forests

Article

The Impact of Digital Economy Empowerment on Green Total Factor Productivity in Forestry

Hanting Chen, Zhuoya Ma, Hui Xiao, Jing Li and Wenhui Chen *

School of Economics and Management, Beijing Forestry University, Beijing 100083, China; 17638343437@163.com (H.C.); zhuoya0813@bjfu.edu.cn (Z.M.); huixiao@bjfu.edu.cn (H.X.); jean_lee1999@163.com (J.L.)
* Correspondence: chenwenhui77@163.com

Abstract: The digital economy is an important engine for promoting green economic development, and the integration of the digital and real economies can accelerate the transformation of the real economy. In order to explore the multifaceted influence of digital economy on forestry green total factor productivity and its specific presentation form, based on the panel data of 277 cities in China from 2013 to 2019, this paper first used the super SBM model to measure the level of forestry green total factor productivity and adopted the entropy method to measure the level of the digital economy in each region. Secondly, the influence and mechanism of the digital economy on green total factor productivity in forestry were explored by using fixed-effect and intermediate-effect models, and the heterogeneity of the digital economy on forestry green total factor productivity was analyzed based on different regional classification methods. Finally, the spatial spillover effect of the digital economy was explored in depth by the spatial Durbin model. The results are as follows: firstly, there is a significant inverted U-shaped relationship between the digital economy and forestry green total factor productivity, which first promotes and then inhibits. Secondly, the relationship between the digital economy and the level of urban green innovation shows a positive U-shaped relationship, first inhibiting and then promoting, and can have an indirect impact on forestry green total factor productivity by promoting the level of green innovation. Third, China is still on the left side of the inverted U-shaped relationship between the digital economy and forestry green total factor productivity, i.e., it is at a stage where the digital economy can significantly contribute to forestry green total factor productivity. Fourth, the effect of the digital economy on green total factor productivity in forestry is heterogeneous in the east, central, and west and is more pronounced in regions with faster economic development or rich natural resources. Fifth, the impact of the digital economy on forestry green total factor productivity has a significant positive spatial spillover effect.

Keywords: digital economy; green total factor productivity in forestry; green innovation; spatial spillover effects

Citation: Chen, H.; Ma, Z.; Xiao, H.; Li, J.; Chen, W. The Impact of Digital Economy Empowerment on Green Total Factor Productivity in Forestry. *Forests* **2023**, *14*, 1729. https://doi.org/10.3390/f14091729

Academic Editor: Carolyn E. Smyth

Received: 2 August 2023
Revised: 20 August 2023
Accepted: 24 August 2023
Published: 27 August 2023

1. Introduction

Forestry is an important industry for national economic development and plays a significant role in achieving a carbon peak and carbon neutrality at the current stage. As an ecosystem that carries both ecological and economic benefits, forestry has become China's largest green economy [1–3]. Against the backdrop of the increasing severity of the problems facing the global climate, research on environmental issues by countries around the world has also rapidly increased. The development of forestry may enhance environmental welfare while catalyzing economic advancement, thus receiving more and more attention [4]. However, traditional forestry has distinct characteristics of extensive development [5], leading to issues such as resource waste and environmental pollution, while people pursue the growth of forestry production value. Under extensive development, the ecological benefits of forestry have not been realized [6]. As global environmental problems become more severe, countries seek economic development while placing more emphasis on environmental protection, and the development of all industries is shifting towards more intensive and sustainable development pathways. In particular, forestry, as an important component of maintaining ecological balance and economic growth, needs to shift towards a greener and more sustainable direction to better exert its multifaceted effects. Meanwhile, China places tremendous emphasis on pursuing high-quality, green development and ecological transition within the forestry sector. The Forestry and Grass Industry Development Plan (2021–2025) proposes to be good at discovering and resolving outstanding issues in resource utilization, innovation capacity, and environmental protection during the development of forestry. This requires improving resource utilization efficiency and vigorously researching, developing, and promoting green forestry production technologies. Forestry green total factor productivity (GTFP), which considers environmental protection factors and incorporates indicators related to green development and sustainability on the basis of measuring productivity with traditional factors of production, can comprehensively measure the utilization rate and development efficiency of forestry resources. It can also reflect the role of technological innovation in forestry production [7,8]. Earlier research on forestry total factor productivity focused mainly on specific sectors within forestry, such as Helvoigt and Adams, who used stochastic frontier analysis to estimate technological efficiency and productivity in the Pacific Northwest sawmill industry in the United States from 1968 to 2002 [9]; Hseu and Shang, who calculated Malmquist productivity indices for the pulp and paper industry in OECD (Organization for Economic Cooperation and Development) countries from 1991 to 2000 using a nonparametric frontier method [10]. Subsequently, some scholars expanded the research scope to the entire forestry industry, with DEA (data envelopment analysis) models and derived models gradually becoming the main methods for measuring forestry production efficiency [11,12]. With the increasing emphasis on ecological environments by countries, forestry GTFP has gradually become an important indicator for measuring the level of green transformation and environmental protection in forestry and has been widely applied in related research [8,13]. Conducting relevant research on forestry GTFP in Chinese cities can provide a theoretical basis for the green transformation and high-quality development of China's forestry industry and also serve as a reference for the green development of forestry in countries around the world.

However, there is still room for improvement in the current forestry GTFP level in China. On this basis, exploring the driving factors and influence mechanisms for improving forestry GTFP has become a research hotspot. The development of the digital economy is considered one of the important paths for improving forestry GTFP, mainly by bringing fundamental changes to forestry development through the evolution of production technologies and governance models. Specifically, the digital economy, as a new economic form in the information age, is data-centric, based on network information technology, mediated by modern network information platforms, and constantly improves the digitalization and networking capabilities of the real economy by integrating with it, further enhancing the capacity for transformation and upgrading of traditional industries [14]. Since China officially accessed the international Internet in 1994, its digital economy has rapidly improved, with the scale and indigenous innovation capabilities of the digital economy achieving leapfrog development. According to the China Data Factor Market Development Report (2021–2022), the scale of China's data factor market reached 81.5 billion CNY in 2021. The influence of the digital economy has covered all aspects over time, playing a huge role in the reform of the social governance system, the development of clean energy, and industrial integration [15–17].

As the scale of the digital economy continues to expand and the degree of integration with the real economy deepens, more and more scholars pay attention to the mechanism of action between the digital economy and production efficiency and study the specific relationship between them. Qiu and Zhou confirm that the development of the digital economy can improve regional total factor productivity based on a quasiexperiment in the National Big Data Pilot Zone [18]. Pan et al. argue that there are two main reasons for the digital economy to improve total factor productivity [19]. Zhang further confirms that the digital economy can promote total factor productivity through spatial spillover effects [20]. Yang and Jiang further explore the spatial spillover effects between the two [21]. With the increasing emphasis on environmental issues, many scholarly studies on productivity have focused more on the green productivity aspect by considering environmental protection and pollution control in various fields. Fan and Yin were the first to confirm that digital financial development enhances green total factor productivity by promoting entrepreneurial activity and technological innovation [22]. Zhou et al. expanded their study from digital finance to the overall effect of the digital economy on green productivity [23]. Liu et al. argued that the digital economy can increase China's GTFP in the dynamic long term by promoting industrial structural transformation, but there are large differences among regions, and the higher the level of GTFP, the more the digital economy promotes GTFP [24]. Zhao et al. on the other hand, in terms of the transmission mechanism of the digital economy on GTFP, further found that the digital economy also promotes the growth of urban GTFP by upgrading the production technology of enterprises and eliminating polluting enterprises from the market [25]. However, most of these studies assume that the impact of the digital economy on GTFP is linear. Considering the existence of more forms of this impact, Lyu et al. analyzed the specific forms of the impact of the digital economy on GTFP based on previous studies and proved that there is a nonlinear U-shaped relationship between the two [26]. Although there has been a wealth of research on the impact of the digital economy on GTFP, the current research on the impact of the digital economy on GTFP mainly focuses on the GTFP of various industries as a whole or focuses on the secondary industry and other aspects of GTFP, and most of the studies dedicated to studying the relationship between the digital economy and agriculture take agriculture as a whole and explore the impact of the digital economy [27,28], and few studies on the impact of the digital economy on forestry GTFP relationship. In addition, the measurement of the level of the digital economy in the relevant studies is relatively uniform and does not fully reflect the level of development of the digital economy. At the same time, the development of the digital economy is affected by Metcalfe's Law and Mack's Law, so its impact on the real economy may be nonlinear, which needs to be given more attention in existing research.

