerating cities are at a critical stage of transitioning from old

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to new economic drivers, making the cultivation of emerging industries and the implementation of green development models particularly urgent. Digital infrastructure provides efficient data circulation platforms, intelligent management systems, and widely connected IoT facilities, offering crucial technological empowerment-not merely financial support-to emerging industries such as the digital economy and green environmental sectors, as well as green transformation projects in traditional industries. This significantly accelerates their industrial green transformation process. Mature cities generally possess relatively strong economic foundations and well-established industrial systems. Digital technologies can deeply integrate with existing industrial frameworks, optimizing production processes and improving energy and resource utilization efficiency, thereby steadily advancing green transformation. Consequently, these cities also exhibit a significant positive impact.

Table 7. Regression Analysis of Different Types of Resource-based Cities

	Growing Type	Mature Type	Declining Type	Regenerating Type
GDFO	0.015	0.061*	0.036	0.057*
	(0.20)	(1.88)	(0.62)	(1.69)
FDI	-0.003	-0.002*	0.000	-0.004**
	(-1.08)	(-1.82)	(0.20)	(-2.08)
REV	0.113*	0.039	0.095**	0.044
	(1.76)	(1.53)	(2.01)	(0.80)
UR	-0.055	0.016	0.015	0.039
	(-0.88)	(0.93)	(0.43)	(1.43)
LGDP	0.101***	0.033***	0.044***	0.064***
	(6.53)	(4.42)	(3.27)	(4.09)
LPOP	0.003	-0.046**	-0.151***	-0.161**
	(0.04)	(-2.02)	(-3.59)	(-2.05)
_cons	-0.325	0.596***	1.051***	0.885**
	(-0.76)	(4.06)	(4.02)	(2.24)
N	154	660	253	154
R^2	0.543	0.312	0.406	0.574
F	13.172	23.350	13.131	14.706
Year FE	YES	YES	YES	YES
City FE	YES	YES	YES	YES

Notes: ***p<0.001, **p<0.01, *p<0.05

Second, for growing and declining cities, the regression coefficients for digital infrastructure are positive but not statistically significant, indicating that its promoting effect has yet to fully materialize in these cities. For growing cities, the lack of significance may stem from a mismatch in development stages. The current focus of such cities likely remains on rapid infrastructure expansion and large-scale resource development, with digital infrastructure still in its nascent stages. The benefits of deep integration between digital infrastructure and green technologies have yet to emerge. However, this also suggests that growing cities hold immense potential for future green growth. Once digital infrastructure is well-developed and aligned with industrial planning, their green transformation may accelerate rapidly. For declining cities, the limited role of digital infrastructure reflects more complex and profound challenges in their transformation. These cities often face multiple constraints, including resource depletion, a monolithic industrial structure, brain drain, and historical environmental liabilities. In this context, mere investment in digital infrastructure is insufficient to drive transformation

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independently. Green transformation requires not only technological tools but also advanced management practices, skilled talent, clear alternative industry plans, and sustained policy support. Digital infrastructure here serves more as an enabler rather than a primary driver, with its effectiveness contingent on a systematic transformation strategy. Thus, while the direction is correct, its standalone impact is statistically difficult to detect.

Furthermore, the performance of control variables supports the above observations. Economic development level (LGDP) exhibits a highly significant positive impact across all four types of cities, highlighting that robust overall economic strength is a common foundation for supporting green transformation in any city type. Meanwhile, foreign direct investment (FDI) shows a significant negative or weak impact in mature and regenerating cities. This may indicate that, during critical transformation phases, traditional FDI may not effectively align with local green innovation needs and could even create a "pollution haven" effect, warranting vigilance from policymakers.

Based on geographical location factors, resource-based cities are categorized into two types: the northern region and the southern region. To systematically examine the heterogeneity of the effects of economic decentralization on the industrial green transformation of different types of resource-based cities, this study conducts baseline regression tests on the two distinct types of resource-based city samples. The regression results are presented in Table 8.

