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Original Research

Digital Economy, Environmental Regulation and Urban Green Development- A Study Based on 282 Prefecture-Level Cities in China

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Abstract

The booming digital economy has injected new momentum into the high-quality development of China's economy. This paper empirically examines the impact of the digital economy and environmental regulation on green development in China by using the SBM-GML model to measure the level of green development in Chinese cities using data from 282 prefecture-level cities in China from 2011-2019 and explains the mechanism of the digital economy and environmental regulation on the green development of cities. The results show that the digital economy significantly improves the level of green development in Chinese cities and plays a positive moderating role in the process of environmental regulation to improve the level of green development in Chinese cities. Industrial structure upgrading is an important mediator of the digital economy and environmental regulation in empowering green total factor productivity; in terms of heterogeneity, both the digital economy and environmental regulation significantly increase the level of green development in cities in southern China and resource-based cities. In contrast, the digital economy and environmental regulation are the main drivers for non-digital economy pilot cities and non-resource cities, respectively.

Keywords: digital economy, environmental regulation, green development, upgrading of industrial structure, urban heterogeneity

Introduction

In recent years, the negative externalities brought about by the tightening of environmental resources, the declining carrying capacity of ecosystems, and the frequent occurrence of extreme weather have constrained China's economy from going further. High growth in industrial waste emissions, deterioration of water quality, destruction of vegetation, serious desertification, and environmental damage to people's health have occurred from time to time. Therefore, China proposes to plan its development based on harmony between human beings and nature and focus on promoting a comprehensive green transformation of economic and social development. From a connotation point of view, green development is a development that achieves the greatest economic and social benefits at the least cost to resources and the environment and takes

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the “greening” and “decolonization” of the process and results of economic activities as the main content and means of development. How to break the traditional economic development model of “high input, high pollution, and high emission” and promote the city to take the road of green development is an important issue for the construction of China’s strong nation in the new era. At the same time, with the rise of digital technology as the backbone of the scientific and technological revolution and industrial change, the digital economy has gradually become a new engine for global economic recovery [1]. Until 2022, the scale of China’s digital economy has reached 50.2 trillion yuan, with a nominal year-on-year growth rate of 10.3%, a growth rate that has been significantly higher than the GDP growth rate for 11 consecutive years, and the overall scale has ranked second in the world for many consecutive years, demonstrating the vigorous vitality and unlimited potential of the digital economy. Therefore, China should give full play to the important role of the digital economy in driving the optimization and upgrading of economic structure and promoting green development, and utilize the digital economy to empower green development in all areas of society.

Strengthening technological innovation and enhancing the efficiency of factor allocation, as well as keeping a close eye on the construction of ecological civilization, are the key mechanisms and inherent requirements for practicing the concept of green development and realizing the green transformation of Chinese cities. On the one hand, due to the use of big data, the Internet, and other high-tech to help information interaction, the digital economy reduces the transaction costs of enterprises in obtaining production information and upgrading production skills, promotes the technological level-up and green transformation of the whole industry, overcomes the limitations of the traditional factors of production on economic growth, breaks through the boundaries of space and time in the traditional sense, and empowers innovation, research, and development and resource allocation in all aspects to enhance the efficiency of economic operation and promote the green development of the city [2]. On the other hand, the formulation and implementation of environmental regulations can not only prompt enterprises to take more environmentally friendly actions to reduce environmental pollution and ecological damage, but also promote technological innovation and industrial upgrading and facilitate the greening of socio-economic transformation. Through the guidance of environmental regulations, enterprises will pay more attention to environmental protection and sustainable development, thus realizing a virtuous cycle of economic growth and environmental protection.

Digital technology not only improves the ability to integrate social resources and monitor the environment [3] but also facilitates the reduction of dependence on and depletion of natural resources, which in turn leads to the protection of the ecological environment [4]. Regarding the measurement of the digital economy, there is no recognized indicator system to measure the digital economy. Mesenbourg used an e-commerce index to measure the level of development of the digital economy [5], Haltiwanger and Jarmin used the data of e-commerce, scientific, and technological infrastructures and combined them with the characteristics of the population, the workers, etc. to construct the indicator system of the digital economy [6]. Zhang and Li constructed a set of accounting systems to measure the scale of the digital economy industry from the perspective of digital industrialization and industrial digitization, based on an input-output table [7]. Wang used the entropy value method, the Super-SBM model, and the Haken model to measure the digital economic resilience, digital economic efficiency, and synergistic evolution mechanisms of 31 provinces, municipalities, and autonomous regions in China, respectively, and examined the relationship between the resilience of the digital economy and efficiency [8]. Huang constructed a comprehensive index system to measure the development status of the urban digital economy from the dimensions of the Internet and digital finance and evaluated the level of the digital economy of each prefecture-level city in China by using principal component analysis [9]. At the micro level, Gong and others argue that the digital economy can stimulate breakthrough innovations, improve the internal structure of firms, and enhance the level of risk response of firms [10, 11]; at the meso level, Jiang and others have found that the digital economy is conducive to the structural upgrading of various industries and sustainable high-quality development [12-14]; and at the macro-level, Li showed that the digital economy can promote the high-quality development of the economy and society, enhance total factor productivity, and optimize the employment structure [15].