Therefore, based on the above research, this paper explored the specific relationship between the digital economy and forestry green total factor productivity (GTFP); how the digital economy affects forestry GTFP; and whether the influence has spatial heterogeneity and spillover effects. Regarding the above issues, this paper took the panel data of 277 prefecture-level cities in China from 2013 to 2019 as samples, and used the super-efficiency SBM (slack based measure) model to measure forestry GTFP. On this basis, the fixed-effects model and the intermediate-effects model were used to investigate the relationship between the digital economy and forestry GTFP, the action mechanism of the digital economy, the time trend of influence and spatial heterogeneity, and the spatial Durbin model was used to investigate whether the impact of the digital economy on forestry GTFP has a spatial spillover effect.

2. Research Hypothesis

2.1. Digital Economy and Green Total Factor Productivity in Forestry

The digital economy is a new type of economic development driven by data resources as the key production factor, digital technology innovation as the core power and modern information networks, and digital infrastructure and other digital platforms as important carriers [29]. The digital economy has basic characteristics such as high marginal returns, decreasing marginal cost, and externalities. It can provide intelligent, networked, and digitalized technological support for green forestry production, thereby improving the scientization and automation of forestry production, transforming forestry production methods from traditional extensive operations to modernization, and upgrading forestry GTFP through industrial restructuring [3], enhancing the overall production efficiency of forestry. In addition, as a new form of green economy, the integration of the digital economy with the real economy can effectively promote efficient matching of supply and demand, enhancing the speed and accuracy of information exchange [30]. This enables forestry to better grasp market demand, expand marketing channels for forestry products, and achieve diversified marketing. Moreover, the digital economy can also strengthen the fluidity of forestry information through data integration, forming a green development model of the forestry industrial chain [31], and optimizing the operational efficiency of the industrial chain.

Although the digital economy can promote the development of the real economy to some extent, it also generates certain negative impacts. Despite effectively improving production efficiency, the development of the digital economy also consumes a large amount of energy, causing pollutant emissions. The production, construction, maintenance, and upgrading of the equipment required as well as the technologies consume more resources and emit more carbon dioxide and solid waste. When applied to forestry, this can lead to decreased prices of traditional forest products, increased waste emissions, and impediments to improving green forestry productivity. Although the digital economy has extensive applications and can improve the development quality of the real economy, deep integration with the real economy is a prerequisite [32]. The development level of industries also needs to match the development level of the digital economy. Forestry has characteristics such as long production cycles, naturalness, and high risks in operations [33]. Failure to adjust development models in a timely manner means the role of the digital economy in promoting green forestry production cannot be fully realized. Excessive investment in the digital economy while the forestry industry cannot accommodate and utilize the dividends of the digital economy will result in massive energy consumption and resource waste due to digital economy investments, thus reducing green production efficiency in forestry. China is currently in a stage of high-speed digital economic growth with huge investments, so the impact on forestry GTFP may exhibit two stages: (1) As a traditional industry, forestry improves production efficiency and upgrades industrial structure through integration with the digital economy, increasing GTFP rates. (2) Later on, forestry's own characteristics may make it unable to adapt to the rapid development of the digital economy. Providing resources for the development of the digital economy in traditional ways leads to excessive concentration of resources and a crowding effect. This reduces the integration between the digital economy and forestry, eventually unfavourably impacting forestry GTFP.

2.2. Digital Economy and Green Innovation

Green innovation is an important way to achieve sustainable development of the economy, resources and the environment, to promote optimal changes in the production chain and to promote efficient use of resources [34]. The digital economy has brought about a change in information technology, which has also become a key factor in technological innovation. The digital economy has made information sharing and knowledge acquisition among innovation subjects easier and more convenient, effectively facilitating access to information and creating conditions for improving innovation capabilities. Meanwhile, the digital economy improves the efficiency of resource allocation and use, reduces the emission of pollutants and waste of resources, enhances production efficiency, and at the same time strengthens people's ability to protect the environment, which also has a significant impact on improving the level of green innovation and is conducive to the realization of high-quality development driven by green innovation [35]. However, the digital economy may have a negative impact on green innovation in the early stages, because at the beginning of the development of the digital economy, innovation subjects did not have enough knowledge of the emerging elements of the digital economy to fully play a role of the digital economy in promoting green innovation. At the same time, due to the traditional model of infrastructure, equipment production, and human resource training required at the early stage of digital economy development, it may lead to insufficient attention and investment in human resources at the early stage of green innovation development, thus hindering the improvement of the level of green innovation.

2.3. Digital Economy, Green Technology Innovation and Green Total Factor Productivity in Forestry

In addition to the direct impact of the digital economy itself on forestry GTFP, it may also indirectly affect forestry GTFP by promoting green technology innovation. By enabling digitalized applications and management, the digital economy breaks down barriers to information flow. This can improve traditional market environments, allowing producers to quickly and accurately capture differentiated demand information for green products in the market [36]. This enhances producers' competitiveness regarding green innovative products. Moreover, the digital economy aims to reduce costs in human resources, capital, etc. This enables more funds to be invested in the R&D and promotion of green innovation technologies, improving production efficiency and green innovation levels [37]. The improvement in green innovation levels can facilitate the development and application of green and ecofriendly technologies, lower barriers to green technologies, and promote technology diffusion, thereby increasing forestry green total factor productivity. Hence, the digital economy affects forestry green total factor productivity through green innovation by introducing green innovative technologies, transforming urban forestry industries from traditional extensive production management models to green, low-carbon and clean energy approaches [38]. It also enables dynamic adjustment of production factors in industries to improve forestry green total factor productivity. Meanwhile, the application of green innovation technologies enables information sharing and collaboration between innovation entities, providing an intrinsic impetus for the growth of forestry GTFP [3], and providing theoretical support for reducing undesirable outputs in forestry.

2.4. Spatial Spillovers of the Digital Economy and Green Total Factor Productivity in Forestry

As the digital economy lowers thresholds for acquiring and exchanging information and weakens restrictions on factor mobility and commodity exchange imposed by spatial distance and other elements, it promotes industrial agglomeration in the real economy. In addition to expanding physical spaces, it also facilitates industrial networking and informatization [39]. The digital economy can enhance information connections between upstream and downstream industries, improving the integrity and networking of industrial chains. Capabilities for knowledge and technology sharing are also significantly enhanced, generating greater economies of scale. Technological spillovers also facilitate industrial interactions and collaborations between regional industries, enabling more advanced management experiences and convenient resource allocation [39]. Meanwhile, open information sharing is more conducive to encouraging industries to replicate the successful experiences of surrounding leading industries. When dealing with competitive pressures in the market environment, this can enhance the competitiveness of their own products and services, which is beneficial for improving overall forestry GTFP in the region [40].