As shown in the table above, green digital finance demonstrates a robust promoting effect in the southern region, with a coefficient of 0.110 that is significant at the 1% level. In contrast, its impact in the northern region is minimal and statistically insignificant, with a coefficient of 0.025. This stark disparity can be attributed to the markedly different "digital ecosystems" and transformation contexts between the north and south.

Table 8. Regression Analysis of Resource-Based Cities in Different Geographic Locations

	Northern Region	Southern Region
GDFO	0.025	0.110***
	(0.82)	(3.66)
FDI	-0.002***	0.001
	(-2.68)	(0.97)
REV	0.011	0.008
	(0.33)	(0.33)
UR	0.008	0.034**
	(0.36)	(2.28)
LGDP	0.053***	0.019**
	(7.30)	(2.24)
LPOP	-0.119***	-0.029
	(-3.60)	(-1.37)
_cons	0.774***	0.606***
	(3.90)	(4.33)
N	715	506
R^2	0.264	0.520
F	20.976	38.070
Year FE	YES	YES
City FE	YES	YES

Notes: ***p<0.001, **p<0.01, *p<0.05

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The significant effectiveness of green digital finance in the southern region benefits from its inherent advantages and a virtuous cycle of economic development. First, the southern region, particularly the Yangtze River Delta and Pearl River Delta, has developed a lightweight and advanced industrial structure dominated by high-end manufacturing, the digital economy, and modern services. Such an industrial structure exhibits a natural affinity with digital technologies, enabling digital infrastructure to rapidly integrate into existing industrial chains. This integration enhances green total factor productivity directly by optimizing supply chain management, empowering smart manufacturing, and fostering new green business models. Second, the southern region typically features more dynamic private economies, more mature factor markets, and a more flexible business environment. This provides fertile ground for the innovative application and marketization of digital technologies, allowing digital investments to be transformed into green productivity more efficiently.

In contrast, the limited role of green digital finance in the northern region reflects its underlying structural challenges. On one hand, the northern economy, particularly in North and Northeast China, has historically developed a path dependence dominated by traditional heavy industries such as energy, chemicals, and heavy equipment manufacturing. This "heavy" industrial structure exhibits strong inertia in transformation, and its integration with digital technologies faces higher technical barriers and transformation costs. If digital infrastructure fails to deeply align with the green transformation of core production processes, its effects may remain superficial. On the other hand, the northern region may face more severe institutional constraints, such as a relatively lower degree of marketization, stronger government intervention in the economy, and insufficient innovation vitality. These factors may hinder the market-driven efficiency of digital infrastructure development, causing its technological dividends to dissipate within rigid institutional frameworks.

The performance of other variables further supports this interpretation. The larger and more significant coefficient of economic development level (LGDP) in the northern region suggests that green transformation there relies more heavily on traditional scale-driven economic growth. The significantly negative coefficient of foreign direct investment (FDI) in the north may corroborate the "pollution haven" hypothesis, indicating that the region has attracted relatively low-end and high-pollution international industrial transfers. The significantly negative coefficient of population size (LPOP) in the north may be associated with structural pressures such as population outflow and aging, which impose additional burdens on the region's green transformation.

6. Conclusion

Currently, China’s resource-based cities have achieved phased progress in promoting industrial green transformation, providing robust support for the sustainable development of the overall economy. However, this process still faces structural constraints, manifested as multiple challenges, including insufficient industrial diversification, lagging development of high-end green industries, persistent pressures in industrial pollution emission control, and relatively limited funding for transformation. Based on the theoretical framework and empirical tests presented earlier, this chapter systematically summarizes the research findings and provides a comprehensive interpretation of the current state of industrial green transformation in resource-based cities, as well as the pathways and mechanisms through which green digital finance operates.

