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Research Article

The Impact of Digitization on Green Innovation Performance: Evidence Based on Panel Data of 228 Prefectural-Level Cities in China

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At present, in the context of the era of energy and digital reform enabling the "dual carbon" goal, in order to improve the performance of urban green innovation, digitalization has become more and more important. Based on panel data, taking 228 prefecture-level cities in China from 2003 to 2019 as an example, this study expounds three dimensions of promoting green innovation performance in the internal mechanism of digital development: direct transmission mechanism, indirect transmission mechanism, and regional heterogeneity transmission mechanism. This article uses mechanism analysis and adopts a dynamic spatial panel model and systematic GMM method to empirically test the growth effect of green innovation performance endowed by digitization. This article found that green innovation performance showed regional heterogeneity and urban heterogeneity after adding carbon dioxide emissions from energy consumption, and digital development significantly improved the level of innovation performance. Further research found that digitalization has a positive impact on technological innovation, and technological innovation also has a positive impact on green innovation performance. And technological innovation plays a mediating role between digitalization and green innovation performance. Different intensities of environmental regulation play a positive moderating role in the impact of digitalization on green innovation performance.

1. Introduction

The digital economy, including hardware manufacturing, software and IT consulting, information services, and other information technology and communication technology (ICT), has been spawned, promoted, and vigorously developed. Emerging digital industries dominated by new-generation data technologies like big data, 5th generation mobile networks, cloud computing, and network security have become an integral part of the the digital future. China's "14th Five-Year Plan" clearly regards the digital economy as an important means to market China's economic development in the future [1]. More importantly, in an important period of accelerating the transformation of the development mode, the developing digital economy can have a technological impact on the standard economy, which will help the traditional economy undergo digital transformation and upgrading [2]. But along with the vigorous development of the economy, there is also a huge environmental cost. According to information discharged by the National Bureau of Statistics of China in 2020, China's total economic output has accounted for 17% of the planet's economy. However, according to the World Energy Statistical Yearbook, China's primary energy consumption will account for 26.13% in 2020. Therefore, a green and long-term development approach has become an inevitable choice for China's development.

Green innovation is closely associated with ecological and environmental protection, so green innovation is an inevitable choice to promote economic development with high quality and solve environmental problems [3, 4]. In relevant documents such as “Made in China 2025,” it is proposed to encourage innovation in green manufacturing technology to promote the long development of the producing business. On this basis, combined with the impact of the latest “carbon neutrality and carbon emission” environmental protection policy, the performance of my country’s green innovation is measured, and the development status and evolution law of China’s green innovation are analyzed. Heterogeneity analysis is carried out on the relationship between digitalization and green innovation performance, and the effect of digitalization is analyzed by considering the influence of technological innovation and environmental regulation. On the one hand, this research helps to objectively appraise the established order of China’s inexperienced economic development, and on the other hand, it additionally helps to optimize environmental supervision, thus delivering the goods to a win-win state of affairs for the setting and, therefore, the economy.

The concept of the digital economy was first proposed by the OECD in the 1990s [5]. The digital economy has begun to take shape with the development of a series of technical means such as computing, storage, and network. For the calculation of the digital level, Zhang and Jiao constructed an evaluation index system for China’s digital development [6]; Xu and Zhang summarized the measurement methods and accounting of the Internet economy and digital economy [7]. For the research in the field of green innovation, Li constructed the green innovation performance evaluation index system for the first time [8]; Hua used the green innovation performance of 30 provinces (autonomous regions and municipalities) to obtain new strengths: scientific and technological environment, energy consumption, and environmental protection are the three major factors moving the great performance of green innovation [9]. Regarding the impact of digitalization on innovation, Zhou et al. found from the perspective of the county (district, city) level that the improvement of regional digital access level is contributive to improving innovation performance [10]; Wang et al. studied the enterprise level. The influence of the comprehensive level of digitalization on the green technology innovation of resource-based enterprises is studied, and it is found that the regional digitalization level has an “inverted U-shaped” relationship with the green technology innovation of enterprises [11]; Li et al. studied the influence of digitization on innovation performance and believed that digital product innovation has a promoting effect on green manufacturing performance [12]. The relationship between digitalization level and green innovation performance. Yang et al. analyzed the link between producing intelligence and green innovation performance and its internal mechanism using a dynamic space model. He found that manufacturing digitization and intelligence have a positive relationship with green innovation performance [13]. Sun et al. found that Internet technology penetration contains a positive abstraction spillover impact through a study on the issue impact of the country’s regional green innovation capabilities [14]. Based on the OECD data, KPWW method, and multi-panel regression analysis, Wang et al. found that the comprehensive impact of digital industrial technology empowers green innovation [15].

In the research direction of the digital economy, the existing studies mostly explore issues of digital technology innovation unilaterally. In the field of green innovation, scholars mostly focus on green performance. So what impact does the level of digitization have on green innovation performance? How does digitally driven technological innovation affect green innovation performance? How does environmental regulation work in between? This research studies the impact of digitalization on green innovation performance according to different viewpoints and advances more designated arrangement suggestions for computerized change in light of the truth of China’s turn of events. The purpose and research problem of our research is to investigate the effects of digitalization on green innovation performance and the relationship between the two under the intermediary conduction of environmental supervision and industrial structure upgrade. This research will provide a policy basis for 228 regional cities in China to formulate sustainable development strategies according to their realities.

