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# Research on the Role of Digital Finance in Urban Green Innovation

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**Abstract:** Promoting green innovation is an important way to implement the dual carbon strategy and build an innovative country. Based on the panel data of 250 cities in China from 2011 to 2018, this paper constructs a two-way fixed-effect model, an intermediary effect model and a spatial Durbin model, and empirically studies the impact and mechanism of digital finance on urban green innovation. The results show that digital finance can improve the ability of urban green innovation, and its enabling effect mainly comes from improving the financial service model and improving the digital level. However, the role of digital finance in improving the efficiency of green innovation is not significant. Digital finance can promote urban green innovation by promoting the development of the Internet and alleviating the distortion of labor factors. A good environment for innovation will enhance the role of digital finance in promoting green innovation. Through further analysis, the spatial spillover effect of digital finance on green innovation at this stage is dominated by the siphon effect while the "trickle-down" effect is blocked.

**Keywords:** digital finance; green innovation; spatial spillover effect

## 1. Introduction and Literature Review

Since the reform and opening up, China has focused on economic development but has not paid attention to the construction of the ecological environment. However, with the Fifth Plenary Session of the 18th Central Committee of the Communist Party of China putting forward the new development concept of "innovation, coordination, green, openness, and sharing" (Xinhua News Agency: Communiqué of the Fifth Plenary Session of the 18th Central Committee of the Communist Party of China. 29 October 2015), "Green development" has gradually come into people's sight. In 2021, the State Council issued the "Opinions on Completely, Accurately, and Comprehensively Implementing the New Development Concept and Doing a Good Job in Carbon Peak and Carbon Neutrality" to make overall arrangements for the dual carbon strategy. Stimulating the endogenous power of green innovation is the key to implementing the dual carbon strategy. Different from traditional technological innovation, green innovation has the attribute of "environmental benefit", which can produce dual externalities in the innovation process, that is, it has the knowledge spillover effect of innovation activities and can also reduce the potential environmental costs, which is an important strategic support for promoting the process of green industrialization and building a beautiful China. However, China's green innovation has problems such as financing constraints, large regional disparities, and insufficient incentive mechanisms (https://www.thepaper.cn/newsDetail_forward_12925499, accessed on 21 November 2024), and solving these problems is of great significance for promoting green transformation and realizing the dual carbon strategy. With the rapid development of digital finance in China, its business format is diversified and its penetration is increasing, showing great potential to promote product innovation (https://finance.sina.com.cn/



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money/bond/2024-03-01/doc-inakupnp0593949.shtml, accessed on 21 November 2024). At present, there is a lot of research on the importance of digital finance for regional and corporate innovation [1–3]. But can digital finance empower regional green innovation? What mechanisms does digital finance use to promote regional green innovation? Is there a spatial spillover effect of digital finance on regional green innovation? There is no very common understanding of these issues.

The concept of green innovation and related research originated in the 1990s. There is no unified understanding of the concept of green innovation. Zhang et al. believe that the definition of green innovation can be divided into three types, namely reducing environmental impact, introducing ecological thinking, and environmental innovation [4]. Some scholars believe that green innovation, including green institutional innovation and cultural innovation, has expanded from the technical level to the whole society. Regarding the motivation of green innovation, Rennings [5] constructed a framework of market, technology, and management, in which the market part and its included competition, labor costs, consumer demand, and market share are the key factors influencing corporate green innovation.

Existing studies have analyzed the relationship between digital finance and innovation. On the one hand, the role of digital finance in promoting corporate innovation from a micro perspective has been studied. For example, Liang et al. found that digital inclusive finance can improve the technological innovation capabilities of small and medium-sized enterprises and has a stronger innovation incentive effect on private and small-scale SMEs [6]. On this basis, Wan Jiayu et al. studied the role of digital finance in promoting enterprise innovation from three dimensions [7]. Zheng et al. found that digital finance plays greater role in breakthrough innovation than in incremental innovation [8]. On the other hand, the relationship between digital finance and regional innovation has been discussed from a macro perspective. Du Chuanzhong et al. [9] asserted that digital finance can provide new impetus for improving the level of regional innovation and put forward two ways to improve the supply and demand of regional innovation capabilities. Pan Shuang et al. further found that digital finance has a more significant role in promoting innovation in small and medium-sized cities [10]. There is also a section of literature that explores the relationship between digital finance and green innovation. For example, Qiao Bin et al. found that the role of digital inclusive finance in promoting corporate green innovation has an intermediary mechanism of deleveraging and incentivizing shareholders, and it is more obvious in non-state-owned enterprises, heavily polluted areas, and enterprises in the central and western regions [11]. Wei Shiwei et al. found that the digital economy can improve the output of urban green innovation, showing that it takes into account the inclusive function of small and medium-sized cities and plays a more prominent role in regions with a high level of marketization [12].

In addition to telling China's story, some scholars also focused on the relationship between digital finance and innovation from an international perspective. Syed Kumail et al. explored the multi-pronged link between innovation, digital adoption, and fintech, revealing a two-way causal relationship between innovation and digital adoption, and finding that fintech development is less connected to these dimensions [13]. Misati et al. studied the impact of digital financial innovation on financial depth and economic growth in Kenya and found that there was a positive correlation between digital financial innovation and financial depth, with the largest impact of Internet use and mobile financial services and the least impact of bank branches [14]. This financial innovation has a positive impact on economic growth. Jun et al. investigated how digital platform capabilities affect innovation performance using data collected from 647 SME managers working in Pakistan and found a significant and positive relationship between digital platform capabilities, improvisation capabilities, and organizational readiness and innovation performance, with firms shifting from traditional

operational activities to digitalization [15]. Jeremiah et al. examined the interaction between information and communication technology (ICT) adoption and innovation and the role of this digital interaction for financial development in Africa and sub-regions, and found that ICTs contribute to the improvement of innovation performance [16]. In summary, the positive correlation between digital finance and innovation is universal in developing countries, and the main factor is the adoption of digital technologies.

The above results show that there are not many studies focusing on the relationship between digital finance and urban green innovation and their mechanism, and the research in this paper is a supplement to this problem. The marginal contributions of this paper are as follows: first, in this paper, we verify whether the "Porter hypothesis" is applicable to the field of digital finance and analyze the role of digital finance on green innovation and green innovation efficiency. Second, this paper explores the role path and intermediary mechanism of digital finance on urban green innovation from the perspectives of Internet development and the distortion of labor factors. Third, based on the above research results, the moderating impact of the innovation environment in the process of digital finance empowering green innovation is verified. Fourth, from the perspective of spatial spillover, it is verified that the spatial spillover effect of China's current digital financial development on green innovation is mainly siphoning. It is important to note that this paper is based on data from before the pandemic, showing the causal relationship between China's digital finance development and green innovation in the past time period, so the conclusions may differ from the current facts.