The concept of green development was first introduced in The Steady State Economy [16], and over time, especially since the economic crisis, how to promote green development has become a hot topic of international debate. In China, green development refers to a new development model that takes environmental protection as an important pillar of sustainable development within the constraints of ecological and environmental capacity and the carrying capacity of environmental resources. The scope of international research on green development covers sustainable development [17], green GDP [18], green economy [19], green government [20], urban green space [21], and green architecture [22]. Raihan investigated the role of ICT, economic growth, population, and energy use on green development in Malaysia using the autoregressive distributed lag method [23]. Hwang and Tan argued in the study that to promote green urban development, the coverage of government incentives should be extended to the use of green products and technologies [24]. Feng evaluated the green development performance index using data envelopment-based analysis, and the measurement results showed that the green development pattern of developed and developing regions was extremely unbalanced [25]. Wang used stochastic frontier analysis and the Malmquist index and applied the spatial Durbin model to analyze the spatial effect of green technology innovation on green total factor productivity from a regional perspective [26]. An econometric approach is used to determine how labor-management relations play a role in green development [27]. Li takes 11 provinces and cities along the Yangtze River Economic Belt in China as samples and analyzes that the relationship between industrial agglomeration and green development is an inverted U-shape, and digital transformation can positively strengthen this inverted U-shape relationship [28]. Li measured the green total factor productivity and efficiency of 77 developing countries by using a data envelopment analysis method combined with a global non-radial directional distance function and a common frontier Malmquist index and found that electricity and emission reduction technologies, economic agglomeration effects, and industrial restructuring brought by foreign direct investment (FDI) can promote developing countries' green development [29]. Wu found that fiscal decentralization has a significant negative impact on green development, with negative spillover effects [30].

Regarding the impact of the digital economy on green development, Han and Liu, based on the idea of division of labor in neoclassical economics, found that under the dual role of the government's green system and the market regulation mechanism, the digital economy can improve the efficiency of transactions through technological change and promote the transformation of the transaction from the "black division of labor" mode to the "green division of labor" mode to empower green development [31]. Yang used the entropy value method for the first time to measure digitalization, technological innovation, and green economic development and included them in the same analytical framework by constructing the PVAR model [32]. Zhao empirically tested 284 cities in China and found that the "digital divide" between high- and low-ranking cities exacerbates the differences in the impact of the digital economy on green development and that the rationalization of the industrial structure and the improvement of the environment are the main pathways for the transmission of the digital economy effect [33]. Liu constructed the evaluation index system from three aspects of industrial digitalization capacity, socio-economic benefit capacity, and ecological resource carrying capacity, and empirically analyzed that the digital economy has a positive impact on the green development of the traditional manufacturing industry through digital innovation, industrial upgrading, and human capital, and there exists a positive spatial autocorrelation pattern of "east high and west low", which has a non-linear impact on the intensive production of the traditional manufacturing industry [34]. Ji based research on the panel data of manufacturing industries in 2002, 2005, 2007, 2010, 2012, 2015, and 2017, and the study concluded that the digital service industry can reduce carbon emissions and promote the green development of the manufacturing industry through innovative intermediary mechanisms [35].

Regarding the impact of environmental regulation on green development, Hao based research on the panel data of 286 prefectural-level cities in China and analyzed that environmental regulation can promote green development through technological innovation, and the industrial structure has a positive regulating effect [36]. Yang using inter-provincial panel data in China, the empirical evidence suggests that environmental regulations have a greater impact on green development efficiency in the eastern and developed regions, while their impact on other regions is relatively small [37]. Du found that vertical environmental regulation has a U-shaped effect on the local green development index, and when it is higher than 1.561, the green governance effect begins to appear [38]. Pan conducted a natural experiment with a time-varying double-difference model of Chinese urban panel data using the Environmental Protection Interview Program (EPI), the most stringent environmental monitoring program in China's history, and showed that the EPI was able to lead to a 35.6% increase in green total factor productivity, and it is more significant in cities with lower initial green total factor productivity levels and lower economic levels [39]. Yin categorized cities into three systems: lagging green economy, lagging environmental regulation, and lagging technological innovation, and found that the impact of pollutant emissions is greater than the expenditure on pollution control in the cities with lagging environmental regulation, whereas the government's attention and the cultivation and attraction of talents are the basis of technological innovation in the lagging cities [40].

For the co-effectiveness aspect of green development, Yang and Liang found that the growth of the digital economy can greatly improve green eco-efficiency through fixed-effects and spatial econometric modeling, while environmental regulation is a beneficial moderator. Moreover, the positive contribution and moderating effect of environmental regulation and the digital economy on green eco-efficiency are manifested in the patterns of "east is strong and west is weak", "east is weak and west is weak", and "first weak then strong" [41]. Cheng and Yang integrated digital economy, environmental regulation, and sustainable development into the same system to construct a coupling coordination degree model and found that the national coupling coordination degree is between moderate and good at the time level, generally showing a "W" type upward trend, and has a localized spatial autocorrelation pattern [42].

To summarize, academics have conducted in-depth research on the impact of the digital economy and environmental regulation on green development, but there are the following shortcomings: First, most of the existing literature focuses on one aspect of the digital economy and the high-quality development of the economy, and the green value behind the digital economy has yet to be further explored. Second, the research on digital economy and green development is mostly about mechanisms and path selection, and part of the quantitative research literature mainly measures the level of digital economy development at the provincial and industry levels, ignoring the differences among cities within provinces. Third, the current scholars are mostly focused on the study of the impact of environmental regulation on economic efficiency, and because of the influence of industrial characteristics, industrial development status, etc., its positive and negative effects on economic development conclusions are not consistent, so it needs to be further explored. Fourth, most of the existing literature has separately studied the impact of the digital economy and environmental regulation on enhancing the level of urban green development and has not included the three in the same framework for analysis to study the joint role of the digital economy and environmental regulation.