The marginal contributions of this article are as follows: firstly, this article measures the green innovation performance of 228 cities in China and conducts an analysis of its current situation. Furthermore, from the three components of digital foundation, digital application, and digital development, the degree of digitalization is estimated, the comprehensive level of regional digitalization is measured, and the existing research is effectively supplemented. Second, in the context of the digital economy, we theoretically clarify the path and logic of the effect of digitalization on green innovation performance and focus on analyzing the regulatory role of environmental regulation and the intermediary mechanism of technological innovation from the views of environmental regulation and innovative technology. Third, the use of prefecture-level city panel data provides in-depth quantitative test evidence for the mechanism and effect of digitization on green innovation performance. And from the views of digitization of different regional systems and digitization of area heterogeneity, digitization influence on green innovation performance is discussed. We provide reference value for the region to achieve green development and promote digital transformation.

2. Basic Theory and Hypotheses

2.1. The Effect of Digitalization on Green Innovation Performance. According to the theory of environment adaptability, enterprises need to respond quickly to the changing external environment [16]. For regional green innovation performance, the main body is the enterprises. The digital development environment formed by relying on the background of the digital economy is a brand-new external environment for enterprises. We review the scholars' existing research on how the regional digitalization level affects green technology innovation and summarize it into three aspects.

(1) Digital foundation: the digital foundation is the basic foundation for consolidating the digital development of society. The core is constructing a national integrated big data center, which can effectively gather data from organizations such as government, industry, and enterprises and Internet data. Utilizing the interconnectivity of interregional information networks can obtain the spatial spillover effect of green innovation performance [17].

(2) Digital application: the essence of digital application reflects the application ability of information technology in innovation. The continuous expansion of digital applications can effectively narrow the gap of the digital divide between regions, innovate production modes, and raise the level of efficiency of green development [18, 19].

(3) Digital development level: the improvement of the degree of digital development can accelerate the digital transformation of enterprises. The digital industry with the new generation of information technology as the basis, such as the cloud and the Internet computing, can help enterprises understand changes in market demand, adjust production plans promptly, optimize resource allocation, and achieve multilevel supply and demand matching.

To sum up, in line with the growth in the digital economy, the digital industry development will be integrated deeply with the green integration of big data, the Internet, and some other modern technologies. The rising digital level may favorably contribute to the regional green innovation performance. Therefore, this research proposes Hypothesis 1:

Hypothesis 1. (H1): Digitalization has a favorable influence on the performance of green innovation.

2.2. The Mediating Effect of Technological Innovation. According to technical innovation theory, Joseph A. Schumpeter highly valued the innovation of production technology and the change in production methods [20]. Industrial digital transformation and upgrading can support the research and development of production technology and bring thinking about production methods. In the early stage of the digital economy, digitization was low, and at this time, the production sector required high costs to promote industrial optimization and upgrading [21]. With the combination of the digital economy and the traditional economy, the level of digitalization has improved, the cost of acquiring production factors such as talents, capital, and technology has decreased, and many R&D costs have been saved, which makes it easier for production departments to obtain advanced production factors and resources, thereby promoting technological innovation [22, 23]. Therefore, this research proposes Hypothesis 2.

Hypotheses 2. (H2): The level of digitalization is positively related to technological innovation.

Technological innovation is manifested in two forms. One is the increase in productivity brought about by efficiency-based technological progress, that is, "process innovation," and the other is the creation of new products to expand consumption sets, that is, "product innovation" [24]. The improvement of technological innovation can significantly reduce production and operation costs, promote the achievement of optimal scale, and form scale effects, thereby continuously improving green innovation performance [25]. At the same time, enterprises can apply for green patents through technological innovation and continue to gain competitiveness [26]. In terms of different types, the technological innovation at the end of an enterprise can improve pollution control capabilities; technological innovation in process improvement can improve production efficiency and reduce unnecessary waste; technological innovation in product development can help broaden the market [27]. In addition, technological innovation helps gain the government's trust and win the favor of consumers, forming a premium for green products [28, 29]. From the above literature review and analysis, it can be found that there is a close relationship between the level of regional digitalization, technological innovation, and green innovation performance. On top of that, the current research puts forward Hypotheses 3. and 4.

Hypotheses 3. (H3): Technical innovation can have a positive influence on green innovation performance.

Hypotheses 4. (H4): Digitalization positively influences technological innovation and technological innovation positively influences green innovation performance. Technological innovation serves a mediation role.

2.3. The Moderating Effect of Environmental Regulation. According to the externality theory, environmental regulation policies may have a non-market-oriented impact on enterprises [30]. For regional green innovation performance, the main body is the enterprises in the region. Under strict environmental regulations, enterprises are more willing to invest in environmental technology, resource utilization, energy saving, and consumption reduction, etc. The policy can reduce the emission of pollutants, strengthening the management of environmental protection efficiency. With the improvement of the ecological environment, showing the positive externality of the environment [31], the promotion of digitalization can achieve higher green innovation performance. On the contrary, under weaker environmental regulation, enterprises usually pay less attention to it, the environmental protection investment required by enterprises is much higher than the penalty for environmental failure, and the ecological environment cannot be improved [32, 33]. Due to the negative externality of pollution, the promotion of digitalization cannot achieve higher green innovation performance [34]. To sum up, under the external governance constraints of environmental regulation,

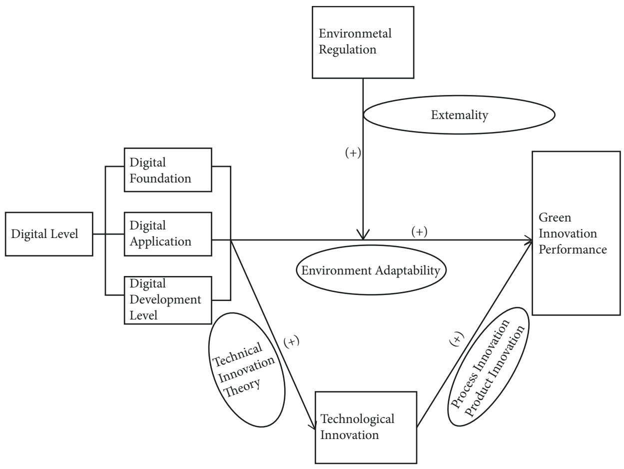

Figure 1: Hypothetical conceptual model.

digitalization may be more conducive to improving green innovation performance. Hence, Hypothesis 5 is proposed in the present study:

Hypotheses 5. (H5): Environmental regulation takes up a positively moderating factor in the impact digitalization influences on green innovation performance.