Using panel data from 111 resource-based cities in China from 2013 to 2023, this study systematically examines the impact and mechanisms of green digital finance on industrial green transformation, arriving at the following key conclusions:

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First, the development level of green digital finance in China showed a continuous upward trend during the study period, but regional imbalances remain prominent. In terms of development stages, digital inclusive finance has entered the intelligence-driven 3.0 phase, with significant improvements in financial service coverage, depth of usage, and digitalization. However, the development level of green digital finance in the eastern region is significantly higher than that in the central and western regions, exhibiting a gradient decline from east to west. Meanwhile, resource-based cities still face severe challenges in industrial green transformation. Although the total volume of industrial pollutant emissions has shown a declining trend, emission intensity remains high, and the pace of emission reduction is slow. Issues such as a monolithic industrial structure, short industrial chains, and low value-added persist, and the traditional high-consumption, high-emission industrial development model has yet to undergo fundamental change. Transforming resource-based cities from a reliance on resource consumption to a technology and innovation-driven development model remains a long-term and arduous task.

Second, green digital finance significantly promotes the industrial green transformation of resource-based cities. Baseline regression results indicate that a one-unit increase in the development level of green digital finance raises industrial green total factor productivity by 0.0519 units, significant at the 5% statistical level. Further mechanism analysis reveals that this promotion effect operates through three transmission pathways: (1) The human capital enhancement effect-the interaction term between green digital finance and human capital has a coefficient of 0.0303, significant at the 1% level, indicating that it effectively improves the green literacy and innovation capacity of the workforce by supporting environmental education and green skills training. (2) The financing constraint alleviation effect-the interaction term between green digital finance and financing constraints has a coefficient of 0.101, significant at the 1% level, confirming that it reduces information asymmetry and broadens financing channels through digital technologies, providing critical financial support for green technological innovation in industrial enterprises. (3) The industrial structure advancement effect-the interaction term between green digital finance and industrial structure advancement has a coefficient of 0.0678, significant at the 1% level, indicating that it effectively promotes the transition of the industrial structure toward green and low-carbon directions by accurately identifying and targeting green industrial activities. These findings systematically elucidate the mechanisms through which green digital finance influences industrial green transformation, clarifying its key role in driving the process and providing a solid theoretical foundation and empirical evidence to incentivize green technological innovation in industrial enterprises.

Third, the impact of green digital finance on the industrial green transformation of resource-based cities exhibits notable heterogeneity. Specifically, its positive effect is most pronounced in regenerating and mature cities, while its promoting effect is relatively weaker in growing and declining cities. From the perspective of economic development levels, the promoting effect of green digital finance shows a U-shaped pattern, being significant in low-income and high-income cities but insignificant in middle-income cities. Geographically, resource-based cities in the southern region benefit more significantly from green digital finance than those in the northern region. These heterogeneous characteristics reflect differences among resource-based cities in terms of industrial structure, technological foundations, and institutional environments, suggesting that policy formulation must consider the specific conditions and transformation stages of each city.

Fourth, the industrial green transformation of resource-based cities exhibits significant path dependency. According to the System GMM estimation results, the one-period lag coefficient of industrial green total factor productivity reaches 0.809, indicating that previous transformation outcomes have a sustained reinforcing effect on subsequent progress. This finding suggests that industrial green transformation is a gradual and cumulative process,

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requiring policy continuity and stability to avoid major fluctuations in the transformation trajectory.

References

[1] Li Xiaoxi, Liu Yimeng, Song Tao. Calculation of the Human Green Development Index. Social Sciences in China, 2014(6): 69-95.

[2] Liu Bing, Zhang Lei. Evaluation of Green Development Level in Shandong and Analysis of Countermeasures. Inquiry into Economic Issues, 2017(7): 141-152.

[3] Wu Chuanqing, Huang Lei. Evolutionary Trajectory, Performance Evaluation, and Green Development of Urban Agglomerations in the Middle Reaches of the Yangtze River. Reform, 2017(3): 65-77.

[4] Kuang Yuanfeng, Peng Daiyan. Analysis of Environmental Production Efficiency and Environmental Total Factor Productivity in China. Economic Research Journal, 2012(7): 62-74.