The possible marginal contribution of this paper lies in the following: In terms of research perspectives, green and high-quality development is the development direction of China's future urbanization, and the profound changes brought about by the digital economy to China's cities should not be confined to the aspect of economic growth, but should also be incorporated into the perspective of green and sustainable development. This paper incorporates environmental regulation into the framework of the study of the digital economy at the level of green development, which theoretically identifies the synergistic effect of the digital economy and environmental regulation on green development. In terms of research level, in order to examine the development level of each city, this paper starts from the prefecture-level city level and examines its heterogeneous influence from the aspects of geographic location and city attributes; in terms of research methodology, it introduces the intermediary channel of upgrading the industrial structure and examines in depth the path selection and transmission mechanism of the digital economy and environmental regulation to promote the green development of the city.

Theoretical Mechanism and Research Hypothesis

Direct Effect on Urban Green Development

The main ways in which the digital economy empowers green development include promoting the transformation of green production methods, enhancing green innovation capacity, and improving green regulatory efficiency. First, the development of the digital economy can enhance the green total factor productivity, which is not only conducive to enterprises to improve the complexity of product technology and accelerate the digital transformation of operations [43], deepen the level of embeddedness in the enterprise's global value chain [44], but also promote the improvement of the efficiency of information interaction, reduce energy consumption, and improve the efficiency of resource utilization. Moreover, the digital economy has given rise to new business forms such as the sharing economy and platform economy, which reduce the waste of resources and services, enhance the public's awareness of environmental protection, and promote the green development of cities. Secondly, due to the positive externality of green technological innovation, the development of the digital economy can also promote the spillover of high-efficiency, low-cost, and low-loss innovative technologies, expanding the radiation scope and technological frontier of urban green technological innovation while significantly driving regional green innovation. The agglomeration and diffusion effects of green technological innovation can have a positive impact on the improvement of the development quality of neighboring regions [45] and promote the coordinated development of urban and rural areas, ecological sustainability, and sustainable development of various regions. Third, the development of big data and the Internet can help the government integrate digital technologies into its daily regulatory work, and the application of these technologies can implement the government's real-time dynamic monitoring of environmental data resources such as air quality, river water quality, and discharge pollution [46], which provides a more reliable quantitative standard and governance basis for the government to assess the qualification of enterprises' discharge governance and, at the same time, provides more convenient policy support for the transformation of green development in the city.

Based on this, this paper proposes hypothesis H1(a): the digital economy can promote the green development of cities.

Reasonable environmental regulation can stimulate firms to invest in the transformation of environmental technologies, innovation of environmental management tools, and productivity enhancement [47], and to seek new environmentally friendly technologies and solutions to help gain a competitive advantage. This will promote the development of urban environmental technology innovation, thus generating the "innovation compensation" effect of products and production processes, which compensates for or even exceeds the cost of compliance [48], which can help to achieve a win-win situation for both the economy and the environment and to gain a first-mover advantage in the international market and enhance national competitiveness and international influence.

Therefore, hypothesis H1(b) is proposed: environmental regulation can promote green urban development.

Indirect Effects on Urban Green Development

The digital economy can, on the one hand, promote the digitalization, networking, and intelligent transformation of traditional industries, encourage enterprises to improve their production, management, and circulation methods, and enhance their production efficiency. On the other hand, the use of the Internet and big data technology can not only personalize and customize production according to user demand and promote product innovation [49] but also release consumer demand and promote the expansion and differentiation of market scale, thus accelerating the optimization and adjustment of industrial structure and transformation and upgrading [50]. Moreover, due to the rapid development of digital technology, the rise of big data, artificial intelligence, and other industries will give rise to new business models and lead to the formation of new industries [51], which will not only change the traditional industrial model and improve production efficiency, but also may lead to a new round of industrial change. At the same time, the arrival of new industries will accelerate the elimination of high-pollution and high-energy-consumption industries, further empowering the green development of cities. It can be seen that the upgrading of industrial structures has an enhanced effect on green total factor productivity.

Environmental regulation, as a means for governments to constrain corporate behavior and decision-making, forces firms to make a green transition by internalizing environmental costs. According to Porter's Hypothesis, environmental regulation not only stimulates innovation and productivity in the short term and offsets the costs of environmental protection, but also increases industrial productivity in the long term, thus facilitating structural transformation. Under stringent environmental regulations, firms that are unable to reduce emissions and increase production at the same time under the given production conditions will focus their resources on developing green technologies and optimizing their production processes [52, 53], and the traditional high-energy consumption, high-pollution, and high-emission industries self-driven green transformation and upgrading, reducing the consumption of environmental resource elements, replacing environmental resource elements with human capital, green technology, and other elements, promoting the optimization and upgrading of the factor structure and industrial change, thus affecting the green development efficiency.

Therefore, this paper proposes hypothesis H2: The digital economy and environmental regulation promote urban green development by promoting industrial structure upgrading.

The Regulatory Effect of the Digital Economy on Environmental Regulation and Promoting Urban Green Development

Since traditional environmental regulation is a government policy measure, it is essentially a governmental act that contains economic incentives such as governmental investment subsidies and sewage charges in addition to the enactment of environmental regulations. Despite the support of the legal framework, with the rapid development of the economy and society, the public's demand for environmental quality has increased, and awareness of environmental protection has been strengthened. However, the intensity and radiation scope of the implementation of environmental regulation that relies solely on the power of the government are limited [54, 55]. The purpose of environmental regulation is to improve environmental quality and accelerate the transformation of the economic growth mode, so in the context of the digital era, the government can use the Internet, blockchain, and other advanced digital technologies as an environmental information service platform to accept the public's feedback on the quality of the environment and discipline the main body of the sewage discharge [56]. The digital economy has given rise to a new mode of economic development, broadened the financing channels and methods of enterprises, enhanced the green innovation ability of enterprises, gradually increased public awareness of environmental protection, made it easier to achieve results in environmental regulation, and ultimately realized the common development of economic development and ecological civilization.