## 2. Analysis of Theoretical Mechanism

### *2.1. The Direct Impact Mechanism of Digital Finance on Urban Green Innovation*

Schumpeter was the first to mention the link between credit, bankers and innovation, noting that credit and bankers "make possible the realization of new combinations [17]". Subsequent scholars affirmed the role of finance in promoting technological innovation from the perspectives of financing, risk, information, and incentives [18]. As an emerging form of finance, digital finance has the common attributes of finance, so it can also promote urban green innovation. First, digital finance has stimulated the demand for green innovation in cities. On the one hand, due to cost and risk factors, traditional financial institutions are not highly motivated to finance urban SMEs, so the incentive effect on SMEs is not strong. On the other hand, due to the cumbersome process of traditional financing methods, high transaction costs, and high financing thresholds for enterprises, the enthusiasm of capital demanders is reduced and local enterprises are hindered from carrying out green innovation activities. To a certain extent, the technical empowerment and product innovation characteristics of digital finance itself can reduce the financing risks of financial institutions for different types of enterprises, enable them to provide more diverse financing products that serve different types of enterprises, and give full play to the "long-tail effect" so as to expand the scope of services and improve service quality and encourage more small and medium-sized enterprises to carry out green innovation. At the same time, it can also reduce the transaction costs of financial institutions and enterprises and the financing threshold of enterprises, as well as improve the enthusiasm of enterprises for green innovation. In addition, digital finance has prompted innovators to increase investment in green innovation. On the one hand, digital finance can alleviate information asymmetry and reduce financing risks. Digital finance can break through the temporal and spatial limitations of the flow of financial elements, optimize the supply of financing, and improve the efficiency of financial operations [19]. Due to the uncertainty and long-term feedback characteristics of innovation activities, it faces serious information asymmetry problems [20]. Through the use of big data, cloud computing, blockchain and other tech-

nologies, digital finance can improve the accessibility and timeliness of financial services, alleviate information asymmetry, and then encourage enterprises to increase investment in innovation. On the other hand, the high-risk identification characteristics of digital finance can strengthen the risk management of financial services, thereby reducing financing risks, making financing activities more easily capable of breaking through the time and space limitations, broadening the scope of the capital market, thereby enhancing the financing competition between enterprises and promoting enterprises to carry out high-quality innovative activities to attract financing. Finally, digital finance reduces non-green innovation decisions and strengthens green regulation. The application of digital technology can improve the efficiency of resource integration and environmental monitoring capabilities [21] so that enterprises can better screen out better green innovation projects and provide them with key support, eliminating some non-green innovation projects. At the same time, it can also improve the ability of enterprises to supervise green innovation and avoid green innovation risks. All these can increase the willingness of enterprises to participate in green innovation, which in turn will improve the green innovation capacity of the region as a whole.

Digital finance can reduce transaction costs, improve the efficiency of capital allocation and the ability of enterprises to screen and supervise green innovation, all of which can help boost the efficiency of green innovation. However, the development of digital finance is also constrained by the improvement of regional green innovation efficiency. First of all, China's service industry is not sufficiently integrated with the Internet, and institutional reform is urgently needed, which makes the operation of digital finance inefficient [22]. The inefficiency of digital finance will eventually be related to the innovation activities of enterprises, affecting the efficiency of green innovation. Second, China's financial industry does not serve the real economy enough, and it even has a tendency to deviate from serving the real economy, which increases the difficulty of enterprise financing, leading to the distortion of capital factor prices and increasing the innovation cost of enterprises, indirectly affecting the quality of enterprise innovation, and ultimately limiting the efficiency of green innovation. Finally, the central–local decentralization model makes local governments short-sighted. The development of digital finance does not mean completely free financing activities, and local governments may extend an "intervention hand" to set up barriers to capital flow, resulting in resource dislocation, increasing the financing difficulty of enterprises in other regions, and then reducing the efficiency of green innovation activities of enterprises in other regions. At the same time, excessive government subsidies may affect the identification and management of high-quality green innovation projects and regulatory innovation activities and hinder the improvement of green innovation efficiency of enterprises in the region. In summary, this paper proposes Hypothesis 1:

**H1:** *Digital finance will promote urban green innovation, but it will not significantly improve the efficiency of urban green innovation.*

### *2.2. The Intermediary Mechanism and Adjustment Mechanism of Digital Finance to Empower Urban Green Innovation*

The development of the Internet has brought about a new round of scientific and technological revolution, promoted the application of digital technology and data production factors in the financial field, realized the transformation of the content and form of financial activities [23], and gave birth to a new digital financial format. At the same time, with the continuous deepening of digital finance, it also promoted the construction of information infrastructure, which in turn led to further development of the Internet. The Internet can expand the breadth and depth of innovation resource integration, reduce innovation costs, and innovate business models [24], thereby incentivizing enterprises to

carry out technological innovation, expand markets, and promote innovation activities. In addition, the Internet has the characteristics of time and space spanning and sharing, which objectively expands the market scale, intensifies the competition and information exchange between regional enterprises, promotes the "collaborative breakthrough" of technology between enterprises, and stimulates regional enterprises to improve technology and products, thereby promoting the improvement of enterprises' green innovation capabilities.

The existing literature explains the role of digital finance in alleviating the misallocation of labor resources from the perspectives of labor pool effect and human capital effect [25,26]. By alleviating the distortion of labor factors, digital finance can be promoted to empower green innovation. First, from the perspective of the labor pool effect, digital finance can alleviate the financing constraints of enterprises and labor. On the one hand, it can make enterprises more willing to absorb high-quality labor such as green technicians and avoid the "lock-in effect" of enterprises reducing labor costs due to insufficient funds, resulting in low-end production products and high energy consumption and high pollution. On the other hand, it promotes the regional flow of labor, prompts enterprises in urgent need of green technology talents such as energy conservation and emission reduction to obtain matching labor, realizes the refinement of labor division of labor, objectively increases the accumulation of regional human capital, increases the innovative talent resources of regional enterprises, and improves the green innovation ability of regional enterprises. In summary, this paper proposes Hypothesis 2:

**H2:** *Digital finance promotes urban green innovation by promoting the development of the Internet and improving the mismatch of labor factors.*

A good innovation environment plays an important role in enhancing regional innovation capabilities. Talent agglomeration and financial development level are two important dimensions that affect the innovation environment, which restricts the supply of innovative talents on the one hand and the development of digital finance on the other. The higher the degree of talent concentration in a region, the higher the level of human capital, the more potential people can engage in green innovation activities and the more the development of digital finance can make it easier for enterprises in the region to obtain talents who are engaged in green innovation activities, thereby improving the level of green innovation in the region. The higher the level of financial development of a region, the better its information infrastructure and financing environment, and the less restricted the development of digital finance, the more it can play its role in empowering regional green innovation. In summary, Hypothesis 3 is proposed:

**H3:** *A good environment for innovation will strengthen the role of digital finance in promoting green innovation.*

### *2.3. The Spatial Spillover Effect of Digital Finance Empowering Urban Green Innovation*

Peyroux's "growth pole" theory holds that the agglomeration and development of an industry in a certain region or city inevitably has a radiating effect on the surrounding areas. From the first law of geography, it can be seen that there must be a connection between things that is closely related to distance. Digital finance compresses the distance between time and space through digital technology, supplemented by the natural liquidity of financial elements [27], which makes digital finance have strong spatial spillover. Therefore, it is reasonable to believe that there is a distance correlation between digital finance and regional green innovation, and studying the spatial spillover effect of digital finance on green innovation can better reveal the spatial heterogeneity of digital finance-empowered green innovation and explain the characteristics of digital finance empowered green innovation

in more depth. The specific theoretical mechanisms of digital financial spillover effects can be summarized as radiation effects, competition effects, siphon effects, and trickle-down effects [28]. The radiation effect refers to the inclusiveness of digital finance itself, which can lead to the improvement of the level of green innovation in the surrounding areas. The competition effect refers to the fact that the tournament model promoted by local governments in China can stimulate the development of digital finance in neighboring regions, thereby promoting green innovation in neighboring regions [29]. The siphon effect refers to the high level of digital finance development in a region, which will lead to the cross-regional flow of factors from neighboring regions, resulting in the "polarization" of green innovation. The trickle-down effect refers to the ability of a region to prioritize the development of digital finance and promote green innovation by transferring advanced technology and management experience to neighboring regions.

So what kind of spillover mechanism is suitable for digital finance to empower green innovation at this stage? In Hirschman's theory of "polarization trickle-down effect [30]", the priority development of a region's economy initially causes peripheral labor, capital, and other factors to migrate to the growth pole, which widens the gap between regions and produces the phenomenon of "polarization". With the continuous development of growth poles and the increasing complementarity between regions, the expansion of demand in the first-mover areas brings development opportunities to the late-developing regions. At the same time, the advanced technology and management experience in the growth pole areas spread to the backward areas, producing a "trickle-down" effect. This paper argues that since China's digital transformation is in its infancy, there is still a broad space for the development of digital finance, so the current spatial characteristics of digital finance to empower green innovation are still dominated by siphoning. On the one hand, the inherent high agglomeration of digital finance makes innovation factors such as talents and capital flow to the growth pole regions, so it increases the innovation output of advanced regions and then exacerbates the imbalance of innovation capabilities between regions. On the other hand, the development of digital finance in the first-developing regions has attracted the inflow of advanced innovation elements, but also caused a lack of factors in the late-developing regions, and the late-developing regions are forced to use backward and environmentally unfriendly elements, which restricts the improvement of the green innovation capabilities of the late-developing regions. In addition, due to the prominent local protectionism in China, the diffusion of advanced technology and management experience between regions is hindered. The technological agglomeration characteristics of digital finance are obvious, so it is more likely to produce the phenomenon of "data islands" between regions, which limits the role of "trickle-down" and objectively exacerbates the imbalance of regional green innovation capabilities. Based on the above analysis, Hypothesis 4 is proposed:

**H4:** *There is a space overflow in digital finance in the process of promoting the improvement of urban green innovation*.

Figures 1 and 2 briefly describe the theoretical assumptions, model settings, and conclusions of the paper.

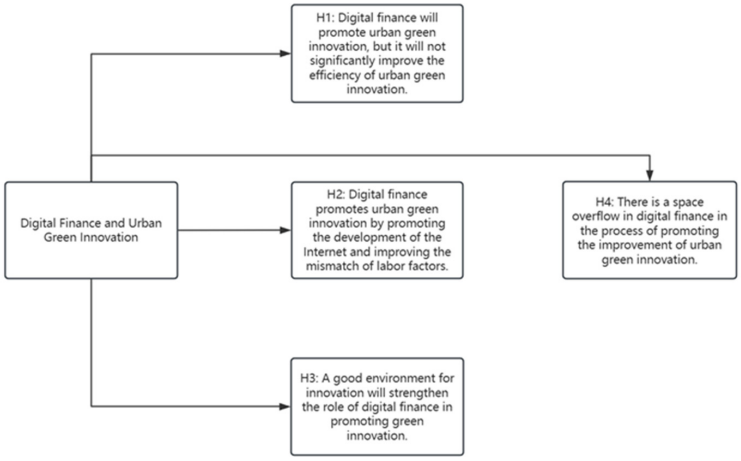


**Figure 1.** Theoretical hypothesis diagram.

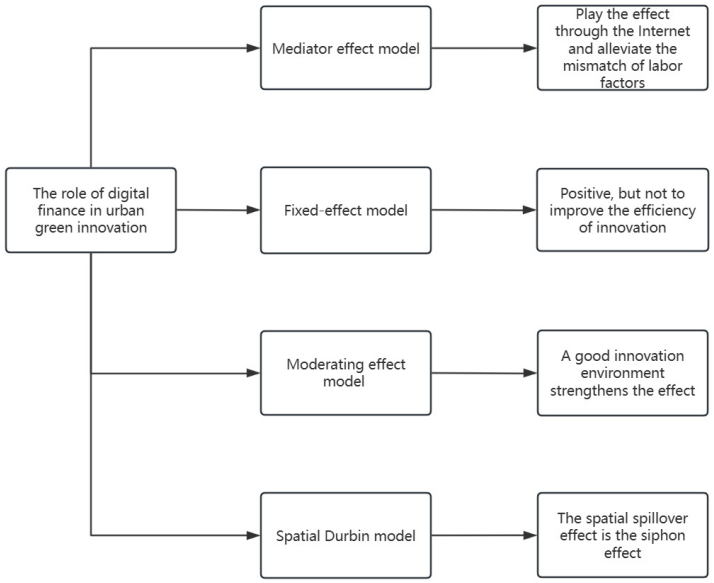


**Figure 2.** Theoretical model and conclusion diagram.

## 3. Research Design

### *3.1. Model Setting*

Based on the methods of Meeusen, Broeck [31], and Aigner [32], a time-varying panel stochastic frontier model was constructed:

$$lnGI_{it} = \beta_0 + \beta_1 l_{it} + \beta_2 k_{it} + \beta_3 pow_{it} + \beta_4 smo_{it} + \beta_5 water_{it} + \beta_6 so2_{it} + \lambda_t + v_{it} - \mu_{it}$$

$$\mu_{it} = e^{-\eta(t-T_i)}\mu_i$$

$GI_{it}$ represents the number of green patent applications, and the data presentation and source are the same as those of the explanatory variables. l and k denote labor and capital input, respectively, using urban employment and fixed capital stock. The number of employed persons is expressed as the sum of the number of employees in urban units and the number of private individuals. The fixed capital stock is calculated by using the perpetual inventory method with reference to the method of Shan Haojie [32]. The rest are power generation ($pow_{it}$), industrial soot emissions ($smo_{it}$), wastewater emissions ($water_{it}$), and sulphur dioxide production ($so2_{it}$). $v_{it}$ is the time-varying error term, which indicates the unobservable factors affecting the individual, $\lambda_t$ represents the time effect, and $\mu_{it}$ is the inefficient term indicating how far the individual is from the efficiency frontier, which

is determined by the time-varying parameter η. If the time-varying parameter is greater than zero, the technical efficiency increases.