[5] Feng Zhijun, Chen Wei. The Impact of Technology Sources on Total Factor Productivity Growth in R&D Innovation: An Empirical Study Based on Large and Medium-sized Industrial Enterprises in China's Regions. Science of Science and Management of S.& T., 2013, 34(3): 33-41.

[6] Li Bin, Peng Xing, Ouyang Mingke. Environmental Regulation, Green Total Factor Productivity, and the Transformation of China's Industrial Development Mode: An Empirical Study Based on Data from 36 Industrial Sectors. China Industrial Economics, 2013(4): 56-68.

[7] Huang Jianhuan. Regional Heterogeneity, Ecological Efficiency, and Green Development. Beijing: China Social Sciences Press, 2016: 38-41.

[8] Zhang Yinghao, Chen Jianglong, Cheng Yu. The Impact Mechanism of Environmental Regulation on Regional Green Economic Efficiency in China: An Empirical Analysis Based on the Super-efficiency Model and Spatial Panel Econometric Model. Resources and Environment in the Yangtze Basin, 2018, 27(11): 2407-2418.

[9] Peng Xing, Li Bin. Research on China's Industrial Green Transformation Under Different Types of Environmental Regulation. Journal of Finance and Economics, 2016, 42(7): 134-144.

[10] Deng Huihui, Yang Luxin. Haze Control, Local Competition, and Industrial Green Transformation. China Industrial Economics, 2019(10): 118-136.

[11] Shen Chen, Li Shenglan, Huang Liangxiong. The Impact Mechanism of Heterogeneous Environmental Regulation on China's Industrial Green Transformation: An Empirical Analysis Based on Mediating Effects. Nankai Economic Studies, 2018(5): 95-114.

[12] Xiao Ying, Lu Liwen. Measurement of Industrial Green Transformation in Resource-based Cities: An Analysis Based on Panel Data of 108 Resource-based Cities in China. Finance & Economics, 2019(9): 86-98.

[13] Wang Hongtao, Cao Wencheng. Analysis of Spatiotemporal Differences and Influencing Factors of Green Finance Development in China. Journal of Shanghai Lixin University of Accounting and Finance, 2022, 34(2): 15-33.

[14] Wang Kangshi, Sun Xuran, Zhang Linxi, et al. Does Financial Digitalization Promote the Development of Green Finance? An Empirical Study Based on China's Listed Industrial Enterprises. Collected Essays on Finance and Economics, 2020(9): 44-53.

[15] Huang Shizhong. The Practice of Shared Value Creation: A Case Study Based on Ant Group. Finance and Accounting Monthly, 2023, 44(13): 3-11.

[16] Chen Wenting, Xu Daheng, Yang Liling. Can the Coupling of Green Inclusive Finance and Rural Revitalization Boost Economic Development? The Theory and Practice of Finance and Economics, 2023, 44(6): 100-107.

[17] Fang Qi, Qian Lihua, Lu Zheng'an. New Trends in Financial Support for the "Dual Carbon" Goals: Outlook on Green Finance Trends for 2023. Finance and Economy, 2023(1): 3-14.

[18] Huang Yiping, Huang Zhuo. The Development of Digital Finance in China: Present and Future. China Economic Quarterly, 2018, 17(4): 1489-1502.

[19] Wu Qingtian, Wen Xiaopei. Synergistic Effects and Mechanisms of Digital Inclusive Finance and Green Finance: Based on the Goal of Common Prosperity. Management Modernization, 2023, 43(5): 47-55.

[20] Zhang Ruihuai. Making Green Finance More Inclusive and Inclusive Finance Greener: Practices and Reflections Based on Regional Financial Reform in Jiangxi. Finance and Economy, 2022(8): 3-8.

[21] Zou Yinyin. Analysis of the Integration Path of Green Finance and Inclusive Finance from the Perspective of Digital Finance Development. Modern Finance, 2022(11): 30-34.