Based on all the above analysis, the following hypotheses were proposed:

Hypothesis 1 (H1). *The impact of digital economy development on green total factor productivity in forestry has an inverted U-shaped nonlinear relationship of promotion followed by inhibition.*

Hypothesis 2 (H2). *The digital economy's effect on green innovation demonstrates a nonlinear trend of initial suppression followed by later facilitation.*

Hypothesis 3 (H3). *The development of the digital economy affects forestry green total factor productivity through green innovation levels.*

Hypothesis 4 (H4). *The development of the digital economy has a spillover effect on green total factor productivity in forestry.*

3. Research Design and Data Sources

In terms of research design, this paper uses a basic fixed-effects regression model to explore the impact of the digital economy on forestry GTFP and its specific form to test Hypothesis 1. Introducing the level of green innovation, a mediated-effects model is used to explore the impact of the digital economy on the level of green innovation in the region, and whether the digital economy affects regional forestry GTFP through the level of green innovation, to test Hypotheses 2 and 3. Finally, a mediated-effects model is used to investigate the impact of the digital economy on the level of green innovation in the region, and the spatial Durbin model is introduced to investigate whether the impact of the digital economy on forestry GTFP has spatial spillover effects, to test Hypothesis 4.

3.1. Econometric Model

3.1.1. Basic Model

This paper first established a general panel benchmark regression model to analyze the impact of the development of the digital economy on green total factor productivity in forestry and to test Hypothesis 1:

$$GTFP_{it} = \beta_0 + \beta_1 TDE_{it} + \beta_2 STDE_{it} + \beta_j Control_{it} + \mu_i + \varphi_t + \varepsilon_{it} \quad (1)$$

where $GTFP_{it}$ is the forest green total factor productivity of province i in year t; TDE_{it} is the core explanatory variable representing the level of digital economy development of city i in year t; $STDE_{it}$ is the squared term of the level of digital economy development, which is used to explore the nonlinear relationship between the digital economy and forest green total factor productivity; $Control_{it}$ represents the control variables that affect the urban forest GTFP of city i in year t; μ_i is the individual city fixed effect; φ_t is the year fixed effect; and ε_{it} is the random error term.

3.1.2. Intermediary Effect Model

According to the analytical hypothesis, the development of the digital economy can have an impact on forestry GTFP by enhancing regional green innovation capacity. Based on the mediating effect model of Wen and Ye [41], this paper tested the mediating effect through a stepwise regression method as follows:

$$GRE_{it} = \beta_0 + \beta_1 TDE_{it} + \beta_2 STDE_{it} + \beta_j Control_{it} + \mu_i + \varphi_t + \varepsilon_{it} \quad (2)$$

$$GTFP_{it} = \beta_0 + \beta_1 TDE_{it} + \beta_2 STDE_{it} + \beta_3 GRE_{it} + \beta_j Control_{it} + \mu_i + \varphi_t + \varepsilon_{it} \quad (3)$$

First, a regression was conducted based on the effect of the digital economy (TDE_{it} and $STDE_{it}$) on forestry green total factor productivity $GTFP_{it}$ (Equation (1)). Then, green innovation level GRE_{it} was taken as the explanatory variable, digital economy TDE_{it} and its square term $STDE_{it}$ as the core explanatory variable for the regression (Equation (2)). The significance of the digital economy and its squared term, as well as the sign of the coefficients in this step, are used to determine the role of the digital economy in green innovation and to test Hypothesis 2. Finally, digital economy TDE_{it}, its square term $STDE_{it}$ and green innovation level GRE_{it} were simultaneously taken as explained variables, forestry green total factor productivity $GTFP_{it}$ was again regressed as an explained variable (Equation (3)). Whether the coefficient is significant, the mediating effect of the digital economy on the forestry GTFP through the effect on the green innovation level is investigated and used to test Hypothesis 3.

3.1.3. Spatial Econometric Model

Green production in forestry is significantly correlated with space, and according to economic geography studies, it is known that factors and product technologies, etc., are mobile between neighboring regions. Therefore, in order to study the spatial spillover effect of the digital economy on forestry green total factor productivity and to test Hypothesis 4, this paper introduced control variables into the model and extended it to a spatial panel econometric model, as shown in Equation (4).

$$\begin{cases} GTFP_{it} = \delta W_{ij} TDE_{it} + \beta X_{it} + \theta_1 \sum_{j=1}^{N} W_{ij} X_{it} + \sigma_i + u_t + \varepsilon_{it} \\ \varepsilon_{it} = \lambda \sum_{j=1}^{N} W_{ij} \varepsilon_{it} + \zeta_{it} \end{cases} \tag{4}$$

where W_{ij} is the spatial weight matrix, considering that the agglomeration dynamics of the forestry industry are closely related to the regional distribution [42], the main spatial matrix used in this paper is the geographical adjacency matrix of each prefecture-level city, δ and λ are the spatial autoregressive coefficients and spatial correlation coefficients, respectively; X_{it} is the explanatory variable for city i in year t, including the primary and squared terms of the digital economy and a series of control variables. ε_{it} is the spatial error autocorrelation term and ζ_{it} is the random disturbance term.

3.2. Variable Selection

3.2.1. Explained Variable

Forestry green total factor productivity (*GTFP*) is the explanatory variable in this paper. Most scholars involved in the current measurement of forestry GTFP used the data envelopment analysis DEA model and its various derivative models to select appropriate forestry input and output variables to measure forestry GTFP. Referring to the studies of Wu, Zhang [8], and Lv et al. [13], the specific measurement indicators are shown in Table 1.

Table 1. Description of indicators for measuring GTFP in forestry.

Indicator Type	Indicator	Definition
Forestry inputs	Labor input	Number of employees in the forestry system at the end of the year (people)
	Land input	Forest area (millionha)
	Capital input	Completed investment in forestry-fixed assets (RMB million)
	Energy input	Total regional energy consumption × gross regional forestry product/gross regional product (million tons of standard coal)
Forestry desired outputs	Economic output	Forestry industry GDP (billion CYN)
	Ecological output	Area afforested in the year (thousands of ha)
Forestry undesired outputs	Forestry wastewater emissions	Regional industrial COD emissions × regional forestry output/regional gross industrial product (million tons)
	Forestry waste gas emissions	Regional industrial SO_2 emissions × regional forestry output/regional industrial GDP (million tons)
	Forestry solid waste generation	Regional industrial solid waste generation × regional forestry output value/regional gross industrial product (million tons)

Notes: COD, the chemical oxygen demand, refers to the oxidation dose consumed when a certain strong oxidizer is used to treat water samples. COD is an indicator of the amount of reducing substances (especially organic matter) in water, which reflects the degree of organic matter pollution to a certain extent. The higher the COD, the more serious the pollution.