From the foregoing theoretical discussion of the hypothesis, this article constructs a conceptual model of the hypothesis, as depicted schematically as Figure 1.

3. Basic Methodology

3.1. Model Settings. This article constructs a dynamic panel threshold measurement model to empirically test the above hypothesis. Taking into account the fact that both green innovation performance and technological innovation have a certain spatial lag effect, this article embraces the systematic GMM technique to gauge the results, which can effectively avoid endogenous problem, and can also examine how Chinese cities take digital express trains to further develop innovation performance according to a dynamic perspective.

3.1.1. Benchmark Regression Model. To test Hypothesis 1, this article constructs the following basic model:

$$\mathrm{GIP}_{i,t} = \rho_0 + \lambda_1 \mathrm{GIP}_{i,t-1} + c_1 D_{i,t} + \beta_m \sum_{m=1}^{6} X_{i,t}^{m} + \mu_i + \gamma_t + \varepsilon_{i,t}. \quad (1)$$

In equation (1), GIP is the explained variable, representing green innovation performance; D is the core independent variable, addressing the degree of digital development; X is a set of control variables, representing other important factors affecting green innovation performance; ρ_0 is a constant term, μ_i means the regional fixed effect, γ_t means the time fixed effect, and $\varepsilon_{i,t}$ means the random disturbance term.

3.1.2. Mediating Effect Model. In order to verify Hypotheses 2–4, we refer to the study by Wen et al. [35] and construct the following test model:

$$\begin{aligned} GIP_{i,t} &= \rho_0 + \lambda_1 \mathrm{GIP}_{i,t-1} + \beta_1 D_{i,t} \\ &\quad + a_m \sum_{m=1}^{6} X_{i,t}^{m} + \mu_i + \gamma_t + \varepsilon_{i,t}, \end{aligned} \quad (2)$$

$$\begin{aligned} \mathrm{GIP}_{i,t} &= \rho_1 + \lambda_2 \mathrm{GIP}_{i,t-1} + \beta_2 D_{i,t} + \gamma_1 \mathrm{Tech}_{i,t} \\ &\quad + b_m \sum_{m=1}^{6} X_{i,t}^{m} + \mu_i + \gamma_t + \varepsilon_{i,t}, \end{aligned} \quad (3)$$

$$\begin{aligned} \mathrm{Tech}_{i,t} &= \rho_2 + =_3 \mathrm{Tech}_{i,t-1} + \beta_3 \mathrm{D}_{i,t} \\ &\quad + c_m \sum_{m=1}^{6} X_{i,t}^{m} + \mu_i + \gamma_t + \varepsilon_{i,t}. \end{aligned} \quad (4)$$

The above model (2) builds a total effect model; model (3) and model (4) are direct effect and indirect effect models, respectively, in which Tech is the mediating variable. Only when the coefficient γ_1 in equation (3) and the coefficient β_3 in equation (4) are both notable, the mediating effect can be proved.

3.1.3. Moderating Effect Model. At the point when the force of environmental regulation is reinforced, it will act as a moderating effect between digitalization and green innovation performance. Therefore, env``ironmental regulation is used as a moderating variable, and the following model is constructed:

$$\begin{aligned} \mathrm{GIP}_{i,t} &= \rho_3 + \lambda_4 \mathrm{GIP}_{i,t-1} + \beta_4 D_{i,t} + \gamma_2 \mathrm{ER}_{i,t} \\ &\quad + \gamma_3 \mathrm{ER} \times \mathrm{D}_{i,t} + d_m \sum_{m=1}^{6} X_{i,t}^{m} + \mu_i + \gamma_t + \varepsilon_{i,t}. \end{aligned} \quad (5)$$

In equation (5), ER is a moderator variable, representing the intensity of environmental regulation. If the coefficient γ_3 in equation (5) is significant, the moderating effect exists.

3.2. Description of Variable Measurement Methods

3.2.1. Explanatory Variable

(1) Specific Measurements of Green Innovation Performance. GIP reflects the degree of green innovation into output to output in a certain period, that is, with green innovation and output ratio or green innovation efficiency equivalent. GIP is also a unity of economic performance, innovation performance, and ecological performance and is an important indicator for measuring the level of green innovation. This article consults Jia et al. [36] and Li et al.'s research method [37] and uses a DEA approach to measure green innovation performance. Labor (L), Energy (E), and Capital Stock (K) are input elements. The measurement of the labor force in this article embraces the number of representatives in R&D units of prefecture-level urban areas. The measurement of capital stock, calculated using the perpetual inventory

method to work out R&D, is mainly based on 2000. The measurement of energy uses the total energy consumption per region. The expected output is innovation generation (*G*), which is expressed by the number of green invention patent applications in prefecture-level cities. Undesirable outputs include carbon dioxide (C), sulfur dioxide (S), industrial wastewater (W), and industrial soot (D). The measurement of varbon dioxide (C) is equal to the energy consumption of each region × energy converted standard coal × carbon dioxide emission coefficient × carbon emission rate. Sulfur dioxide (S) is represented by the sulfur dioxide outflows of prefecture-level urban areas. Industrial wastewater (W) is represented by the release of modern wastewater in prefecture-level urban areas. Industrial soot (D) is represented by the industrial soot emissions of prefecture-level cities.