Based on this, this paper proposes hypothesis H3: The digital economy can positively modulate the contribution of environmental regulation to the greening of cities.

To this end, this paper constructs a theoretical framework of digital economy and environmental regulation empowering green development, as shown in Fig. 1.

Material and Methods

Sample Selection and Data Sources

This paper uses a panel of 282 prefecture-level cities from 2011 to 2019 as a sample for empirical testing, and the main data come from the China Urban Statistical Yearbook, China Research Data Service Platform (CNRDS), and China Economic and Financial Research Database (CSMAR). The green total factor productivity and digital economy-related indexes are mainly from the China Statistical Yearbook, the China Urban Statistical Yearbook, and the China Environmental Statistical Yearbook. Among them, the digital financial inclusion index adopts the latest data released by the Digital Finance Research Center of Peking University

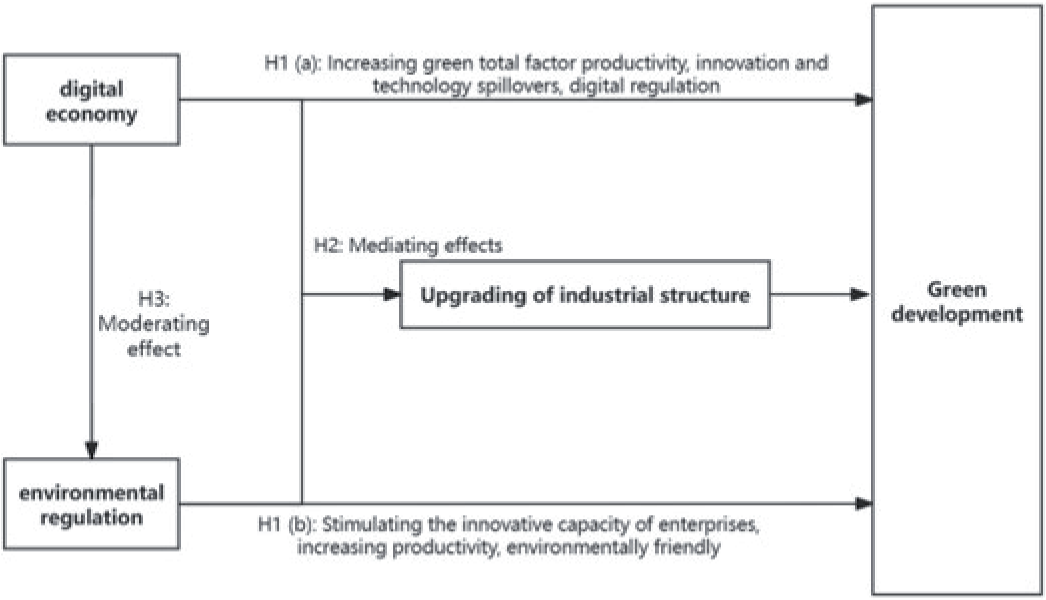

Fig. 1. Theoretical framework.

in cooperation with Ant Financial Services. The word frequency of environmental vocabulary was captured from the government work report of each prefecture-level city by using Python, and the government work report document was obtained from the official website of each prefecture-level city government.

Model Construction

Baseline Regression Model

To explore the direct impact of the digital economy and environmental regulations on urban green development and test H1, this paper constructs the benchmark measurement model as follows:

$$GTFP_{i,t} = \alpha_0 + \alpha_1 Digit_{i,t} + \alpha_2 Ere_{i,t} + u_i + v_t + \varepsilon_{i,t}$$

Where i stands for region, t stands for year, $GTFP_{i,t}$ stands for urban green total factor productivity level, $Digit_{i,t}$ stands for urban digital economic development level, $Ere_{i,t}$ stands for environmental regulation intensity, μ_i and stands for urban fixed effect and time fixed effect, $\varepsilon_{i,t}$ is a random disturbance term.

As a new economic model, the digital economy, relying on the Internet, blockchain, and other information technologies, has broadened the sources of funding for environmental regulation incentives and promoted economic agents to pay attention to environmental quality, which has played a positive incentive role in the improvement of the level of green development in cities [57]. Therefore, the cross-multiplier term between digital economy and environmental regulation is introduced based on the baseline measurement model, and the model is as follows:

$$GTFP_{i,t} = \alpha_0 + \alpha_1 Digit_{i,t} + \alpha_2 Ere_{i,t} + \alpha_3 Digit_{i,t} * Ere_{i,t} + u_i + v_t + \varepsilon_{i,t}$$

Intermediary Effect Model

To further explore the indirect effect of the digital economy on urban green development, the mediation effect model [58] is used to test H2, which is set as follows:

$$Upgrade_{i,t} = \alpha_0 + \alpha_1 Digit_{i,t} + \alpha_2 Ere_{i,t} + u_i + v_t + \varepsilon_{i,t}$$

$$GTFP_{i,t} = \beta_0 + \beta_1 Digit_{i,t} + \beta_2 Ere_{i,t} + \beta_3 Upgrade_{i,t} + u_i + v_t + \varepsilon_{i,t}$$

Where, $Upgrade_{i,t}$ represents the intermediate variable.

Variable Selection

Explained Variable: Green Development

In this paper, total factor productivity GTFP is used as a proxy variable for the level of green development of cities, and the non-expected output SBM model and Global Malmquist Luenberger (GML) index are applied to measure the level of green development of cities [59]. The system of input-output indicators is shown in Table 1.