After comparing the previous GTFP measurement methods, this paper constructed a super SBM model for measuring GTFP in forestry, which has two advantages over the traditional DEA model [43]. On the one hand, the input-output slack variables are introduced into the objective function to maximize the improvement of efficiency values;

on the other hand, the efficiency differences between decision-making units (DMUs) can be effectively distinguished. For the wth DMU, the efficiency is specified as:

$$\rho = \min \frac{1+\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^x}{x_{iw}}}{1-\frac{1}{s_1+s_2}\left(\sum_{k=1}^{s_1}\frac{s_k^y}{y_{kw}}+\sum_{l=1}^{s_2}\frac{s_l^z}{z_{lw}}\right)}$$
$$s.t.\begin{cases} x_{iw} \geq \sum\limits_{j=1,j\neq w}^{n} \lambda_j x_j - s_i^x, \forall i; \\ y_{kw} \leq \sum\limits_{j=1,j\neq w}^{n} \lambda_j y_j + s_k^y, \forall k; \\ z_{lw} \geq \sum\limits_{j=1,j\neq w}^{n} \lambda_j z_j - s_l^z, \forall l; \\ s_i^x \geq 0, s_k^y \geq 0, s_i^z \geq 0, \lambda_j \geq 0, \forall i,j,k,l \end{cases} \quad (5)$$

where x, y, and z represent forestry inputs, desired forestry outputs, and undesired outputs, respectively; s^x, s^y, and s^z are the corresponding slack variables; m, s_1, and s_2 represent the number of variables for forestry inputs, desired outputs, and undesired outputs, respectively; λ represents the weight vector; and ρ represents the efficiency value of the super SBM. The three conditional constraint equivalents represent adjustments to the actual input, desired output, and undesired output of the forestry efficiency level, respectively. When all slack variables are equal to 0, the decision unit is effective. According to the constraint conditions, the more output there is and the less input and undesirable output there are, the closer the slack variables are to 0, and the core efficient to the DMU.

3.2.2. Core Explanatory Variables

The digital economy (*TDE*) and its square term (*STDE*) are the core explanatory variables in this paper. There is no consistent approach to measuring the level of digital economy development at the city level. Given the availability of data and drawing on the ideas of Zhao et al. [44] and Huang and Zhu [45], this paper measured the digital economy in terms of Internet development. Specifically, it used the number of Internet broadband access users per 100 people, the ratio of computer software and software industry employees to urban unit employees, the total telecommunication services per capita, and the number of mobile phone users per 100 people and standardized these four indicators and weighted them by the entropy method to obtain a comprehensive index of digital economy development. Among them, the Internet development indicators are mainly obtained from the China City Statistical Yearbook.

3.2.3. Mediating Variable

The level of green innovation (*GRE*) is the mediating variable in this paper. In this paper, we referred to Dong and Wang [46] and used the number of green patent applications (10,000) to measure green innovation. The indicator of the number of green patent applications includes three types of green patents as a whole, green invention-based patents and green utility model patents [47]. In 2010, the World Intellectual Property Organization (WIPO) developed a set of green patent lists and international classification codes based on the environmentally sound technologies listed in the United Nations Framework Convention on Climate Change (UNFCCC). In this paper, the State Intellectual Property Office database was searched for these codes, and the number of green patent applications in each city was compiled and summarized.

3.2.4. Control Variables

In order to avoid other possible factors influencing green total factor productivity in forestry, the following control variables were selected in this paper with reference to studies such as Wu and Zhang, Wang et al., Zheng et al., and Gao et al. [8,48–50]. The size of the forestry industry (*IS*) is expressed as the ratio of provincial gross forestry product to GDP at the end of the year, which reflects the development of the forestry industry; the technological progress of local enterprises (*TEC*) is expressed as the ratio of expenditure on science and technology to GDP, and Gao et al. argued that technological progress is conducive to increasing productivity [50]. The education importance level (*EDU*), expressed as the ratio of education expenditure to regional GDP, can reflect the importance of education and the educational level of the labor in a region to some extent. The environmental pollution index (*POLL*) was calculated using industrial wastewater emissions, industrial sulfur dioxide emissions, and industrial smoke (dust) emissions in each city, following the practice of Dong and Wang [46], to reflect environmental degradation; the income level of residents (*IN*) was expressed as the average monthly income of regional residents and logarithmically to measure regional economic development and residents' living standards. Wang et al. argued that the level of regional economic development can represent a region's ability to pursue green innovation and productivity growth [51].

Based on the above research design, the framework diagram of this paper (Figure 1) was proposed.

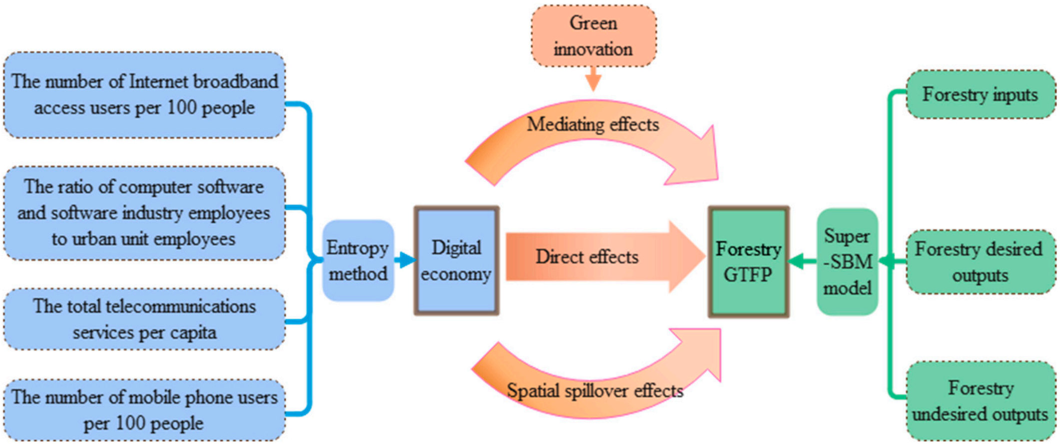

Figure 1. Framework diagram.

3.3. Data Sources

The 277 prefecture-level cities from 2013 to 2019 were selected for the study. The study did not cover Hong Kong, Macau, and Taiwan, as well as areas with more serious data deficiencies, such as Lhasa, in the Tibet Autonomous Region. Indicator data were obtained from the China City Statistical Yearbook and the statistical yearbooks and bulletins of cities at the prefecture level and above. Some of the missing values were filled by regression, linear interpolation, and approximate annual means. To overcome the influence of outliers, this paper applied tailing to continuous variables at the 1% and 99% quantile levels or above, and the descriptive statistics of the main variables are shown in Table 2.

Table 2. Descriptive statistics of the main variables.

Variable Type	Variable	Mean	Standard Deviation	Min	Max
Dependent variable	*GTFP*	0.549	0.312	0.095	1.428
Core independent variable	*TDE*	0.123	0.086	0.041	0.563
	STDE	0.022	0.043	0.002	0.317
Mediating variable	*GRE*	0.089	0.198	0.001	1.271
Control variables	*IS*	0.096	0.058	0.015	0.296
	TEC	0.003	0.002	0.001	0.014
	EDU	0.034	0.015	0.013	0.089
	POLL	0.08	0.074	0.002	0.435
	IN	10.294	0.257	9.781	11.004

4. Empirical Results

Sections 4.1 and 4.3–4.5 of this part focus on the empirical study of the impact of the digital economy on forestry GTFP to test Hypothesis 1. The details include four parts: the form of the impact, the time trend of the impact, the robustness test of the empirical evidence, and the analysis of the heterogeneity of the impact. Section 4.2 focuses on the relationship between the digital economy and the regional level of green innovation and whether the digital economy can have an impact on forestry GTFP through green innovation, using stepwise regression to test Hypotheses 2 and 3. Section 4.6 focuses on whether the impact of the digital economy on forestry GTFP has spatial spillover effects through empirical analysis, which is used to test Hypothesis 4.