(2) Measurement Results of Green Innovation Performance in Each Region. This article computes the energy performance and environmental performance of 228 prefecture-level urban in China from 2003 to 2019 to synthesize the green innovation performance. Figure 2 depicts a comparative statistical graph of energy performance and environmental performance from 2003 to 2019. Outcome metrics are shown in Figure 2: both energy performance and environmental performance have maintained stable development. And energy performance is higher than environmental performance, which shows that China's Energy Preservation and Emanation Decrease Strategy have achieved better results in energy saving than emission reduction in the process of implementation in recent years. The value of the overall GIP must be greater than 0 and less than 1. The closer its value is to 1, the better the GIP is. It tends to be seen from Figure 2 that China's green innovation performance is for the most part at a high level, which indicates that the energy environment has achieved remarkable achievements.

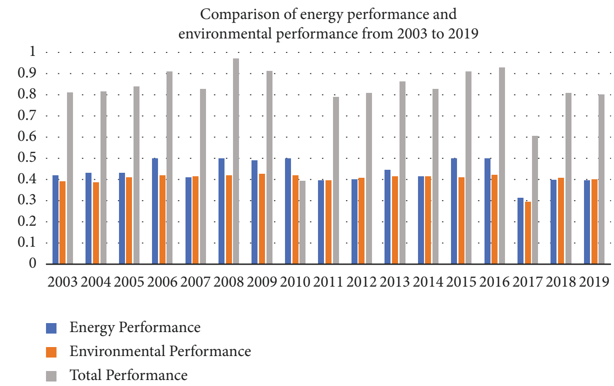

Figure 2: Comparison of energy performance and environmental performance from 2003 to 2019.

3.2.2. Explanatory Variable

(1) Measurement of Digitalization Level. The digital measurement of each region uses the indicator method. The specific index measurement method is shown in Table 1. From the three secondary indicators of the digital foundation, digital application, and digital development of prefecture-level cities, regional digitalization is comprehensively measured. The digital foundation includes five three-level indicators: unit fiber optic cable length, per capita long-distance and local telephone exchange capacity, the per capita mobile telephone exchange capacity, and the per capita Internet broadband access port. Digital applications include Internet penetration and fixed-line subscribers per capita. The level of digital development includes the proportion of digital industry personnel to all employees, the proportion of digital industry income to all industry income, and the proportion of digital industry fixed assets to all industry fixed assets. Finally, this article uses the entropy weight TOPSIS method to calculate the weight and calculate the digital comprehensive score.

(2) Measurement Results of Digital Comprehensive Level in Each Region. This article calculates the comprehensive digitalization level of 228 urban area in China from 2003 to 2019. Figure 2 depicts the digitalization level of each region. According to the sequence of Chinese cities implementing the coastal opening policy, this study divides the sample cities into the eastern region cities that implemented the policy first, the central region cities that implemented the policy in the middle, and the western region cities that implemented the policy last. According to the differences in the economic development of each city, it is classified into central cities and peripheral cities; among them, central cities refer to large cities with important status, comprehensive functions, and pivotal roles in China. According to the results in Figure 3, the digitalization level increased year by year from 2003 to 2019, and the digitalization level of Eastern cities was generally between 0.4 and 0.8. The digitalization level of Midwest cities is between 0.2 and 0.6. It can be seen that the comprehensive level of digitalization in the Eastern region is higher than Midwest region. The digitalization level of central cities is between 0.6 and 1, while that of peripheral cities is between 0.4 and 0.8. It can be seen that the digitalization level of central cities is higher than that of peripheral cities.

3.2.3. Mechanism Variables. (1) *Mediating Variable: Technological Innovation (Tech).* The level of technological innovation depends on the level of investment, that is, the level of R&D investment and the number of R&D personnel. Considering the availability of data, the measurement method of technological innovation in this article is the proportion of scientific research funds in each city to the total economic output. The more the R&D investment, the stronger the technological innovation capability of the enterprise. (2) *Moderating Variable: Environmental Regulation (ER).* There are numerous ways of estimating the intensity of environmental regulation. This research utilizes the comprehensive metrics approach proposed by Dong and Wang [38] and Wen et al. [35] for measurement. First, calculate the unit economic pollution emissions $x_{ij} = u_{i,j}/y_{i,j}$ of waste gas, wastewater, and solid waste produced in the industrial production of each prefecture-level city, where $u_{i,j}$

Table 1: Digitalization level indicator measurements.

Secondary indicators	Tertiary indicators
Digital foundation	Length of fiber optic cable per 10,000 square kilometres per 10,000 population Per capita long-distance telephone exchange capacity Local telephone capacity per capita Mobile phone switching capacity per capita Five three-level indicators of per capita Internet broadband access ports
Digital application	Mobile phone penetration Internet penetration Per capita landline subscribers
Digital development	The proportion of digital industry personnel Digital industry revenue share The proportion of fixed assets in the digital industry

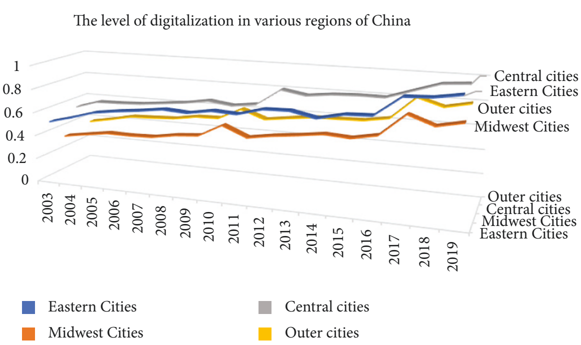

Figure 3: Digitization levels by regions in China.

represents the jth type of pollutant discharge in the ith city and $y_{i,j}$ represents the regional economic output. Second, standardize it $x'_{i,j} = (\max x_{i.j} - x_{i.j})/(\max x_{i.j} - \min x_{i.j})$. Among them, $x_{i.j}$ means the value of the index j in the ith year, $\min x_{i.j}$ represents the minimum value among the j indexes, and $\max x_{i.j}$ represents the maximum value among the j indexes. Third, determine the weight of each pollutant discharge $w_{i,j} = x_{i.j}/\overline{x}_{i.j}$; finally, comprehensively measure $ER = \sum_{j=1}^{3} w_{i,j} \times x_{i,j}$.