The C-D production function is defined as follows:

$$Y_{it} = A_{it} K_{it}^{\alpha} L_{it}^{\beta}$$

The econometric model is established as follows:

$$\ln\left(\frac{Y}{L}\right)_{it} = \alpha + \beta_{ik} \ln\left(\frac{Y}{K}\right)_{it} + u_i + \lambda_t + \varepsilon_{it}$$

where $\beta_{ik}$ is the elasticity of capital output. $Y$ is the real output, expressed in real GDP; $K$ and $L$ are expressed in terms of capital and labor inputs; fixed capital stock and employment are expressed, respectively, as follows: $u_i$ is the individual effect, $\lambda_t$ represents the time effect, and $\varepsilon_{it}$ is the random interference. The fixed capital stock is calculated using the perpetual inventory method with reference to the method of Shan Haojie [33], and the number of employed persons is expressed as the sum of the number of urban units and individual and private employees.

Defining the elasticity of labor output $\beta_l = 1 - \beta_k$, $s_i$ represents the ratio of the output value of city i to the total output. Then, the absolute distortion index of labor is

$$\gamma_{il} = \frac{\frac{l_i}{\sum_{i=1}^{n} l_i}}{\frac{s_i \beta_{il}}{\sum_{i=1}^{n} s_i \beta_{il}}}$$

Drawing on the method of Ji Shuhan et al., the labor mismatch index is defined as $\tau_l = 1/(1 - \gamma_l)$ [34], and the absolute value is taken at the same time to obtain the labor relative distortion index.

Based on the theoretical basis and research hypotheses mentioned above, the benchmark regression model is set as follows:

$$GI_{it} = \alpha + \theta_1 DIF_{it} + \sum_{i=1}^{n} X_{it} + u_i + \lambda_t + \varepsilon_{it}$$

$$GIE_{it} = \alpha + \theta_1 DIF_{it} + \sum_{i=1}^{n} X_{it} + u_i + \lambda_t + \varepsilon_{it}$$

$GI_{it}$ represents green innovation capacity, $GIE_{it}$ represents green innovation efficiency, $DIF_{it}$ represents the level of development of digital finance, $X_{it}$ represents the control variable, $u_i$ represents the individual effect, $\lambda_t$ represents the time effect, and $\varepsilon_{it}$ is a random distractor.

In order to test the mechanism of digital finance influencing green innovation, the mediation effect model is set up as follows with reference to the method of Wen Zhonglin et al. [35]:

$$\text{M1}: \ GI_{it} = \alpha + \theta_1 DIF_{it} + \sum_{i=1}^{n} X_{it} + u_i + \varepsilon_{it}$$

$$\text{M2}: \ M_{it} = \alpha + \theta_1 DIF_{it} + \sum_{i=1}^{n} X_{it} + u_i + \varepsilon_{it}$$

$$\text{M3}: \ GI_{it} = \alpha + \theta_1 DIF_{it} + M_{it} + \sum_{i=1}^{n} X_{it} + u_i + \varepsilon_{it}$$

$GI_{it}$ represents green innovation capacity, $DIF_{it}$ represents the level of development of digital finance, $M_{it}$ represents mediation variables, $X_{it}$ represents the control variable, $u_i$ represents the individual effect, and the $\varepsilon_{it}$ is a random distractor.

In order to test the moderating effect of the innovation environment, the model is set up as follows:

$$GI_{it} = \alpha + \theta_1 DIF_{it} + \theta_2 DIF_{it} * ADJ_{it} + \sum_{i=1}^{n} X_{it} + u_i + \lambda_t + \varepsilon_{it}$$

$GI_{it}$ represents green innovation capacity, $DIF_{it}$ represents the level of development of digital finance, $ADJ_{it}$ represents innovative environment, $X_{it}$ represents the control variable, $u_i$ represents the individual effect, $\lambda_t$ represents the time effect, and $\varepsilon_{it}$ is a random distractor.

In order to study the spatial spillover effect of digital finance on green innovation, the spatial Durbin model is used for analysis. The model settings are as follows:

$$GI_{it} = \alpha + \rho \sum_{i=1}^{n} w_{ij} GI_{it} + \theta_1 DIF_{it} + \pi \sum_{i=1}^{n} w_{ij} DIF_{it} + \sum_{i=1}^{n} X_{it} + \delta \sum_{i=1}^{n} w_{ij} X_{it} + u_i + \varepsilon_{it}$$

where $w_{ij}$ represents the spatial weight matrix, $GI_{it}$ represents green innovation capacity, $DIF_{it}$ represents the level of development of digital finance, $X_{it}$ represents the control variable, $u_i$ represents the individual effect, $\varepsilon_{it}$ is a random distractor.

### *3.2. Variable Selection and Data Description*

This paper selects a sample of 250 prefecture-level cities from 2011 to 2018, and the data are from the China City Statistical Yearbook, the State Intellectual Property Office, and the Peking University Digital Financial Inclusion Index (2011–2018).

#### 3.2.1. Green Innovation (GI)

The number of green patent applications in each prefecture-level city, i.e., the sum of the number of green invention patent applications and the number of green utility model patent applications is matched by WIPO's green list of the International Patent Classification.

#### 3.2.2. Green Innovation Effectiveness (GIE)

It is measured by the time-varying panel stochastic frontier model. The specific process is described in the model setting.

#### 3.2.3. Explanatory Variable: Digital Finance (DIF)

Referring to the research of Guo Feng et al., the "Peking University Digital Inclusive Finance Index" was used as a proxy variable for the development level of digital finance in the region [36]. The index includes a total of 33 indicators in three dimensions: breadth, depth, and level, which can scientifically and accurately describe the development of digital finance in the region.

#### 3.2.4. Mediator Variable (M) and Moderating Variable (ADJ)

Internet development (INTER) is represented by the number of regional Internet users, and the distortion of labor factors (ABSTUAL) is calculated by drawing on the method of Ji Shuhan [34]. Specific steps are shown in the model setting.

The measurement of the innovation environment refers to the practice of Han Lu et al. [37]. It uses the two dimensions of talent agglomeration and financial development in which the number of employees in the scientific and technological research and the service industry is used to measure talent agglomeration (TAG). Financial Development (FINDEV) is measured by the ratio of local bank deposits and loans to GDP using the practice of Gan Xing et al. [38].