4.1. Basic Model Analysis of the Impact of the Digital Economy on Forestry GTFP

Before running the model regressions, this paper conducted a Hausman test on the use of fixed or random effects for the model. The test indicated that a fixed effects model should be used, and the regression results of the digital economy on forestry GTFP estimated by the fixed effects model (FE) are listed in Table 3. Columns (1) and (2) of Table 3 show that both *TDE* and *STDE* are significant at least at the 5% level with or without the inclusion of control variables, with the *TDE* term being significantly positive and the *STDE* term being significantly negative, i.e., The impact of the digital economy on forestry GTFP shows a nonlinear inverted U-shaped relationship of promotion followed by inhibition, and it can be seen that the inflection point of the impact of the digital economy on forestry GTFP is at a level of digital economy development of approximately 0.343, and the results confirm H1. The reason for this may be that in the early stages, when the digital economy was in its infancy and developing rapidly, it was able to integrate quickly with forestry and gradually increase its level of integration, which had a positive impact on forestry GTFP, improving forestry productivity, resource use efficiency, speeding up the flow of information, and reducing pollutant emissions. At a later stage, due to its long production cycle and high degree of naturalness, forestry is not able to respond to the impact of the digital economy in a timely manner. If the digital economy develops beyond the optimal level of integration with forestry, a crowding effect will occur, and the rapid development of the digital economy will crowd out the resources needed for forestry development, at which point the inhibiting effect of the digital economy on forestry GTFP will begin to outweigh the promoting effect, resulting in a significant reduction in forestry GTFP.

Regarding the control variables, the coefficients for the level of technological progress (*TEC*) and the income level of the population (*IN*) are significantly positive, indicating that as the level of technological progress and the income level of the population increase, the GTFP of urban forestry increases accordingly. The possible reason for this is that an increase in the level of technological progress in cities leads to an increase in urban productivity and resource use efficiency, which in turn leads to an increase in forestry GTFP, while a higher level in income of the population represents a greater ability of the population to pursue green development and green technological progress, and their forestry GTFP is correspondingly higher, which is consistent with the results of Wu et al. and Yuan et al. [52,53]. The significant negative coefficients for the importance of education (EDU) and the pollution indices (POLL) can be explained by the long cycle time required for education to be invested in the development of human resources and then transferred to social production, while in the short term, an increase in the share of government investment in education will result in more resources being directed to education, leaving less resources for forestry development. In addition, the increase in wealth from higher levels of education will stimulate economic growth, ultimately increasing the demand for energy, which will be detrimental to the growth of forestry GTFP in the short term [54,55]. An increase in the pollution index leads to environmental degradation, which reduces environmental quality, forest land conservation, and forest product production, and reduces forestry GTFP. The size of the industry (IS) was not found to have a significant effect on forestry GTFP during the study period.

Table 3. Basic regression results.

Variable	(1)	(2)	(3)	(4)
	FE	FE	FE	FE
	GTFP	GTFP	GRE	GTFP
TDE	1.091 ***	1.169 ***	−0.403 ***	1.242 ***
	(3.40)	(3.71)	(−2.82)	(3.94)
STDE	−1.400 **	−1.704 ***	1.519 ***	−1.979 ***
	(−2.35)	(−2.90)	(5.71)	(−3.35)
IS		0.361	−0.723 ***	0.492 *
		(1.26)	(−5.54)	(1.70)
TEC		15.046 ***	18.855 ***	11.635 ***
		(4.25)	(11.75)	(3.17)
EDU		−1.514 *	−0.804 *	−1.369
		(−1.67)	(−1.96)	(−1.52)
POLL		−0.547 ***	0.053	−0.557 ***
		(−5.33)	(1.14)	(−5.43)
IN		0.391 ***	0.040	0.384 ***
		(4.95)	(1.12)	(4.87)
GRE				0.181 ***
				(3.34)
_cons	0.447 ***	−3.562 ***	−0.268	−3.513 ***
	(15.63)	(−4.43)	(−0.73)	(−4.38)
N	1939	1939	1939	1939
R2	0.761	0.773	0.885	0.774

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. (1) and (2) respectively represent the regression results of the benchmark model after control variables are not added and after control variables are added. (3) is the regression result of digital economy on green innovation level; (4) is the model result after adding intermediary variable green innovation level; (2)–(4) constitutes stepwise regression method.

4.2. Modeling the Intermediary Effects of Adding Green Innovation

The mediation effects model was chosen to test the mechanism of the impact of the digital economy on forestry GTFP, and the results are shown in columns (3) and (4) of Table 3. Column (3) shows that the coefficient of the *TDE* term of the digital economy is negative and the coefficient of the *STDE* term is positive, i.e., there is a positive U-shaped nonlinear relationship between the digital economy and the level of regional green innovation. This may be due to the fact that the development of the digital economy in the early stage still requires the construction of infrastructure, the production of equipment, and the training of talents, which require a large amount of social resources to flow into the digital economy and limits the growth of the regional green innovation level. However, in the later stage, the development and investment of the digital economy will promote the application and transformation of technological innovation results and improve the level of green innovation, and H2 is verified. On this basis, this paper included green innovation in the model of the impact of the digital economy on forestry GTFP. The regression results are shown in column (4) of Table 3, where the coefficients of the digital economy and its quadratic term and the green innovation term (*GRE*) are all significant, and the impact of the digital economy on the forestry GTFP is still inverted U-shaped, proving the existence of the mediating effect of the level of green innovation. The inflection point of the impact of the digital economy on the level of green innovation is around the digital economy level of 0.129, which is smaller than the level at the inflection point of the impact of the digital economy on the forestry GTFP. This indicates that with the development of the digital economy, both the level of green innovation and forestry GTFP are positively correlated with the digital economy level within a certain interval of the digital economy development level, i.e., it proves that the digital economy promotes the level of green innovation in the region by stimulating H3.

4.3. Robustness Test of the Basic Model

4.3.1. Instrumental Variable Method

While this study draws on previous research to identify key determinants of forestry GTFP, unobserved variables may still bias the estimates and lead to endogeneity concerns. To address endogeneity concerns and ensure robust estimates, this paper implements an instrumental variable approach.

Following Zhu and Ma [56], this paper designated the historical number of fixed telephone lines (FTEL) as an instrumental variable for the digital economy based on relevance and exclusivity criteria. The digital economy closely relates to the diffusion of modern communication technologies, which trace back to traditional infrastructures [43,55]. Thus, regions with more developed traditional communications tend to have more advanced digital economies, meeting the relevance requirement. Meanwhile, the impact of historical fixed lines on current forestry GTFP diminishes over time as usage decreases [43], satisfying exclusivity. Specifically, national internet users from 2012 to 2018 interacted with 1984 regional fixed lines per 10,000 people to instrument the digital economy, controlling for individual and time-fixed effects. Regressions in Table 4, column 1, demonstrate an inverted U-shaped relationship between the digital economy and forestry GTFP, underscoring the robustness of previous results.

Table 4. Robustness test results.

Variable	(1)	(2)
	GTFP	GTFP
TDE	15.382 *	1.114 ***
	(8.505)	(0.322)
STDE	−41.9148 **	−1.426 **
	(20.739)	(0.614)
Control variables	Yes	Yes
_cons	0.614	−3.595 ***
	(2.6)	(0.803)
N	1939	1911
R2		0.774

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. (1) and (2) represent robustness test results using instrumental variables and excluding municipalities, respectively.

4.3.2. Excluding Municipalities

Considering that the municipalities directly under the central government have a huge economic volume and population size beyond that of ordinary prefecture-level cities, the four municipalities in the sample, Beijing, Tianjin, Shanghai, and Chongqing, were excluded from the paper, and the excluded sample was rerun in the regression. The results are shown in column (2) of Table 4, which are basically consistent with the results of the previous benchmark regression, demonstrating the robustness of the previous results.