[22] Huang Zhuo, Wang Pingping. Empowering Green Finance Development with Fintech: Mechanisms, Challenges, and Policy Suggestions. Social Science Journal, 2022(5): 101-108.

[23] Zhong Kai, Liu Yihan, Wang Yueyuan. Research on the Impact of Fintech on Green Credit: Evidence from Commercial Banks. Foreign Economics & Management, 2023, 45(11): 3-18.

[24] Liang Fang, Zhao Yong, Huang Zhuo. Fintech, Macroeconomic Uncertainty, and Proactive Risk-Taking of Commercial Banks. China Economic Quarterly, 2022, 22(6): 1869-1890.

[25] Wang Renzeng, Zhan Shuhe. A Study on the Synergistic Impact of Digital Inclusive Finance and Green Finance on High-Quality Economic Development. Modern Economic Research, 2023(7): 59-70.

[26] Guo Genlong, Yang Jing. Can Financial Development Alleviate the Resource Curse? An Empirical Analysis Based on China's Resource-based Regions. Economic Issues, 2017(9): 47-52.

[27] Zhang Li, Gai Guofeng. Can Human Capital and Financial Development Break the "Resource Curse"? A Study Based on Panel Data of China's Coal Cities. Contemporary Economic Research, 2020(4): 58-67.

[28] Xian Chengyi, Zhang Dehua. Does Green Finance Improve Environmental Quality? Evidence from Western China. Journal of Regional Financial Research, 2022(3): 24-30.

[29] Yang Danni, Wang Junwen. Green Finance, Credit Resource Allocation Efficiency, and High-Quality Urban Development. Credit Reference, 2023, 41(9): 78-85.

[30] Gong Q, Ying L, Dai J. Green Finance and Energy Natural Resources Nexus with Economic Performance: A Novel Evidence from China. Resources Policy, 2023, 84: 103765.

[31] Peng Xing, Li Bin. Research on China's Industrial Green Transformation Under Different Types of Environmental Regulation. Journal of Finance and Economics, 2016, 42(7): 134-144.

[32] Ren S, Li X, Yuan B, et al. The Effects of Three Types of Environmental Regulation on Eco-Efficiency: A Cross-Region Analysis in China. Journal of Cleaner Production, 2016, 173: 245-255.

[33] Ghisetti C, Mancinelli S, Mazzanti M, et al. Financial Barriers and Environmental Innovations: Evidence from EU Manufacturing Firms. Climate Policy, 2017, 17(1): 131-147.

[34] Li J, Zhang G, Ned J P, et al. How Does Digital Finance Affect Green Technology Innovation in the Polluting Industry? Based on the Serial Two-Mediator Model of Financing Constraints and R&D Investments. Environmental Science and Pollution Research, 2023, 30(29): 74141-74152.

[35] Fang L, Zhao B, Li W, et al. Impact of Digital Finance on Industrial Green Transformation: Evidence from the Yangtze River Economic Belt. Sustainability, 2023, 15(17): 12799.

[36] Zhu Yue, Zhang Juntao. Research on the Impact of Digital Finance Development on Urban Economic Green and Low-Carbon Transformation. Urban Problems, 2022(10): 64-71+81.

[37] Li Manjing. The Impact of Digital Finance on Economic Growth in Resource-based Cities. Science Technology and Industry, 2023, 23(19): 85-91.

[38] Chen Xiaoming, He Sihua, Feng Rui. Research on the Incentive Effect of Digital Finance on Corporate Green Technology Innovation. Wuhan Finance, 2022(12): 53-62.

[39] Chen Y. Cleaning Russian Oil Industry for Energy Resource Exploration and Industrial Transformation Towards Zero Carbon Green Recovery: Role of Inclusive Digital Finance. Resources Policy, 2024, 88: 104436.

[40] Lan Zirui, Zhang Shuhua. The Impact of Digital Inclusive Finance on Corporate Green Innovation and Its Mechanism Test. Statistics & Decision, 2023, 39(10): 155-159.