Explanatory Variables

(1) Digital economy

Due to different measurement scopes and methods, the current results of scholars at home and abroad on the scale of the digital economy are quite different.

Table 1. Input-output index system of urban green development level.

Primary index	Secondary index	Three-level index
Input factor	Factors of labor	Number of employees at the end of the year (10,000)
	Capital element	Fixed capital stock (100 million yuan)
	Energy factor	Total electricity consumption (KWH)
	Resource factors	Water supply of the whole society (10,000 tons)
		Urban construction land area (sq. km)
Expected output	Economic growth	Real Gross regional Product (100 million yuan)
	Social benefit	Annual average wage of urban residents (Yuan)
	Ecological benefit	Total urban green space (sq. km)
Undesirable output	exhaust emission	Total industrial SO_2 emissions (10,000 tons)
	Wastewater discharge	Total industrial wastewater discharge (10,000 tons)
	Solid waste discharge	Total industrial soot emissions (10,000 tons)

Table 2. Evaluation index system of comprehensive index of urban digital economy development.

Primary index	Secondary index	Three-level index	Index attribute
Digital economy Comprehensive Development Index	Internet related practitioners	Information transmission and computer services employees accounted for the proportion of urban units employed	Positive
	Internet penetration rate	Number of broadband Internet access users per 100 people	Positive
	Internet-related output	Telecommunications traffic per capita	Positive
	Number of mobile Internet users	Number of mobile phone users per 100 people	Positive
	Development of digital financial inclusion	China Digital Financial Inclusion Index	Positive

Considering the availability of data, this paper is based on Internet development, using four indicators: the proportion of information transmission and computer service employees in urban units, the number of Internet broadband access users per 100 people, the per capita volume of telecommunication services, and the number of cell phone subscribers per 100 people, and combining with China's Digital Inclusive Finance Index to characterize the level of digital financial development to conduct a principal component analysis to obtain a composite indicator and a specific indicator system. The specific index system is shown in Table 2.

(2) Environmental regulation

Current research has not yet reached a consensus on the measurement of environmental regulation intensity, and the main measurement methods are as follows: first, the entropy value method is used to calculate the industrial emissions of three wastes; second, from the amount of investment in environmental governance, the higher the input cost means the stronger the environmental regulation; third, the number of penalties for regional environmental protection cases is used to measure the number of penalties, and the lower the number of penalties the stronger the strength of the environmental regulation; fourth, the examination of sewage charges, environmental taxes and other environmental regulation-related indicators [60]; the fifth is to use the frequency intensity of environmental regulation words in government reports and the number of environmental proposals from CPPCC National People's Congresses in each region to examine. Based on the existing research and data availability, this paper constructs 27 environmental words with reference to Zhao Xiao et al. and selects the proportion of environmental word frequency in the word frequency of the work report of the prefecture-level city government to measure the intensity of environmental regulations [61].

Intermediary Variables

Generally, industrial structure upgrading can be measured by the proportion of non-agricultural industry, the industrial structure hierarchy coefficient, the proportion of tertiary industry and secondary industry output value, the Moore structural change index, the proportion of high-tech industry, and other indicators. In this paper, concerning Zhou [62], the measurement formula is as follows:

$$Upgrade = \sum q_i |x_i| + q1 * 1 + q2 * 2 + q3 * 3$$

Among them, q_i is the proportion of the output value of the i industry.

Control Variables

The control variables selected in this paper include: foreign direct investment (FDI) is characterized by the share of actual utilized foreign capital in GDP; financial development (Fin) are expressed by the ratio of the balance of deposits and loans of financial institutions to GDP at the end of the year; fiscal decentralization (Fd) is reflected by the ratio of budgeted revenues to budgeted expenditures; scientific and technological inputs (Tec) is expressed by the ratio of scientific and technological expenditures to GDP; and market dynamism (Ent) is measured by the share of private sector employment to the total labor force. To avoid pseudo-regression, FDI is standardized.

Descriptive Statistics

The descriptive statistics of the variables involved above are shown in Table 3, where the mean value of Green Total Factor Production Level (GTFP) is 1.005, the minimum value is 0.488, and the maximum value is 1.633. The mean value of the Digital Economy Development Index (Digit) is 0.797, the minimum value is 0.0567, and the maximum value is 13.05. The mean value of Environmental Regulation (Ere) is 0.00351, the minimum value is 0.000294 and the maximum value is 0.0124.

Results and Discussion

Baseline Regression Results

The regression results of whether the digital economy and environmental regulation can promote the green development level are shown in Table 4. Considering that the panel data will be disturbed in the area and time dimensions, resulting in biased regression coefficients, it is necessary to control for individual fixed effects and time fixed effects. Columns (1) and (2) show the effects of digital economy and environmental regulation on the level of urban green development both with and without considering control variables, respectively; column (3) shows the regression results after controlling for region and time fixed effects and introducing control variables; column (4) shows the effects of the cross-multiplication term of digital economy and environmental regulation on the level of urban green development under control variables.

It can be found that the digital economy, environmental regulation intensity, and urban green development are positively correlated regardless of whether control variables are added or not. Taking column (3) as an example, for every unit increase in the digital economy, the total factor productivity of urban green will be increased by 0.007, which may be since the digital economy can reduce the dependence on and consumption of natural resources and, to a certain extent, improve the efficiency of the utilization of factors of production and promote technological advances, thus empowering green development. This suggests that the digital economy is conducive to promoting the green development of Chinese cities, thus confirming H1: for every unit increase in the intensity of environmental regulation, the green total factor productivity of cities can be increased by 0.001. The insignificant impact of environmental regulation on China's green development may be because environmental regulation has a certain lag in incentivizing and supervising the production of green innovations, and the improvement of the efficiency of green development is a continuous accumulation process. Moreover, due to the spatial spillover effect of

Table 3. Descriptive statistics.