4.4. Time Trend Analysis of the Impact of the Digital Economy on Forestry GTFP

Referring to Li and X.Z and Li and J.Y [57], this paper added the cross terms of TDE and year of digital economy development level to model (2) in Table 3 and performed a double fixed effects model estimation with 2013 as the base period to further investigate the dynamic characteristics of the impact of digital economy development on forestry GTFP. The estimation results are presented in Table 5. The coefficient of the level of development of the digital economy in 2013 is significantly positive, indicating that the digital economy had a positive effect on forestry GTFP at that time. Since 2014, the cross-term coefficient between the digital economy and the year has been significantly positive but shows a decreasing trend. The coefficient of the cross-term is not significant in 2016, but shows a significant positive correlation in 2017, and a significant tangential growth trend in 2018 and 2019, indicating that the current impact of China's digital economy on forestry GTFP is still in the positive impact stage and on the left side of the inflection point. The impact slowed down before 2016 and did not have a significant impact in 2016, probably due to the development of the digital economy focused on the construction of infrastructure and equipment and attaching importance to the accumulation of quantity before 2016, but the degree of integration with the real economy, such as forestry, hit a bottleneck in 2016, and the reason for the significant positive impact reappearing after 2016 is probably due to the government's transformation of the development of the digital economy increased importance, a series of events such as the G20 Hangzhou Summit in 2016, which put forward initiatives on the development and cooperation of the digital economy, and the inclusion of the digital economy in the government work report for the first time in 2017, have facilitated progress in the integration of the digital economy with the real economy, such as forestry. This is in line with the description of the development stage of the domestic digital economy in the 2017 China Digital Economy Development Report, and the development trend of China's digital economy in the study by Mao and Zhang [58].

Table 5. Time trend analysis of the impact of the digital economy on GTFP in forestry.

Variable	GTFP
DE	0.812 **
	(2.46)
STDE	−1.764 ***
	(−2.83)
TDE2014	0.521 ***
	(3.16)
TDE2015	0.395 **
	(2.43)
TDE2016	0.219
	(1.34)
TDE2017	0.300 *
	(1.82)
TDE2018	0.324 *
	(1.95)
TDE2019	0.521 ***
	(3.16)
cons	−3.848 ***
	(−4.77)
Control variables	Yes
_cons	−3.848 ***
	(−4.77)
N	1939
R2	0.774

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

4.5. Heterogeneity Test of the Impact of the Digital Economy on Forestry GTFP

As China's vast geography has led to differences in economic development, resource integration, and optimal allocation efficiency across China's regions [59], the impact of the digital economy on forestry GTFP may vary across regions. This paper examined the heterogeneity of the digital economy in GTFP from the perspective of geographic location.

4.5.1. By Geographical Location

As for the heterogeneity analysis of the impact of the digital economy on forestry GTFP, the regression was carried out on the cities of the three regions, respectively, from the perspective of the geographical division of eastern, central, and western China. The results are presented in columns (1) to (3) of Table 6. It can be seen that the impact of the digital economy on forestry GTFP is still significant in eastern and western China and shows an inverted U-shape. However, it is not significant in the central region. This may be because the western region has more resources, a lower population density than the eastern and central regions, and less environmental pressure. The digital economy can play a better role in the forestry GTFP. In the eastern region, although the population density is high, and the environment is under great pressure, but the level of science and technology is relatively high, the innovation ability is strong, the degree of opening up to the outside world is high, and the climate is humid, the forest area is large, the development level of the digital economy is high, and it can influence the forestry GTFP through technological progress. In the central region, due to the high population density, high environmental pressure, and smaller forest area than in the eastern and western regions, the forestry development cannot adapt to the level of development of the digital economy, and the digital economy cannot have a significant impact on the green production of forestry through technology or resources.

Table 6. Results of heterogeneity analysis.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	GTFP	GTFP	GTFP	GTFP	GTFP	GTFP	GTFP	GTFP
TDE	1.271 **	0.035	2.480 ***	0.886 ***	4.644 ***	2.725 ***	−0.821	2.046 ***
	(2.37)	(0.06)	(4.87)	(2.63)	(5.37)	(3.93)	(−1.10)	(3.44)
STDE	−1.978 **	0.779	−4.262 ***	−1.150 *	−8.941 ***	−5.560 ***	2.796	−2.807 ***
	(−2.33)	(0.58)	(−3.56)	(−1.87)	(−5.14)	(−2.84)	(1.35)	(−2.93)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
_cons	−5.239 ***	−3.115 **	−2.997 ***	−3.323 ***	−8.851 ***	−2.575 **	−1.231	−5.685 ***
	(−3.16)	(−2.38)	(−2.77)	(−3.87)	(−3.78)	(−2.47)	(−0.78)	(−3.48)
N	693	700	546	1771	168	531	598	762
R2	0.781	0.801	0.876	0.811	0.843	0.862	0.838	0.774

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. (1)–(3), (4)–(5) and (6)–(8) represent regression heterogeneity analysis results of samples from different regions according to geographical location, Hu Huanyong line and economic development level, respectively.

4.5.2. By the Hu Huanyong Line

To further explore regional heterogeneity, regressions were run for cities east and west of the 'Hu Huanyong line' in terms of the geographical, demographic divide. The results are shown in columns (4) and (5) of Table 6, where column (4) is for the more densely populated cities east of the 'Hu Huanyong line' and column (5) is for the less densely populated cities west of the 'Hu Huanyong line'. It can be seen that the impact of the digital economy on forestry GTFP is significantly inverted U-shaped on both the east and west sides, while the coefficient shows that the curve is flatter on the east side and that the inflection point of the impact of the digital economy on forestry GTFP is after the west side. This is probably because the east side is more densely populated, has a higher level of digital economy development, and is more capable of technological innovation, which can improve the efficiency of integrating the digital economy with forestry and better exploit the effect of the digital economy on forestry GTFP than the west side, which is less densely populated and has a lower level of economic development.

4.5.3. By Level of Economic Development

In addition to the above two types of heterogeneity analysis, this paper further considered the heterogeneous impact of the digital economy on forestry GTFP from the perspective of the level of economic development by dividing the cities into three regions based on their gross urban product (GDP) into low, medium, and high levels of economic development, and the results are shown in columns (6) to (8) of Table 6. It can be seen that the impact of the digital economy on forestry GTFP shows a significant inverted U-shape in the regions with a lower and higher level of economic development, while there is no significant impact in the regions with a medium level of economic development. The reason for this may be that the development of the digital economy is at an early stage in regions with a low level of economic development, and forestry production is also a more crude development model, while the development of the digital economy can be adapted more quickly to the development of forestry, driving regions with a low level of economic development to improve the total factor productivity of forestry through industrial upgrading and technological progress, while the more developed economic regions are more open to the outside world and the more developed regions have a higher degree of openness to the outside world and have more frequent access to excellent foreign technology. At the same time, these regions have a higher level of technological innovation and development of the digital economy, as well as more advanced forestry production and management models, which makes the more developed regions a good basis for achieving a high degree of integration of the digital economy with forestry and thus a significant impact. On the other hand, areas with a medium level of economic development may be in a stage of economic transition or a bottleneck in the integration of the digital economy with forestry, so that the impact of the digital economy on forestry GTFP is not significant. With the deep integration of the digital economy and forestry development, the impact of the level of digital economy on forestry GTFP will also gradually become significant.

4.5.4. Quantile Regression

In order to analyze the impact of the digital economy on forestry GTFP under different scenarios, this paper used a panel quantile regression model to examine the impact of the digital economy on forestry GTFP at different levels of forestry GTFP. In this paper, three quartiles of 0.25, 0.5, and 0.75 were selected for estimation, and the results are shown in Table 7. It can be seen that *TDE* and *STDE* are not significant at 0.5 quantiles, but are significant at 0.25 and 0.75 quantiles, indicating that the relationship between the digital economy and forestry GTFP can only be reflected when forestry GTFP is low or high. When forestry GTFP is low, the impact of the digital economy on forestry GTFP is positive and U-shaped. In other words, with the development of the digital economy, areas with a low level of forestry GTFP will gradually show an upward trend, while areas with a high level of forestry GTFP will gradually change from an upward trend to a downward trend. This may be due to the rapid development of the digital economy, which can gradually increase the degree of industrial integration with forestry and increase forestry GTFP in the early stages, while in the later stages, due to the rapid development of the digital economy and the relatively slow and long-cycle development of forestry, which is not easy to transform, the degree of integration will decrease after reaching the optimal level of integration, and the digital economy will gradually exert a suppressive effect on forestry GTFP.