#### 3.2.5. Control Variables

Based on the existing literature, the following control variables are selected:

(1) Economic growth (ECO). Economic growth can ensure the supply of funds for enterprise innovation, stimulate the motivation of enterprises to explore markets and earn profits, and then affect green innovation activities. This paper uses GDP per capital to measure economic growth.
(2) The size of the city. The larger the city, the stronger the agglomeration effect of innovative elements such as talents and capital, and the higher the concentration of industries, which not only accelerates technological integration but also reduces the resistance to innovation. In this paper, the total population at the end of the year is used to measure the size of the city.
(3) The status of industrial structure (INSTR). The transformation of the industrial structure to technology intensive improves the output of innovation, and a reasonable industrial structure can provide a good external environment for innovation activities. This paper uses the proportion of the tertiary industry in GDP to measure the regional industrial structure.
(4) Consumer demand (DEM). Consumers' green preference can directly affect the willingness of enterprises to innovate green. This paper is measured by the total retail sales of consumer goods per capita.
(5) Industrial agglomeration (IAGG). Industrial agglomeration can exert scale effects, accelerate knowledge spillover, and improve regional innovation capabilities. In this paper, the number of industrial enterprises above the designated size is used to measure the level of industrial agglomeration. Descriptive statistics for the variables are shown in Table 1.

**Table 1.** Descriptive statistics of variables.

| Variables | Number of Samples | Mean | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| DIF | 2000 | 156.697 | 62.076 | 23.88 | 302.983 |
| GI | 2000 | 772.311 | 2161.748 | 1 | 340.97 |
| GIE | 2000 | 0.812 | 0.116 | 0.065 | 0.970 |
| BREADTH | 2000 | 147.153 | 59.455 | 4.49 | 290.318 |
| DEPTH | 2000 | 155.181 | 65.232 | 12.49 | 325.679 |
| LEVEL | 2000 | 190.970 | 80.905 | 3.39 | 581.23 |
| DEM | 2000 | 21,204.52 | 18,504.33 | 0.391 | 145,815.7 |
| ECO | 2000 | 52,201.48 | 33,974.74 | 887.7 | 467,749 |
| INSTR | 2000 | 39.999 | 9.814 | 14.36 | 80.98 |
| IAGG | 2000 | 1324.91 | 1543.621 | 21 | 107.76 |
| SIZE | 2000 | 479.695 | 487.494 | 19.5 | 11,098.4 |
| INTER | 1999 | 97.606 | 117.641 | 4.256 | 127.4 |
| ABSTUAL | 1677 | 7.087 | 19.214 | 0.001 | 255.115 |
| TAG | 1749 | 14,049.3 | 44,736.27 | 200 | 712,481 |
| FINDEV | 1994 | 2.780 | 2.133 | 0.588 | 37.526 |

## 4. Empirical Results and Analysis

### *4.1. Analysis of the Regression Results of Digital Finance and Urban Green Innovation*

Tables 2 and 3 show the regression results of the two-way fixed-effect model. The *p*-value of Hausman's test is zero, indicating that a two-way fixed-effect model is reasonable. Table 1 shows the regression results with green innovation as the dependent variable, where (1) is the regression result without the control variable, (2) is the regression result with the control variable, and (3) to (5) are the regression results of the three dimensions of digital finance. Table 2 shows the regression results with green innovation efficiency as the dependent variable, and Columns (1) and (2) are the regression results without control variables and with control variables, respectively.

**Table 2.** Benchmark regression results.

| | (1) GI | (2) GI | (3) GI | (4) GI | (5) GI |
|---|---|---|---|---|---|
| DIF | 48.043 *** | 34.863 *** | | | |
| | (4.28) | (3.63) | | | |
| BREADTH | | | 10.544 | | |
| | | | (1.62) | | |
| DEPTH | | | | 18.106 *** | |
| | | | | (2.90) | |
| LEVEL | | | | | 4.929 *** |
| | | | | | (3.20) |
| CONTROL | No | Yes | Yes | Yes | Yes |
| _CONS | −2211 *** | −1126.143 ** | 85.794 | −368.554 | 293.964 |
| | (−3.44) | (−2.07) | (0.12) | (−0.70) | (0.46) |
| Individual effect | Yes | Yes | Yes | Yes | Yes |
| Time effect | Yes | Yes | Yes | Yes | Yes |
| N | 2000 | 2000 | 2000 | 2000 | 2000 |
| r2_a | 0.203 | 0.282 | 0.259 | 0.274 | 0.267 |

Note: *** $p < 0.01$, ** $p < 0.05$. t-statistics are reported in the parentheses. We control the city-level clustering standard error.

**Table 3.** Regression results of digital finance and green innovation efficiency.

| | (1) GIE | (2) GIE |
|---|---|---|
| DIF | 0.000.287 | 0.000.275 |
| | (0.45) | (0.41) |
| CONTROL | No | Yes |
| _CONS | 0.766 *** | 0.839 *** |
| | (22.92) | (10.81) |
| Individual effects | Yes | Yes |
| Time effect | Yes | Yes |
| N | 2000 | 2000 |
| r2_a | 0.010 | 0.015 |

Note: *** $p < 0.01$. t-statistics are reported in the parentheses. We control the city-level clustering standard error.

The benchmark regression results show that there is a significant positive correlation between the level of digital financial development (DIF) and the green innovation capability (GI), which is significant at the 1% level and is still significant at the 1% level after adding control variables one by one. Taking the regression results in Column (2) as an example, the number of green patents increases by 34.863 on average for every one increase in the digital finance development index. However, the impact of digital finance development on green innovation efficiency (GIF) is not significant. This validates Hypothesis 1. From the perspective of cost–benefit analysis, the benefits of green innovation and efficiency improvement caused by the development of digital finance in China have not yet offset the cost losses caused by resource misallocation, so there will be a situation of technological inefficiency. Further observation of Columns (3) to (5) shows that the impact of the depth of digital finance use and the degree of digitalization on green innovation is significant, except that the breadth of digital finance coverage has no significant impact on green innovation. This shows that digital finance empowers green innovation not through the wide coverage of payment accounts but through diversified financial services and more mobile, affordable, creditworthy, and convenient financial services.

### *4.2. Testing of Intermediary and Adjustment Mechanisms*

Tables 4 and 5 show the empirical results of the influencing mechanisms and moderating factors of digital finance on green innovation. Missing samples are automatically rejected. In Table 4, Columns (1) to (3) list the regression results with Internet development

(INTER) as the mediating variable, (4) to (6) as the regression results with labor factor distortion (ABSTUAL) as the mediating variable, and in Table 5, Columns (1) to (3) list the regression results for the two moderating variables of adding talent agglomeration (TAG) and financial development (FINDEV).

From the empirical results in Columns (1) to (6) in Table 4, the indirect effects of Internet development and labor factor distortion as an intermediary mechanism are positive, and the Sobel test is at least 5% significant, which confirms Hypothesis 2. At the same time, it is observed that the regression results of the direct effect of digital finance development on green innovation are inconsistent after the intermediary mechanism is excluded separately. This may indicate that there are other mechanisms for the impact of digital finance on green innovation, which leads to uncertainty about the outcome. The results in Columns (1) to (3) of Table 5 show that the moderating terms of talent agglomeration and financial development are both positive and significant at the 1% level, which affirms the positive moderating role of innovation environment in digital finance empowering green innovation and further confirms Hypothesis 3.