Variables	N	Mean	sd	Min	Max
GTFP	2,538	1.005	0.0509	0.488	1.633
Digit	2,538	0.797	0.976	0.0567	13.05
Ere	2,528	0.00351	0.00145	0.000294	0.0124
FDI	2,529	0.0168	0.0176	0.00000177	0.198
Fin	2,520	2.389	1.168	0.588	21.30
Fd	2,538	0.474	0.268	0.0149	6.521
Tec	2,533	0.00292	0.00378	0.0000056	0.0631
Ent	2,529	1.155	1.165	0.0519	45.16

Table 4. Baseline regression result.

Variables	GTFP	GTFP	GTFP	GTFP
digit	0.008***	0.008***	0.007**	
	(4.19)	(3.41)	(1.99)	
ere	0.020***	0.019***	0.001	0.008
	(3.52)	(3.26)	(0.13)	(1.20)
Digit*ere				0.016***
				(3.23)
FDI		-0.022*	-0.063***	-0.020*
		(-1.89)	(-2.67)	(-1.77)
Fin		0.003***	-0.000	0.003***
		(2.83)	(-0.01)	(3.24)
Fd		-0.001	-0.001	0.001
		(-0.25)	(-0.42)	(0.25)
Tec		0.145	-0.661	0.192
		(0.49)	(-1.48)	(0.63)
Ent		0.001**	0.001	0.001**
		(2.15)	(0.57)	(2.18)
Constant	0.992***	0.987***	0.985***	0.990***
	(414.24)	(301.13)	(157.84)	(290.80)
Observations	2,538	2,506	2,506	2,506
R-squared	0.026	0.034	0.154	0.031
Id FE	NO	NO	YES	YES
Year FE	NO	NO	YES	YES

Robust t-statistics in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

environmental regulation, cities hope to "free ride", and their willingness to undergo self-green transformation is not strong, so their ability to enable green development is weak. This also confirms the fact that existing studies believe that the overall impact of environmental regulations on the efficiency of urban green development is U-shaped, which is first inhibited and then promoted.

Column (4) shows that the digital economy plays a positive moderating role in the process of environmental regulation to enhance the level of green development in Chinese cities, i.e., the digital economy can alleviate the financing constraints of economic agents, the government can use this to enhance the strength of economic incentives, and enterprises can obtain a steady stream of financial support to upgrade the production structure, enhance the intensity of green innovation, and coordinate the creation of an orderly green production environment, which strengthens the extent of the promotion of environmental regulation for green development, thus confirming H3.

Endogeneity Analysis

Since urban green total factor productivity benefits from the rapid development of the digital economy and the enhancement of environmental regulation by local governments, while the level of development of the digital economy may also depend on the demand for upgrading current production technology, there may be a reverse causality between the digital economy, environmental regulation, and urban green development. Moreover, there are more factors affecting green development: combining data availability and existing research perspectives, this paper may have the problem of omitted variables. Concerning Nunn and Qian [63], this paper selects the number of post offices per million people and the number of landline telephones in each city in 1984 and tries to construct an interaction term with the number of Internet users in the country in the previous year to obtain instrumental variables, respectively. The inner logic is that before the popularization of landline telephones, mail was the basic way for people to communicate and transfer information, and at the same time, the post office is also the executive department of laying fixed-line telephones, so the distribution of post offices has affected the distribution of fixed-line telephones to a certain extent in history. The prosperous development of the digital economy and the formulation and implementation of national policies cannot be separated from the popularization of fixed-line phones and cell phones. The emergence of the Internet has greatly changed the state of people's lives. A new generation of digital technologies, such as big data and other digital technologies, continues to promote China's economy through "digital reality symbiosis", so fixed-line telecommunication infrastructure will also affect the application of digital economy technology and the implementation of environmental regulations. So, choosing the number of fixed telephones and the number of post offices as instrumental variables satisfies the correlation requirement. Moreover, with the popularization of cell phones and the development of Internet technology, the impact of the number of post offices and fixed-line telephones on economic and social development decreases with the decline in the frequency of use, which also meets the requirement of exclusivity.

Table 5 reports the instrumental variable regression results without and with the inclusion of control variables. The results show that after considering endogeneity, the digital economy and environmental regulation can still lead to a significant increase in urban green total factor productivity, i.e., the basic conclusion that the digital economy and environmental regulation can promote urban green development still holds.

Table 5. Instrumental variable test results.

Variables	GTFP	GTFP
ere	18.8533**	15.7537**
	(7.378)	(7.790)
digit	0.0072***	0.0080***
	(0.001)	(0.001)
FDI		-0.0314**
		(0.015)
Fin		0.0015
		(0.001)
Fd		-0.0021
		(0.005)
Tec		0.2344
		(0.436)
Ent		0.0011
		(0.001)
Constant	0.9336***	0.9423***
	(0.025)	(0.025)
Observations	1,899	1,877

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 6. Mediation mechanism test results.