Table 7. Results of panel quantile regression model.

Variables	(1)	(2)	(3)
	0.25	**0.50**	**0.75**
TDE	−1.156 **	0.674	−0.235 *
	(0.018)	(0.252)	(0.088)
STDE	1.922 **	0.611	−0.939 ***
	(0.044)	(0.663)	(0.000)
Control variables	Yes	Yes	Yes

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

4.6. Spatial Spillover Effect of the Impact of the Digital Economy on Forestry GTFP

4.6.1. Spatial Correlation Test

To test whether the digital economy and forestry GTFP are spatially correlated, given the highly territorial nature of forestry, this paper used Moran's I to test the spatial correlation of the variables based on the geographical adjacency matrix for each year. As can be seen from Table 8, the Moran's for both the digital economy and forestry GTFP from 2013 to 2019 are significantly non-zero, indicating that the digital economy and forestry GTFP have a significant spatial correlation. Meanwhile, in order to more intuitively observe the spatial distribution evolution characteristics of the digital economy and forestry green GTFP at the municipal scale, this paper used ArcGIS 10.5 software to visualize the data for 2013 and 2019, respectively, as shown in Figures 2 and 3.

Table 8. Global Moran's I test results.

Year	TDE		GTFP	
	I	*p*-Value	I	*p*-Value
2013	0.467	0.000	0.691	0.000
2014	0.461	0.000	0.790	0.000
2015	0.419	0.000	0.790	0.000
2016	0.395	0.000	0.728	0.000
2017	0.402	0.000	0.784	0.000
2018	0.347	0.000	0.809	0.000
2019	0.300	0.000	0.792	0.000

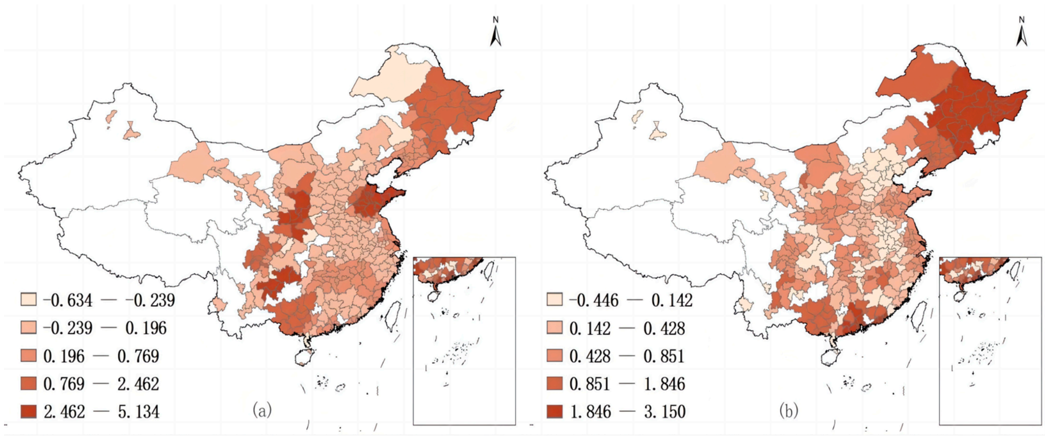

Figure 2. Spatial and temporal evolution of green total factor productivity in forestry in 277 cities in China in 2013 (**a**) and 2019 (**b**).

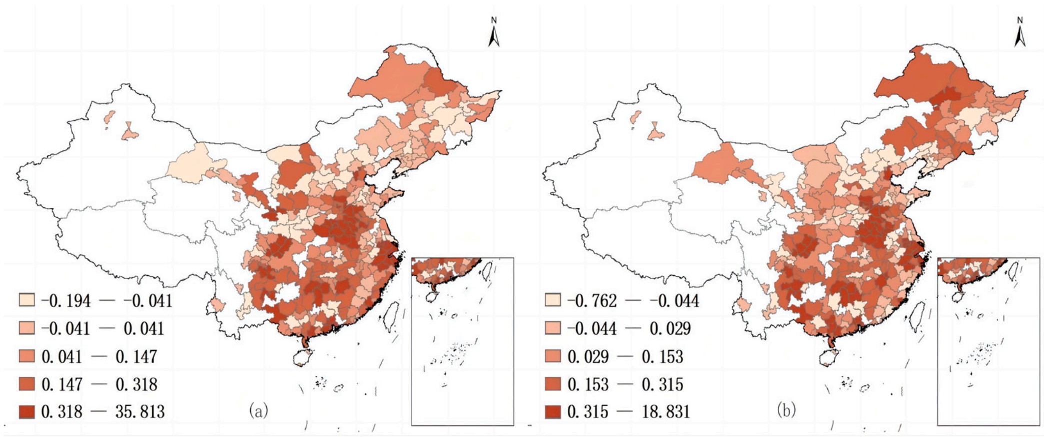

Figure 3. Spatial and temporal evolution patterns of digital economy levels in 277 Chinese cities in 2013 (**a**) and 2019 (**b**).

4.6.2. Regression Results of the Dynamic Spatial Durbin Model

In this paper, the data were first subjected to LM tests, Hausman tests, etc. to determine that a fixed effects spatial Durbin model should be used for regression, and the empirical results are presented in Table 9. From the direct effects, it can be seen that the direct effect of the digital economy on the region's forestry GTFP shows an inverted U-shaped relationship of promotion followed by inhibition. From the indirect effect in column (2), the coefficient of *TDE* is significantly positive, indicating that the spatial impact of the digital economy on forestry GTFP has a spatial spillover effect and can promote the growth of forestry GTFP in neighboring regions, i.e., the development of the digital economy in the region can share the fruits of the development of the digital economy through exchange and learning, industrial upgrading, and information circulation in the industrial chain [3], which has a catalytic effect on forestry GTFP in neighboring regions. The coefficient of *STDE* is negative but does not pass the significance test, indicating that the development of the digital economy in the region has a suppressive but insignificant effect on forestry GTFP in neighboring regions. This verifies Hypothesis 4, demonstrating that the impact of the digital economy on forestry GTFP has spatial spillovers.

Table 9. Results of the dynamic spatial Durbin model.