3.2.4. Control Variables. Given the research of Wang and Wang [39], Jian and Huang [40], Dong and Wang [38], and others, the control variables selected include administrative control (government fiscal expenditure/regional GDP), urbanization (urban population/total population), degree of opening to the outside world (regional import and export volume/regional GDP), human capital, fiscal decentralization (difference between regional government fiscal expenditure and revenue/fiscal expenditure), and industrial structure upgrade (the tertiary industry accounts for the secondary industry). Among them, for the accounting of human capital, the equal educational age method of Barro and Lee was used. That is, $Z = \sum Q_{i,t,j} \times U_j$, where $Q_{i,t,j}$ represents the ratio of the educated population at the j level to the total population, when $j = 1, 2, 3$, $U_j = 6, 12, 16$.

3.3. Sample Selection. The study sample in this article is a balanced panel of data formed by Chinese provinces and prefecture-level cities from 2003 to 2019. Due to missing data, Tibet, Inner Mongolia, Xinjiang, Ningxia, Guangxi, Hong Kong, Taiwan, and Macau, a total of 228 prefecture-level cities, were not counted. The data on industrial pollutant emissions come from the China Environmental Statistical Yearbook. The GDP, year-end population, and investment amount of each city come from the "China Urban Statistical Yearbook," and the energy data come from "China Energy Statistics." The network and electronic information data come from the "Statistical Report on the Development of China's Internet Network" and the "Statistical Yearbook of China's Electronic Information Industry." Technological innovation data come from the China Statistical Yearbook of Science and Technology.

4. Results and Discussion

4.1. Variable Description. Table 2 is the descriptive statistical results. The mean value of green innovation performance (GIP) is 0.8101, the standard deviation is 0.1844, the minimum value is 0.2531, and the maximum value is 1, meaning that the differences in green innovation performance among different cities are still relatively large. The mean of digitization (D) is 0.5704, the standard deviation is 0.3075, the minimum value is 0.1945, and the maximum value is 2.1221, showing the standard deviation is large, indicating a clear regional differentiation in terms of the level of digital development. At the level of mechanism variables, the average value of technological innovation and environmental regulation is relatively low, but the standard deviation is relatively large. To a certain degree, it reflects the reality that some cities are backward in technological innovation and development, and environmental supervision is not in place. At the level of control variables, the administrative control degree (Gov), urbanization level (Urb), and standard deviation of openness (Open) of different prefecture-level cities are all relatively low, but there are obvious differences in human capital education (Z), financial decentralization (Fis), and industrial structure upgrading (Is).

4.2. Benchmark Regression Results. The panel regression model is utilized to estimate formula (1), and the regression is performed from the static panel and the dynamic panel, respectively. At the same time, considering that the comprehensive value range of the constructed green innovation

Table 2: Descriptive statistics.

Variable	Observations	Mean	Std.Dev	Min	Max
GIP	3800	0.8101	0.1844	0.2531	1
D	3800	0.5704	0.3075	0.1945	2.1221
Tech	3800	0.2114	0.2261	0.0087	1.5198
ER	3800	0.2469	0.4139	0.0067	2.8672
Gov	3800	0.1666	0.1153	0.0358	1.1147
Urb	3800	0.1227	0.0881	0.0318	0.6495
Open	3800	0.1023	0.1232	0.002	0.7981
Z	3800	1.1975	0.3917	0.5275	3.1410
Fis	3800	0.5010	0.2207	0.0231	0.9248
Is	3800	0.8647	0.3536	0.2740	2.4730

Table 3: Benchmark regression results.

Variables	Static panel (OLS)		Dynamic panel (system GMM)		
	Fe	Re	Whole	High-regional system	Low-regional system
$GIP_{i,t-1}$			0.1334*** (3.92)	0.1796*** (3.78)	0.1882*** (4.43)
D	0.1759*** (9.77)	0.1638*** (9.99)	0.3181*** (4.48)	0.2535*** (4.06)	0.3490*** (2.87)
Gov	−0.5204*** (−17.38)	−0.5138*** (−17.47)	−0.8303*** (−8.93)	−0.2550*** (−3.30)	−0.6570*** (−8.62)
Urb	−0.5243*** (−7.87)	−0.4924*** (−8.17)	−0.5690* (−1.72)	0.0073 (0.19)	−1.3882*** (−2.79)
Ope	0.0494* (1.68)	−0.0247 (−0.88)	0.2046** (2.59)	−0.0391 (−0.64)	0.1844*** (3.48)
Z	0.0025 (0.22)	−0.0057 (−0.54)	0.0079 (0.19)	0.0625* (1.70)	−0.0136 (−0.37)
Fis	0.0588*** (2.60)	0.0471** (2.28)	0.4282*** (6.08)	0.2068** (2.17)	−0.0395 (−1.27)
Is	−0.0561*** (−4.83)	−0.0380*** (−3.50)	−0.1352*** (−2.89)	−0.1588*** (−2.89)	−0.1493*** (−3.10)
C	0.8757*** (46.96)	0.8795*** (45.50)	0.6511*** (9.13)	0.6659*** (9.27)	0.9293*** (11.40)
AR(1)			0.000	0.000	0.000
AR(2)			0.527	0.139	0.182
Hansen			0.276	0.932	0.350
R^2	0.1200	0.1192			
F test	61.7				
Wald test		419.87			

Note. *, **, and *** mean that the regression coefficient of the variable is notable at the 10%, 5%, and 1% levels, respectively, and the value () is the *t* statistic. The following table is the same.

performance is between [0, 1] and has the property of truncating data, quantile regression is used to estimate its robustness, and the outcomes are displayed in Table 3.