**Table 4.** Results of mediating effect regression.

| | (1)<br>GI | (2)<br>INTER | (3)<br>GI | (4)<br>GI | (5)<br>ABSTUAL | (6)<br>GI |
|---|---|---|---|---|---|---|
| DIF | 0.379 | 0.222 *** | −1.530 ** | 0.369 | −0.048 *** | 0.138 |
| | (0.57) | (7.20) | (−2.48) | (0.49) | (−5.94) | (0.18) |
| INTER | | | 8.618 *** | | | |
| | | | (19.41) | | | |
| ABSTUAL | | | | | | −4.792 ** |
| | | | | | | (2.11) |
| CONTROL | Yes | Yes | Yes | Yes | Yes | Yes |
| _CONS | −2385.375 *** | −116.068 *** | −1385.142 *** | −2551.346 *** | 2.878 | −2537.553 *** |
| | (−14.33) | (−15.07) | (−8.60) | (−13.48) | (1.41) | (−13.41) |
| Sobel test | | −1.530 ** | | | 0.138 | |
| (direct effect) | | (−2.48) | | | (0.18) | |
| Sobel test | | 1.909 *** | | | 0.231 ** | |
| (indirect effect) | | (6.75) | | | (1.99) | |
| N | 1999 | 1999 | 1999 | 1677 | 1677 | 1677 |
| r2_a | 0.515 | 0.649 | 0.592 | 0.511 | 0.218 | 0.512 |

Note: *** $p < 0.01$, ** $p < 0.05$. t-statistics are reported in the parentheses. We control the city-level clustering standard error.

**Table 5.** Regression results of moderating effect.

| | (1)<br>GI | (2)<br>GI | (3)<br>GI |
|---|---|---|---|
| DIF | 4.997 | 14.488 ** | 0.997 |
| | (1.57) | (2.23) | (0.35) |
| TAG | −0.015 | | −0.013 |
| | (−0.87) | | (−0.82) |
| DIF × TAG | 0.000.2 *** | | 0.000.2 *** |
| | (4.34) | | (4.33) |
| FINDEV | | −1113.028 ** | −295.482 *** |
| | | (−3.20) | (−3.06) |
| DIF × FINDEV | | 5.076 *** | 1.184 *** |
| | | (3.12) | (2.81) |
| CONTROL | Yes | Yes | Yes |
| _CONS | 193.599 | 1484.954 | 793.741 ** |
| | (0.56) | (1.42) | (2.26) |
| Individual effect | Yes | Yes | Yes |
| Time effect | Yes | Yes | Yes |
| N | 1749 | 1994 | 1743 |
| r2_a | 0.705 | 0.399 | 0.715 |

Note: *** $p < 0.01$, ** $p < 0.05$. t-statistics are reported in the parentheses. We control the city-level clustering standard error.

### *4.3. Endogenous Treatment*

In order to overcome the two-way causal relationship between digital finance and green innovation, the lag of the digital inclusive finance index is used as the instrumental

variable, and then the two-stage least squares regression method is used. The results show that in the first stage of regression, the instrumental variable coefficient is significantly positive, the unidentifiable test is significant at the 1% level, and the significance of the weak instrumental variable is less than 10%, indicating that the selection of instrumental variables is reasonable. After considering endogeneity, the coefficient of the digital financial inclusion index in the second stage regression results is still positive and significant at the level of 5%. This indicates that the benchmark regression results are robust.

In order to overcome the two-way causal relationship between the moderator variable and the explanatory variable, this paper performs a regression after the lag of all core variables, and the results show that the coefficients of the core explanatory variables are the same as those of the previous regression and are basically significant. Although the significance of the cross-fertilization term of financial development is significant within the 12% level, the significant results of the previous columns can be seen to show that the above conclusions are stable. The results of all endogenous treatments are presented in Appendix A.

### *4.4. Robustness Test*

In order to prove the reliability of the empirical results of digital finance empowering green innovation, this paper selects the number of Internet users (inter) as a proxy variable for the development level of digital finance for regression. At the same time, in order to prove the reliability of the mediation mechanism, the Bootstrap self-sampling method is used to test the mediation effect. The results show that the coefficients of all core variables are at least significant at the level of 5%, indicating that the conclusion is robust. At the same time, the confidence interval of the indirect effect verified by the self-sampling method does not contain zero, indicating that the mediation mechanism is robust. The results of all robustness tests are presented in Appendix A.

## 5. Further Analysis

### *5.1. Spatial Relevance*

Before studying the spatial spillover effect of digital finance empowering green innovation, it is necessary to conduct a spatial correlation test. The global spatial correlation test is generally investigated using the Moran index. The calculation formula is as follows:

$$\text{Moran's I} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}\left(Y_i - \overline{Y}\right)\left(Y_j - \overline{Y}\right)}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}}$$

$S^2$ is the variance of the sample, $Y_i$ and $Y_j$ represent the observations of different prefecture-level cities i and j, n is the 250 prefecture-level cities selected in this paper, and $w_{ij}$ is the spatial weight matrix. The Moran index can be in the range of $[-1, 1]$. If the Moran index is significantly positive at a certain level of significance, it indicates that there is a positive spatial correlation. In this case, the larger the Moran index, the stronger the spatial positive correlation. If the Moran index is significantly negative at a certain significance level, it indicates that there is a negative spatial correlation. At this time, the smaller the Moran index, the stronger the spatial negative correlation. If the Moran index is zero, there is no spatial correlation. For the selection of spatial weight matrix, the spatial distance matrix is selected in this paper. The spatial distance matrix is measured using the reciprocal of the square of the distance between two regions as follows:

$$w_{ij} = \begin{cases} \frac{1}{d_{ij}} \; if \; d_{ij} \geq d \\ 0 \; if \; d_{ij} < d \end{cases}$$

The results of the Moran index are shown in Table 6. It can be seen that from 2011 to 2018, the global spatial autocorrelation coefficient of digital finance and green innovation in each prefecture-level city was at least 5% significant. This indicates that there is a significant and relatively stable spatial agglomeration. In addition, the digital finance index showed high values in the period of 2016–2018. This shows that the spatial relevance of digital finance has been increasing in recent years.

**Table 6.** Moran index test results.

| Year | GI | *p*-Value | DIF | *p*-Value |
|---|---|---|---|---|
| 2011 | 0.020 | 0.000 | 0.090 | 0.000 |
| 2012 | 0.023 | 0.000 | 0.098 | 0.000 |
| 2013 | 0.016 | 0.002 | 0.097 | 0.000 |
| 2014 | 0.016 | 0.002 | 0.084 | 0.000 |
| 2015 | 0.020 | 0.000 | 0.088 | 0.000 |
| 2016 | 0.022 | 0.000 | 0.098 | 0.000 |
| 2017 | 0.018 | 0.002 | 0.107 | 0.000 |
| 2018 | 0.019 | 0.001 | 0.132 | 0.000 |

### *5.2. The Spatial Spillover Effect of Digital Finance on Green Innovation*

Before using spatial econometric model regression, an LM test is required to determine the model form. Commonly used models include SAR, SEM, SDM models, etc. The results of the LM test are shown in Table 7, except for the failure of the LM-lag test; the rest are significant at the 1% level. According to Elhorst's [39] theory, when one of the LM-lag and LM-error fails, the LR test and Wald's test need to be used to select the model. Table 8 lists the results of regression using fixed and random effects with test results.