	GTFP	upgrade	GTFP
digit	0.018***	6.133***	0.018***
	(0.004)	(1.539)	(0.004)
ere	0.031***	10.858**	0.030**
	(0.009)	(3.924)	(0.009)
upgrade			0.001*
			(0.0001)
_cons	0.980***	219.925***	0.953***
	(0.004)	(1.861)	(0.012)
N	2538.000	2533.000	2533.000
r2	0.017	0.011	0.020
r2_a	-0.107	-0.114	-0.103

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Further Analysis

Inspection of Intermediary Mechanisms

Table 6 reports the results of the linear estimation of the digital economy affecting the level of green development in cities. In Column (1), the coefficients of the integrated development index of the digital economy and the intensity of environmental regulation are both significantly positive, indicating that both can promote the green development of cities. Column (2) shows whether the digital economy and environmental regulation can promote industrial structure upgrading, and the regression coefficients of both are significantly positive, indicating that the digital economy can promote industrial transformation and upgrading by improving labor productivity and generating new industries, while environmental regulation, as a means for the government to improve environmental quality and stimulate enterprises to improve resource productivity and actively transform and innovate, has a significant role in promoting industrial structure upgrading. Column (3) shows that the coefficients of both the digital economy and environmental regulation are significantly positive, confirming that industrial structure upgrading plays a fully mediating role in both urban and green development. This is because environmental regulations can force enterprises to carry out technological innovation or adopt innovative technologies, which may increase costs in the short term, but in the long term can enhance the production efficiency and competitiveness of enterprises, thus offsetting the costs of environmental protection, enhancing the profitability of enterprises in the market, and promoting the green growth of the urban economy [64]. Moreover, the digital economy can support green development by eliminating barriers to the movement of capital factors, reducing transaction costs, enhancing the efficiency of the use of traditional capital factors, and facilitating the transformation of corporate structures.

Heterogeneity Analysis

Geographical Location Heterogeneity

The degree of green development varies among Chinese cities due to large differences in resource endowment, economic development foundation, and policy background. To scrutinize the effect of the digital economy on the promotion of green development in cities with different geographical locations, this paper divides the sample of 282 cities in China into north and south cities for group regression with the Qinling--Huai River as the boundary and further subdivided into the Yellow River and Yangtze River basins to examine the north-south differences in digital economy development.

As shown in Table 7, the effects of the digital economy and environmental regulation on green development are significantly positive in both southern and northern cities, and the digital economy plays a stronger role in promoting green development in southern cities. This may be because southern cities have a better economic foundation and a more complete infrastructure in the transition to digitalization, and the implementation of policies has led to the continuous improvement of

Table 7. Results of geographical heterogeneity test.

Variables	Southern city	Northern city	Yellow River basin	Yangtze river basin
digit	0.018***	0.017***	0.021***	0.051***
	(3.79)	(3.16)	(3.30)	(5.07)
ere	0.032**	0.030***	-0.006	0.004
	(2.21)	(2.59)	(-0.26)	(0.15)
Constant	0.984***	0.977***	0.996***	0.937***
	(165.58)	(148.86)	(112.16)	(58.77)
Observations	1,188	1,350	495	324
R-squared	0.020	0.013	0.024	0.083
Number of id	132	150	55	36
Id FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
r2_a	-0.104	-0.111	-0.100	-0.0361
F	10.48	8.015	5.449	12.87

t-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1

the market environment. Some of the central cities have become a highland for attracting talents, which is, therefore, more conducive to the allocation of resources and the transition to green innovation. The Yellow River and Yangtze River regions, as important economic and cultural centers in the North and South, also have a significant role to play in the promotion of the digital economy for green development.

Heterogeneity of Urban Development Types

Resource-based cities are mainly engaged in the extraction and processing of natural resources, such as mines and forests, and a lack of integrated and sustainable development planning has resulted in imbalances in the economic structure and serious ecological damage in the long run. Columns (1) and (2) of Table 8 report the regression results for resource-based and non-resource-based cities in China, respectively. The digital economy and environmental regulation significantly enhance the green development level of both, and the promotion effect is more significant for resource-based cities. This suggests that environmental pollution and resource depletion in resource cities not only require environmental policy regulation but also require the digital economy to drive the green and sustainable development of cities by improving factor allocation and promoting enterprise innovation and transformation.

At present, the development of the digital economy still relies on policy support. According to the list of big data comprehensive pilot zones set up by the state, this paper divides the samples into pilot cities and non-pilot cities to carry out regression, and the results are as shown in Table 8, columns (3) and (4). It can be seen that the digital economy enhances the green development level of non-pilot cities even more, indicating that the comprehensive big data pilot zones have a radiation-driven and demonstration-leading effect and promote the digital construction of cities through policy preferences and other ways to accelerate the transformation of the city's economic structure and the enhancement of the green innovation capacity.

Robustness Test

Eliminate the Influence of Municipalities

Considering that municipalities directly under the central government are on the same administrative level as provinces and are significantly better than ordinary prefecture-level cities in terms of political and economic development, the level of digital economy development and the intensity of environmental regulation enforcement will be very different compared with other prefecture-level cities. To exclude the impact of this special administrative status on the regression results, this paper excludes the sample of municipalities for testing. The regression results are shown in Column (1) of Table 9. After excluding the sample of municipalities directly under the central government, the regression results of the digital economy and environmental regulation on urban green total factor productivity are still positive, and the digital economy has a significant effect on the improvement of green development level, which indicates that the regression results of this paper are still robust.

Table 8. Urban heterogeneity test results.

Variables	Resource-based city	Non-resource-based city	Pilot city	Non-pilot city
digit	0.025***	0.017***	0.013**	0.026***
	(2.62)	(4.27)	(2.39)	(4.63)
ere	0.037***	0.027**	0.076***	0.020**
	(2.84)	(2.14)	(2.83)	(2.17)
Constant	0.979***	0.979***	0.963***	0.981***
	(150.81)	(164.29)	(76.98)	(202.24)
Observations	1,017	1,521	486	2,052
R-squared	0.017	0.017	0.032	0.015
Number of id	113	169	54	228
Id FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
r2_a	-0.108	-0.107	-0.0916	-0.109
F	7.615	11.79	7.158	13.47

Table 9. Robustness test results.