The 1st and 2nd columns of Table 3 display that the coefficients of digitization on green innovation performance are significantly positive at the 1% significant level by performing fixed-effect and random-effect regression on the static panel. However, considering that there is a certain lag period in green innovation, this article uses a dynamic panel for regression analysis, and some studies have pointed out that the systematic GMM method can well take care of the endogeneity issue brought about by utilizing the slack term of the made sense of variable as an illustrative variable. By the way, we select the system GMM to calculate the dynamic panel model. The outcomes are displayed in the 3rd column in Table 3. The regression coefficient of digitalization on green innovation performance is 0.3181, which is notable so at the 1% conspicuous level, meaning that digitalization promotes the improvement of green innovation performance. When the digitalization level increases by 1%, the performance of green innovation increases by 31.81%. To investigate the cause of this result, there may be as follows: first of all, relying on the digital development environment formed by the background of the digital economy, the digital foundation, digital application, and digital evolvement level of the city accelerates the use of information network connectivity between regions and narrows the digital access gap between regions. Secondly, the city's innovative production methods can improve production efficiency and obtain the spillover effect of green innovation performance. Enterprises can understand changes in market demand through the level of digital development, adjust production plans and resource allocation promptly, improve production and operation performance, and promote GIP.

From the regression results of the control variables in Table 3, it can be seen that the level of industrial structure upgrading, government control, and urbanization is essentially negative at the critical level of 1%. When the transformation of polluting industries is more difficult and the government's control is stronger, the pressure on enterprises to discharge pollutants will be greater, and the increase of green innovation resources by enterprises will be detrimental to the performance of technological innovation. At the same time, when the level of urbanization is higher, the agglomeration effect of the urban population will be greater, and the urban energy consumption will be greater, which is not conducive to improving green innovation performance. This conclusion roughly agreed with the

Table 4: The heterogeneity test results.

Variable	By geographical location		By economic Region	
	Eastern cities	Midwest cities	Central cities	Outer cities
$GIP_{i,t-1}$	0.1520***	0.1784***	0.4232***	0.1285***
	(2.86)	(4.95)	(3.74)	(3.87)
D	0.2645***	0.1407*	0.2537**	0.2901***
	(3.21)	(1.94)	(2.16)	(4.32)
$X_{i,t}$	YES	YES	YES	YES
C	0.8075***	0.6110***	0.6117***	0.7153***
	(10.13)	(8.82)	(5.12)	(8.37)
AR(1)	0.000	0.000	0.002	0.000
AR(2)	0.565	0.546	0.943	0.784
Hansen	1.000	1.000	1.000	0.47

findings of Yang Suchang et al. (2020). The openness (Open), human capital (Z), and fiscal decentralization (Fis) are positive at the 10% significant level, indicating that by opening up cities to the outside world, the education level of human capital can be better. The more open the city is to the outside world, the better the level of human education is. The more reasonable the fiscal decentralization is, the more it is helpful to GIP. This article attempts to explore the reason, which may be that cities can increase the degree of opening to the outside world and strengthen foreign trade, which can absorb a large number of foreign investments, the larger the new energy company, the richer its cash flow and the more capital intensive it is, the better it is for the company's green technological innovation, increased energy input and unnecessary production. The promotion of the level of human capital can effectively enhance the level of local environmental knowledge, and the overall overflow of knowledge can heighten the local per capita environmental awareness, reduce unnecessary output reduction, and promote the performance of green innovation. Higher fiscal decentralization means that local governments have greater financial freedom and can allocate resources more reasonably between the economy and the environment, which is helpful for the improvement of GIP. This is also in agreement with the finding of Gao et al. (2018).

The quantile regression results are in the 3rd and 4th columns of Table 3. Taking the digitized mean value of 0.5704 as the quantile, the digitization was divided into a high-regional system and a low-regional system. If the digitization is greater than the mean value, it is a high zone system, and if the digitization is less than the mean value, it is a low zone system. The high-district areas mainly include Beijing, Tianjin, Shanghai and Nanjing, and other high-digital development cities. The low-regional areas mainly include low-digital development cities such as Shijiazhuang, Tangshan, and Handan. From the regression results, we can see that the regression coefficient of digitization with the high-regional system on green innovation performance is 0.2535, and the regression coefficient of the low-regional system is 0.3490, both of which are significant at the 1% significant level. The lagged terms of the explained variables are all obviously positive at the 1% level of significance. It demonstrates that the digitization of the low-regional system has a greater impact on the exaltation of GIP than the high-regional system. Therefore, it is more necessary for cities with a low level of digitalization to carry out the coordinated development of green innovation and actively integrate it into the digital innovation network. Therefore, to fully release the development potential of different urban areas and alleviate the development imbalance between regions, these low-regional cities should work harder and be prepared to deal with the problem of mode conversion in the process of digital development and create a perfect digital development environment, fully grasping the new opportunities brought by digitalization.

4.3. Regional Heterogeneity Test. According to Figure 3 and the variable descriptive statistical analysis, digitization has clear heterogeneity attributes in the area distribution. Therefore, this article will conduct a heterogeneity analysis of the relationship between D and GIP. According to the urban division method of Zhang et al. (2020) and Yang et al. (2019), this study divides Chinese cities into eastern, central, and western regions by geographic location and divides them into central cities and peripheral cities by region. Cities include municipalities, subprovincial cities, and provincial capitals. Table 4 is the heterogeneity test results.