**Table 7.** LM test results.

| Test | Statistic | *p*-Value |
|---|---|---|
| Spatial error: | | |
| Moran's I | 5.524 | 0.000 |
| Lagrange multiplier | 24.596 | 0.000 |
| Robust Lagrange multiplier | 57.651 | 0.000 |
| Spatial lag: | | |
| Lagrange multiplier | 0.09 | 0.765 |
| Robust Lagrange multiplier | 33.144 | 0.000 |

**Table 8.** Regression results of spatial spillover effect.

| | (fe)<br>GI | (re)<br>GI |
|---|---|---|
| Main | | |
| DIF | 34.188 *** | 29.947 *** |
| | (7.67) | (7.11) |
| Control | Yes | Yes |
| _CONS | | −847.039 |
| | | (−0.94) |
| Wx | | |
| DIF | −38.514 *** | −31.027 *** |
| | (−7.42) | (−6.56) |
| Control | Yes | Yes |
| Spatial | | |
| rho | 0.354 *** | 0.413 *** |
| | (2.87) | (3.53) |
| LR-test | 22.91 *** | 21.27 *** |
| Wald-test | 75.95 *** | 69.58 *** |
| N | 2000 | 2000 |
| r2 | 0.2862 | 0.2790 |

Note: *** $p < 0.01$. t-statistics are reported in the parentheses. We control the city-level clustering standard error.

First of all, the model test, the LR test and Wald's test were significant at the 1% level, indicating that the SDM model was the most appropriate. The results of Hausman's test show that it is more reasonable to choose the fixed-effect model. From the regression results, the development level of digital finance and its spatial lag term are both significant at the 1% level, and the spatial autocorrelation coefficient is also significant at the 1% level, indicating that there is a spatial spillover effect in the impact of digital finance on green innovation. Further observation of the regression coefficient shows that the coefficient of digital finance is positive, while the coefficient of the spatial lag term is negative, and the value is greater than the coefficient of the original variable. This shows that, on the one hand, the development of digital finance in a region plays a siphoning effect in neighboring regions, causing the outflow of innovation elements from neighboring regions which in turn restricts the green innovation capabilities of neighboring regions. On the other hand, the adverse effects of this siphoning effect on neighboring regions are greater than those of the region, indicating that the spatial characteristics of China's digital finance are still greater than the "trickle-down" effect. Based on the above analysis, it can be concluded that the current development of digital finance not only promotes the improvement of the level of green innovation in the region, but also leads to the "polarization" of innovation capabilities between regions, which verifies Hypothesis 4. Further observation of the decomposition results shows that the direct and indirect effects of digital finance on promoting green innovation are significant at the 1% level, and the direction and magnitude of the coefficients are consistent with the regression results. At the same time, it was noted that the total effect was not significant, which may be due to the cancellation of the direct effect and the indirect effect.

### *5.3. Spatial Spillover Robustness Test*

In order to prove the robustness of the spatial econometric model results, SAR and SEM model regressions are used to test the existence of spatial correlation. The results in Table 9 show that the spatial autocorrelation coefficients are all significant at the 1% level, indicating that there is a spatial spillover effect. This shows that the original conclusion is robust. The results are presented in Appendix A.

**Table 9.** Decomposition results of spatial spillover effects.

| | Direct Effects | Indirect Effects | Total Effects |
|---|---|---|---|
| DIF | 34.218 *** | −40.924 *** | −6.705 |
| | (7.50) | (−6.36) | (−1.32) |
| DEM | 0.050 *** | 0.020 | 0.070 ** |
| | (12.91) | (0.54) | (1.96) |
| ECO | 0.002 | 0.045 *** | 0.047 *** |
| | (1.10) | (2.82) | (2.98) |
| INSTR | −44.077 *** | 95.824 * | 51.747 |
| | (−5.05) | (1.85) | (1.02) |
| IAGG | 0.069 | −1.327 | −1.258 |
| | (0.71) | (−1.64) | (−1.57) |
| SIZE | 0.267 *** | 0.124 | 0.392 |
| | (4.91) | (0.14) | (0.44) |

Note: *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$. t-statistics are reported in the parentheses. We control the city-level clustering standard error.

## 6. Discussion

This section compares the similarities and differences between the findings of this paper and those of other research results. First, from the results of benchmark regression and further analysis, the conclusion of this paper is more consistent with the previous literature [40–42], that is, the development of digital finance can promote regional green

innovation and has an inter-regional siphon effect. However, the conclusions of this paper on whether digital finance can improve the efficiency of regional green innovation are different from the existing literature [43], which argues that the development of digital finance can improve the efficiency of green innovation between regions. More empirical evidence is still needed on this issue. In terms of mechanism analysis and moderation, this paper proposes a new mechanism that is different from the existing literature [44], that is, digital finance promotes green innovation through the development of the Internet and the reduction in the mismatch of labor factors. However, the existing literature mainly focuses on the mechanism of supplementing traditional finance and promoting green consumption.

## 7. Conclusions and Policy Recommendations

### *7.1. Main Results*

Based on the inclusive finance index of Peking University and China's green patent data, this paper empirically examines the impact of China's digital finance development on green innovation by using a two-way fixed-effect model, an intermediary effect model, and a spatial Durbin model. Considering the spatial heterogeneity, the spatial spillover effect of digital finance on green innovation is studied. The research shows that, first, the development of digital finance can significantly promote regional green innovation, and it mainly plays a role in the depth of digital finance use and the degree of digitalization. However, the role of digital finance development in reducing the efficiency loss of green innovation is not obvious. Second, digital finance can promote green innovation by promoting the development of the Internet and reducing the distortion of labor factors. Third, the innovation environment has a positive moderating effect on the effect of digital finance empowering green innovation. Fourth, the development of digital finance has a spatial spillover effect on green innovation, and it is manifested as a siphon effect.

### *7.2. Theoretical Implications*

This paper has certain theoretical significance. First, this paper theoretically explains the positive role and new mechanism of digital finance on urban green innovation and supplements the relevant theories of digital finance empowering green innovation. Second, this paper verifies the moderating role of regional financial development level and innovation environment. Finally, this paper verifies the spatial spillover effect of digital finance on urban green innovation and explains the siphoning effect of digital finance development in one region on another.