Variables	GTFP	GTFP	GTFP	GTFP
digit	0.007**	0.007**	0.007**	0.002*
	(2.00)	(2.09)	(2.33)	(1.70)
ere	0.001	0.000	0.007	0.001
	(0.08)	(0.03)	(1.13)	(0.26)
FDI	-0.063***	-0.037*	-0.024*	-0.016**
	(-2.66)	(-1.91)	(-1.65)	(-2.02)
Fin	0.000	0.001	0.001	-0.001
	(0.02)	(0.58)	(1.00)	(-0.84)
Fd	-0.001	-0.001	-0.001	0.001
	(-0.41)	(-0.33)	(-0.32)	(0.58)
Tec	-0.664	-0.543	-0.123	-0.417**
	(-1.48)	(-1.49)	(-0.52)	(-2.32)
Ent	0.000	0.000	0.000	0.000
	(0.56)	(0.50)	(0.60)	(0.82)
Constant	0.985***	0.980***	0.975***	0.994***
	(157.26)	(181.94)	(202.19)	(350.48)
Observations	2,479	2,506	2,457	2,506
Number of id	276	279	279	279
R-squared	0.154	0.210	0.237	0.163
Id FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES

Eliminate the Influence of Extreme Values

Considering that the regression results may be affected by extreme values and outliers, this paper shrinks and truncates the samples with the highest and lowest 1% of green total factor productivity, and the regression results are shown in columns (2) and (3) of Table 9. Among them, column (2) is the regression result after shrinking the tails for the extreme 1% values, and column (3) is the regression result after truncating the tails for the extreme 1% values. It can be seen that the regression results of the digital economy and environmental regulation on urban green total factor productivity are still positive, and the digital economy has a significant role in improving the level of green development. The conclusion of the study remains unchanged.

Replace the Explained Variable

For regression robustness considerations, this paper further calculates the green total factor productivity of each prefecture-level city using the super-efficiency-based SBM-DDF model, with the same selection of input and output term indicators as above. The regression results are shown in column (4) of Table 9. It can be seen that the digital economy can still significantly promote regional green total factor productivity, and the research conclusion is robust.

Conclusions

Some of the painful lessons of overexploitation and utilization of nature show that integrating digital technology into green development is of great significance for China to achieve high-quality economic development. Based on the panel data of prefecture-level cities in China from 2011 to 2019, this paper analyzes the mechanism of the digital economy and environmental regulation empowering China's green development by constructing a fixed-effects model and a mediation model based on the perspective of upgrading the industrial structure and further explores the geographic location of the above effects and the heterogeneity of urban development types, with the main conclusions as follows:

First, the development of the digital economy will significantly drive the improvement of the level of green development in Chinese cities, and this conclusion still holds after replacing the explanatory variables, eliminating extreme values, and dealing with endogeneity. Second, environmental regulation has a positive driving effect on the green development of Chinese cities, but because the enhancement of the level of green development is a continuous accumulation of the adjustment process, the promotion effect of environmental regulation on green development is not significant. The digital economy can play a positive regulatory role in the process of environmental regulation to improve the level of green development in Chinese cities. Third, both the digital economy and environmental regulation can indirectly enhance China's green development level by promoting industrial structure upgrading and transformation. Fourth, in terms of heterogeneity, for southern cities with stronger economic foundations, the Yellow River Basin and the Yangtze River Basin, the digital economy favors green development. On the contrary, for weaker economic regions, environmental regulation is the main driving force behind green development in cities. Both the digital economy and environmental regulation have a significant contribution to the level of green development in resource-based cities, and the digital economy has a stronger ability to enhance the level of green development for non-pilot cities, while the environmental regulation impact index is stronger for non-resource-based cities and pilot cities of the digital economy.

Based on the above conclusions, this paper puts forward the following policy recommendations: First, China should actively develop the digital economy, deploy digital infrastructure construction moderately ahead of schedule, vigorously promote the innovative development of digital industries and the digital transformation of industries, enhance the green innovation capacity and innovation efficiency of enterprises, and create a green industrial system with international competitiveness. Second, the national government should coordinate the overall situation, focus on promoting key core technology research and development, firmly grasp the autonomy of digital economic development, integrate digital technology with green transformation in various fields, and increase the promotion and application of advanced achievements and technologies. At the same time, to curb the widening of the "digital divide", the synergistic development of the digital economy and urban greening should be strengthened, and the comprehensive carrying capacity of each region should be improved. For regions with a more developed digital economy, the degree of software industry agglomeration should be enhanced, several eco-dominant enterprises mastering key core technologies with international competitiveness should be cultivated, and world-class digital economy industry clusters should be built; for regions with a less developed digital economy, efforts should be stepped up to promote the construction of digital economy infrastructures, and the use of inclusive finance and other means should be utilized to help regional development, the transformation of resource-oriented cities, the cultivation of emerging cultural industries, and the improvement of the goal of the commonwealth. Thirdly, it is actively improving environmental regulation and other policy systems and digital governance systems, strengthening the coordination of various policies, expanding the channels for the participation of multiple social actors in green governance, and mobilizing the initiative and enthusiasm of the actors to participate in green governance. Actively guiding the flow of capital to resource-saving and environmentally friendly emerging clean industries, real-time monitoring and intelligent surveillance of the production process, improving regulatory efficiency and scientific decision-making, and effectively reducing the energy consumption of enterprise production.

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Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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