The test results in Table 5 show that although the digital development levels of cities in various locales of China are different and show different trends, they all play a positive role in improving urban GIP. The influence coefficient of digitalization on GIP in eastern China is 0.2645, which is notable at the critical level of 1%. The influence of D on GIP in Central and Western China is significant at the 10% level, with a coefficient of 0.1407. The regression of digitalization on green innovation performance in Chinese central cities is 0.2537, which is notable at the critical level of 5%; the regression coefficient of digitalization on GIP in Chinese peripheral cities is 0.2901, which is notable at the critical level of 1%. It is clear that city digitalization has a greater impact on GIP in eastern China than in central and western China. The reason for this result may be that, with its built-in economic, technology, and regional advantages, the eastern region has a relatively developed urban economy, a relatively high level of digital economy development, more extensive digital applications,

Table 5: Robustness test results of digitalization on green innovation performance.

	Digitization of one-order lag	Digitization of two-order lag	Changing digital measurement methods	High-regional system	Low-regional system
$GIP_{i,t-1}$	0.1290*** (3.86)	0.1078*** (3.46)	0.1394*** (4.02)	0.1796*** (3.78)	0.1882*** (4.43)
D	0.2895*** (5.43)	0.1185** (2.56)	0.0839*** (5.00)	0.2535*** (4.06)	0.3490*** (2.87)
$X_{i,t}$	YES	YES	YES	YES	YES
C	0.6583*** (10.72)	0.5983*** (9.65)	0.6058*** (9.08)	0.6659*** (9.27)	0.9293*** (11.40)
AR(1)	0.000	0.000	0.000	0.000	0.000
AR(2)	0.392	0.136	0.524	0.139	0.182
Hansen	0.336	0.829	0.470	0.932	0.350

and powerful execution of ecological guideline arrangements. And technological innovation is also better than in the central and western area, so digitalization has a greater impact on GIP. However, digitalization in China's fringe urban areas has a greater effect on GIP than in central cities. This article investigates why, in implementing the innovation-driven development ploy, China's innovative pilot cities often choose to conduct pilot projects in central cities and optimize the institutional environment and innovation environment through various policy effects. In the process of promoting urban green innovation performance, there is a certain complementary relationship between digital development and policies in major regions. This also shows that it is more necessary for cities in relatively disadvantaged areas to carry out in-depth cooperation and innovation and actively integrate into the innovation network.

4.4. Robustness Test

4.4.1. Digitization of One-Order Lag and Two-Order Lag. Include the one- and two-period lags of digitization of the explanatory variables into the model (1) for calculation. Table 5 shows the robustness test results. The regression coefficient of digitization with a lag period of one period on green innovation performance is 0.2895, which is notable so at the 1% critical level. The coefficient of digitization with a lag of two periods on green innovation performance is 0.1185, which is significantly so at the 5% critical level, which is largely agreed with the previous results.

4.4.2. Changing Digital Measurement Methods. In this article, the digital measurement method is replaced by the principal component analysis method, and then the above model (1) is used to test again. The results show that the influence coefficient of digitization on green innovation performance is 0.0839, which is significant at the 1% significance level.

4.4.3. Quantile Regression. In this study, the mean of digitization is used as the quantile, and digitization is divided into two zoning systems. The digitization degree value is greater than or equal to its mean value, which is divided into a high zoning system, that is, high digitization. Digitization degree values lower than their mean values are classified as low zoning, that is, low digitization. Then, model (1) is retested; the regression results are displayed in the 4th and 5th columns of Table 6. The outcomes display that the effect of digitization on GIP is fundamentally certain at a degree of 1%, regardless of whether it is a high-regional system or a low-regional system, which is the same as the previous results.

4.5. Mechanism Test

4.5.1. Mediating Effect Test. This article refers to the mediation effect test procedure of Wen et al. [35], introduces technological innovation as a mediating variable, and analyzes its transmission role in the independent variable (D) and dependent variable (GIP). Firstly, the effect of digitization on GIP, right off the bat, is examined. Furthermore, the impacts of digitalization and technological innovation on green innovation performance are considered. At long last, the effect of digitization on technological innovation is examined. Considering that there is a certain lag period in Tech and GIP. Therefore, the lag period of the explained variable is included as an explanatory variable in the lag period, and the system GMM is used to regress the models (2)–(4), and the results are displayed in Table 6.

Model (2) in Table 6 is the total effect calculation result. The results show that digitization has significantly promoted improvement of green innovation performance and the lagging of green innovation performance by one period and has a significant positive impact on itself. This shows that after controlling for variables, digitalization will generally facilitate improvements in green innovation performance. Model (3) is the direct effect calculation result. It can be found that both digitalization and technological innovation have a positive and significant influence on GIP, and the green innovation performance lagging one period still has a notable positive effect on itself. Model (4) is the indirect effect calculation result. It can be seen that digitalization has a notable positive impact on technological innovation, and the lagging technological innovation can also have a significant positive impact on itself.

According to the analysis of the empirical results of models (2)–(4), it can be known that the coefficients of explanatory variables on the explained variables in all three models are positive, and all pass the 1% significant level. According to the test of mediating effect by Wen's [35], it can

Table 6: Mechanism test results of digitalization on green innovation performance.