### *7.3. Practical Implications*

In view of the above conclusions, this paper puts forward the following suggestions: First, we should continue to promote the development of digital finance and give full play to the important role of digital finance in realizing the "dual carbon" strategy. Digital finance can alleviate financial repression and solve the problems of financing, risk information and incentives for green innovation, thereby promoting the development of green industries. At the same time, the development of digital finance can accelerate the integration of digital technology and green industries, improve the efficiency of factor allocation, optimize the industrial structure, and promote green innovation. Second, it is necessary to pay attention to some characteristics of the development of digital finance in China that restrict the efficiency of green innovation, deepen the integration of the tertiary industry with the Internet and manufacturing, break down the institutional and institutional barriers to the development of digital finance, improve the productivity of the tertiary industry, alleviate "Baumol's disease", and achieve more inclusive growth. It is necessary to pay attention to avoid excessive financialization of the economy and emphasize the role of financial

services for the real economy and promoting the transformation and upgrading of the manufacturing industry. Local governments should abandon protectionist thinking, reduce unnecessary intervention, promote factor market integration, and reduce the efficiency loss of innovation activities. Third, it is necessary to take advantage of the "long-tail effect" of digital finance, seize the dividend period of digital financial development, break down the institutional and institutional barriers of digital financial services for small and medium-sized enterprises and workers, and give full play to its role in reducing enterprise labor costs, promoting labor mobility, and accumulating human capital so as to promote green technology innovation. Fourth, it is necessary to improve the regional innovation environment. At the government level, it is necessary to strengthen the talent introduction policy, optimize the business environment, and attract the inflow of innovative elements by improving the talent capital investment guarantee system, promoting tax and fee reductions and subsidies for environmental protection enterprises, and building innovation and entrepreneurship platforms so as to promote green innovation. Fifth, it is necessary to pay attention to the siphoning phenomenon of digital finance development on green innovation in neighboring regions, increase support for the development of digital finance in backward regions, promote the free flow of factors between regions, reduce regional disparities, and overcome market segmentation and the phenomenon of "digital divide".

### *7.4. Limitations and Future Lines of Research*

However, there are some limitations to the research in this paper. First, the data used in this paper are outdated and show the relationship between pre-COVID digital finance development and urban green innovation, so the conclusions of this paper may not be applicable at this time. Second, the data used in this paper are all Chinese data, and the conclusions may lack generality. Finally, this paper provides ideas for follow-up research, and it is necessary to further establish cross-border panel data for re-retrieval. In summary, this paper mainly adopts quantitative methods to analyze the correlation between digital finance and green innovation before 2019, and future research should pay more attention to qualitative analysis, which is still lacking. On the other hand, it is necessary to update the time period of the research sample to obtain conclusions that are closer to the present.

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## Appendix A

(1) Endogenous Processing Results

**Table A1.** Results of two-stage least squares regression.

| | | (1)<br>Phase 1<br>DIF | (3)<br>Phase 2<br>GI |
|---|---|---|---|
| DIF lags by one period | | 0.252 ***<br>(4.27) | |
| DIF | | | 57.106 **<br>(2.17) |
| Control | | Yes | Yes |
| Individual | | Yes | Yes |
| Time | | Yes | Yes |
| Number of samples | | 1750 | 1750 |
| R-squared | | | 0.406 |
| Anderson | 5.29 | | |
| LM statistic | [0.000] | | |
| Cragg-Donald | 105.35 | | |
| Wald F Statistic | 18.27 | | |
| Stock-Yogo 10% IV size | 16.38 | | |

Note: *** $p < 0.01$, ** $p < 0.05$. t-statistics are reported in the parentheses. We control the city-level clustering standard error.

**Table A2.** Regression results considering the endogeneity of the moderating variables.

| | (1)<br>GI | (2)<br>GI | (3)<br>GI |
|---|---|---|---|
| DIF lags by one period | 3.906<br>(0.89) | 2.127<br>(0.43) | 1.453<br>(0.40) |
| Tag lags by one period | −0.015<br>(−1.08) | | −0.014<br>(−1.00) |
| DIF lags one period × TAG lags by one period | 0.000.2 ***<br>(4.80) | | 0.000.2 ***<br>(4.77) |
| FINDEV lags by one period | | −798.366 **<br>(−2.50) | −218.665 *<br>(−1.67) |
| DIFF lags by one period × FINDEV lags by one period | | 3.612 **<br>(2.47) | 0.912<br>(1.60) |
| CONTROL | Yes | Yes | Yes |
| _CONS | −4688.866 ***<br>(−3.29) | −6323.679 ***<br>(−3.35) | −3930.461 ***<br>(−3.08) |
| Individual effect | Yes | Yes | Yes |
| Time effect | Yes | Yes | Yes |
| N | 1749 | 1744 | 1743 |
| r2_a | 0.711 | 0.473 | 0.713 |

Note: *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$. t-statistics are reported in the parentheses. We control the city-level clustering standard error.

## (2) Robustness processing results

**Table A3.** Robustness test of baseline regression and moderating effect.

| | (1)<br>GI | (2)<br>GI | (3)<br>GI | (4)<br>GI |
|---|---|---|---|---|
| INTER | 4.114 **<br>(2.72) | 2.044 **<br>(2.07) | 3.076 **<br>(2.35) | 1.974 **<br>(2.05) |
| TAG | | −0.020<br>(−1.32) | | −0.019<br>(−1.26) |
| DIF × TAG | | 0.000.2 ***<br>(4.90) | | 0.000.2 ***<br>(4.91) |
| FINDEV | | | −1104.704 ***<br>(−3.14) | −275.936 **<br>(−3.10) |
| DIF × FINDEV | | | 5.048 ***<br>(3.07) | 1.101 **<br>(2.85) |
| CONTROL | Yes | Yes | Yes | Yes |
| _CONS | 573.549<br>(0.90) | 441.611<br>(1.52) | 2181.749 **<br>(2.33) | 828.880 **<br>(2.76) |
| Individual effect | Yes | Yes | Yes | Yes |

**Table A3.** *Cont.*

| | (1) GI | (2) GI | (3) GI | (4) GI |
|---|---|---|---|---|
| Time effect | Yes | Yes | Yes | Yes |
| N | 1999 | 1748 | 1993 | 1742 |
| r2_a | 0.293 | 0.716 | 0.415 | 0.725 |

Note: *** $p < 0.01$, ** $p < 0.05$. t-statistics are reported in the parentheses. We control the city-level clustering standard error.

**Table A4.** Moderation effect robustness test.

| | Coefficient of Mediating Effect | Standard Deviation | Z-Value | $p > z$ | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| INTER mediating effect | 1.909 | 0.444 | 4.30 | 0.000 | 1.040 | 2.778 |
| ABSTUAL mediating effect | 0.231 | 0.116 | 1.98 | 0.047 | 0.003 | 0.458 |

**Table A5.** Robustness test of spatial spillover effect.

| | SAR GI | SEM GI |
|---|---|---|
| Main | | |
| DIF | 0.886 | 6.086 |
| | (0.49) | (1.27) |
| CONTROL | Yes | Yes |
| Spatial | | |
| rho | 0.563 *** | |
| | (4.66) | |
| lambda | | 0.686 *** |
| | | (5.17) |
| N | 2000 | 2000 |
| r2 | 0.2421 | 0.2436 |

Note: *** $p < 0.01$. t-statistics are reported in the parentheses. We control the city-level clustering standard error.

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