Variable	Model (2) Total Effect	Model (3) Direct Effect	Model (4) Indirect effect	Model (5) Moderation effect
$GIP_{i,t-1}$	0.1334*** (3.92)	0.2133*** (7.19)		0.1433*** (4.19)
$Tech_{i,t-1}$			0.3452*** (6.16)	
D	0.3181*** (4.48)	0.2948*** (5.34)	0.8660*** (4.14)	0.2573*** (3.74)
Tech		0.0593** (2.58)		
ER				−0.0872*** (−3.08)
$D \times ER$				0.1047** (2.22)
Gov	−0.8303*** (−8.93)	−0.8724*** (−7.12)	1.4965*** (12.78)	−0.8837*** (−8.94)
Urb	−0.5690* (−1.72)	−0.2379 (−0.88)	0.8703** (2.39)	−0.4506 (−1.38)
Ope	0.2046** (2.59)	0.1655** (2.14)	0.5220*** (5.59)	0.1704** (2.36)
Z	0.0079 (0.19)	0.0268 (0.66)	0.0837 (1.60)	0.0321 (0.82)
Fis	0.4282*** (6.08)	0.4005*** (5.33)	−0.5855*** (−5.00)	0.4236*** (5.83)
Is	−0.1352*** (−2.89)	−0.1195*** (−2.76)	0.1413*** (2.85)	−0.1018** (−2.25\
C	0.6511*** (9.13)	0.6303*** (9.71\)	−0.0416 (−0.44\)	0.6161*** (8.68\)
AR(1)	0.000	0.000	0.000	0.000
AR(2)	0.527	0.269	0.523	0.502
Hansen	0.276	0.287	0.932	0.264

be known that technological innovation plays a partially mediating role between digitization and GIP. At the same time, it can be calculated that the share of the mediating role of technological innovation in the total effect is 16.14% $(0.8660 \times 0.0593)/0.3181)$. This result verifies Hypotheses H2, H3, and H4 proposed in this study.

4.5.2. Moderating Effect Test. In this article, model (5) in Table 6 is the regression result of the moderating effect. It can be known that the interaction effect between digitization and ER is notable at the 5% critical level and has a coefficient of 0.1047. It can be observed that ER is a positive moderator of the relationship between D and GIP. With the strengthening of environmental regulation, this mediating effect increases, which verifies Hypothesis H5.

5. Conclusions and Policy Implications

Combining China's "carbon neutrality" policy and the background of the digital era, this article adopts the systematic GMM method and dynamic panel regression model to study how digitization affects the green innovation performance of 228 Chinese cities from the medium level and explore how digitalization can achieve the dual effects of environmental protection and innovation performance. There are four conclusions from this study as follows:

(1) Regarding green innovation performance in the context of "carbon neutrality," after adding carbon dioxide emissions from energy consumption, the overall performance of Chinese green innovation appears relatively high, and significant achievements have been made in the energy environment.

(2) Digitization positively impacts green innovation performance. The positive effect has a nonlinear relationship. The result of digitization on green innovation performance is more significant in a low-regional system than in a high-regional system. It shows that it is more necessary for cities with a low level of digitalization to further promote the coordinated development of green innovation and actively integrate it into the digital innovation network.

(3) There is regional heterogeneity between digitalization and green innovation performance. The effect of digitalization on green development execution in eastern districts is more significant than that in

central and western locales [41]; the impact of digitalization in fringe urban on green innovation is more critical than in focal urban areas. It shows that with regard to the energetic advancement of the digital economy, it is more necessary for cities in relatively disadvantaged areas to carry out in-depth cooperation and innovation and actively integrate into the innovation network.

(4) Digitalization unquestionably affects technological innovation advancement, and technological innovation positively impacts green innovation performance. Digitization acts on green innovation performance through technological innovation as an intermediary, and under the external governance constraints of environmental regulation, digitization is more conducive to improving green innovation performance.

From the above research, we make the following four policy recommendations:

(1) Increase digital applications to empower cities with green innovation and intelligence. Improve digital applications from the breadth and depth of digitalization, and deepen digital data application construction in many fields such as pension, education, logistics, and transportation, such as in-depth mining and analysis of data in various fields. The most important task is to focus on the digital divide in the process of digital technology innovation, relying on digital networking and intelligent technology to improve green innovation capabilities.

(2) Vigorously strengthening the construction of technological innovation systems will improve the green efficiency of Chinese cities. First, we should improve the quality of environmental protection and create green products. Second, we need to invest the direction of innovation into green technology to effectively improve the efficiency of green innovation [42]. Third, accelerating the integration of green efficiency in the three industries can effectively reduce the troubles caused by formulation.

(3) Reasonably match the environmental regulation policy and the regional economic development level. Chinese cities should make full use of tools like subsidies and emissions commerce to realize specialized policies for urban environmental regulation. In this way, local Chinese companies can further optimize the innovative compensation effect brought about by environmental regulation. [43].

(4) Fully consider the heterogeneity of cities and the uniqueness of each industry in the city and formulate differentiated industrial innovation policies. At the same time as the comprehensive development of digitalization, the diversified development of industries among Chinese cities will form a digital divide, resulting in differences within the digital industry. In this way, cities at various levels in China can formulate appropriate industrial innovation strategies according to these heterogeneous characteristics.

Data Availability

All data used in this study are available within the article.

Conflicts of Interest

The authors declare no conflicts of interest.

Authors' Contributions

L.J., X.H., and B.H. were responsible for the conceptualization; X.H. and T.Z. contributed to the methodology, software, and data curation; L.J., X.H., and W.L. were responsible for the validation; X.H. and B.H. conducted the formal analysis and visualization; L.J. conducted the investigation; L.J. and X.H. were responsible for the resources; X.H., T.Z., and Z.Z. wrote and prepared the original draft preparation; L.J. and Z.Z. revised, wrote, reviewed, and edited the article; B.H. and W.L. supervised the work; L.J. and X.H. were responsible for the project administration. All authors have read and agreed to the published version of the manuscript.

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