	(1)	(2)	(3)
	Direct Effect	**Indirect Effect**	**Total Effect**
TDE	0.599 ***	2.920 *	3.518 *
	(2.78)	(1.74)	(1.92)
STDE	−1.108 **	−1.207	−2.315
	(−2.54)	(−0.33)	(−0.57)
IS	−0.741 **	0.324	−0.416
	(−2.56)	(0.30)	(−0.40)
TEC	5.579 **	35.789 **	41.368 **
	(2.49)	(2.06)	(2.20)
EDU	−1.056 *	−8.060 *	−9.116 *
	(−1.83)	(−1.83)	(−1.91)
POLL	−0.283 ***	−1.909 ***	−2.192 ***
	(−4.48)	(−4.61)	(−4.79)
IN	0.373 ***	0.259 **	0.632 ***
	(10.42)	(2.29)	(5.50)
Spatial rho	0.850 ***		
	(72.45)		
sigma2_e	0.005 ***		
	(29.79)		
N	1939	1939	1939
R2	0.510	0.510	0.510

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

This concludes the empirical part of the paper and summarizes the results of this section: the first part of this section, i.e., the results of the basic model in Section 4.1, proves that the digital economy has a significant impact on forestry GTFP, and the impact is an inverted U-shape of promoting and then inhibiting, which proves Hypothesis 1. The results of Section 4.2 prove that the impact of the digital economy on the level of green innovation in the region shows a positive U-shape of inhibiting and then promoting, and it can affect forestry GTFP through green innovation. innovation on forestry GTFP, proving hypotheses 2 and 3. Section 4.3 is the robustness test of the results in Section 4.1, proving that the results of the basic model regression are robust. Section 4.4 The results of the time trend analysis show that China is on the left-hand side of the inverted U-shape of the impact of the digital economy on forestry GTFP, i.e., the higher the current level of the digital economy is, the more favorable it is to the improvement of forestry GTFP. Section 4.5 is a heterogeneity test of the impact of the digital economy on forestry GTFP, and the results show that the impact of the digital economy on forestry GTFP is more significant in more economically developed, innovative, and resource-rich regions. Sections 4.4 and 4.5 expand the study of the impact of the digital economy on forestry GTFP horizontally and vertically, respectively. Section 4.6 shows that the impact of the digital economy on the forestry GTFP currently has a positive spatial spillover effect.

5. Discussion and Conclusions

5.1. Discussion

The data as well as the methodology used in this paper are innovative in this field of research, and the results obtained based on the empirical study in Section 4 differ from other studies in the same field. This paper will discuss the differences between this paper and other studies in this field and the reasons for them in terms of both innovations and results. Firstly, in terms of innovations, this paper has the following innovations compared to other studies in this field:

Firstly, while previous studies on the digital economy and green total factor productivity in China's forestry industry have only used provincial-level data for regression, this paper further used more micro-level municipal data to explore the relationship between the two more specifically.

Secondly, unlike previous studies on the impact of the digital economy on total factor productivity in forestry, this paper took into account environmental issues and sustainable development and examined the impact of the digital economy on green total factor productivity in forestry, which is more relevant in the context of the world's increasing attention to environmental issues.

Thirdly, the impact of the digital economy on total green factor productivity in forestry was considered potentially nonlinear, while a quadratic term for the level of the digital economy was included in both the baseline regression and the spatial Durbin model regression to discuss whether the impact of the digital economy on the region and spatial spillovers are nonlinear in nature.

In terms of results, the results of this paper have obvious differences compared with the results of articles with similar research fields, taking the study of Lyu et al. with more citations and the study of Chen et al. with similar research contents as examples, respectively, and the specific points of difference and the analyzed reasons for the differences are as follows:

The results of this paper and the results of Lyu et al.'s study on the relationship between the digital economy and green total factor productivity in China both suggest a non-linear relationship between the digital economy and green total factor productivity, but the relationship is inverted U-shaped in the results of this paper, while it is positive U-shaped in the results of Lyu et al.'s study. The possible reason is that Lyu et al.'s research scope includes the overall green total factor productivity of various industries in China, while forestry is specifically affected by its own characteristics. Traditional forestry has a long cycle and other characteristics that make forestry integrate with the digital economy faster in the early stages, and increase the development speed gap with the digital economy in the later stages. The impact of the digital economy on the green total factor productivity of forestry is inverted U-shaped.

Meanwhile, Chen et al. also studied the impact of the digital economy on forestry green total factor productivity and explored its spatial spillover effects [3]. Compared with Chen et al.'s research, the conclusion of this paper not only includes the positive promoting effect of the digital economy on forestry green TFP, but also the inhibiting effect of the digital economy on forestry green TFP after reaching the turning point, and the relationship between the two shows a U-shaped relationship. The reason may be that the data used are panel data from prefecture-level cities, and the secondary terms of the digital economy are included in the model. The capacity gap between prefecture-level cities and provinces is large. In provinces, the first, second and third industries of forestry can be accommodated simultaneously, but in prefecture-level cities with a higher level of digital economy development, the second, and third industries of forestry may dominate, and the ecological effects of forestry are not obvious. Therefore, it may reflect the inhibiting effect of the digital economy on regional forestry green total factor productivity.

5.2. Conclusions

Based on the panel data of 277 cities in China from 2013 to 2019, this paper measured the level of digital economy and forestry green total factor productivity (GTFP) in each region using the entropy value method and the SBM model, and explored the impact and mechanism of the digital economy (TDE) and its squared term (STDE) on forestry green total factor productivity (GTFP) using the panel fixed and mediated effect models and based on different regional classification methods. The spatial heterogeneity of the digital economy in the forestry GTFP was also analyzed based on different regional classification methods. Finally, the spatial spillover effect of the digital economy on forestry GTFP was examined in detail using the spatial Durbin model. The results are as follows:

Firstly, the digital economy has an inverted U-shaped relationship with forestry GTFP, and when the digital economy reaches a certain level, the effect on forestry GTFP changes from a facilitating effect to a suppressing effect, and the results pass all robustness tests. The time trend analysis shows that China is still on the left side of the inflection point of the inverted U-shaped relationship between the digital economy and forestry GTFP, i.e., the development of the digital economy can still significantly improve the level of forestry GTFP, and the degree of integration between the digital economy and forestry increased at approximately the year 2016 and accelerated from the bottleneck period. Additionally, the heterogeneity analysis shows that the impact of the digital economy on forestry GTFP is more significant in regions with faster economic development, a higher degree of openness to the outside world, richer natural resources, and less environmental pressure.

Secondly, the relationship between the digital economy and urban green innovation level also presents a nonlinear positive U-shaped relationship of first inhibition and then promotion. In the early stage, the digital economy will inhibit the improvement of green innovation level due to equipment construction, resource occupation, and other reasons, and in the later stage, due to the convenience of information acquisition and communication of innovation subjects brought by the digital economy, it will promote the improvement of regional green innovation level.

Thirdly, the digital economy can influence the urban forestry GTFP by influencing the level of urban green innovation. The improvement of the level of the digital economy can reduce the cost of regional information exchange and management and simplify the process of information acquisition and exchange, thus affecting the level of green innovation, and the improvement of the level of green innovation will reduce the emission of pollutants and improve the efficiency of forestry production and sales.

Fourthly, in terms of spatial effects, the impact of the digital economy on forestry GTFP has a significant spatial spillover effect and can significantly and positively influence forestry GTFP in neighboring regions.

5.3. Policy Recommendations

Based on the above research findings, this paper puts forward the following policy recommendations:

Firstly, insist on accelerating the development of the digital economy, do a good job in digital economy infrastructure, equipment manufacturing, and talent training, and improve the speed and quality of digital economy development. According to the level of digital economy measurement and time trend analysis, it is clear that the development of China's digital economy is still able to promote the progress of green total factor productivity in forestry, while there is also the problem of uneven regional development. Especially as China is currently in a critical period of accelerated integration and development of the digital economy and the real economy, more attention should be paid to improving the technological innovation capacity of the digital economy and expanding its coverage. By accelerating the construction of digital infrastructure required by the digital economy such as big data, artificial intelligence, and other aspects; strengthening loan support for digital-related industries, publicity and popularization of information equipment, etc., to improve the development level of the digital economy and expand the coverage of the digital economy in geographical space and various fields of production and life.

Secondly, we should pay attention to the transformation of traditional industries such as forestry and accelerate the integration of forestry and the digital economy. At present, China's digital economy is developing rapidly, while the traditional real economy such as forestry is vulnerable to various constraints, so the speed of integration with the digital economy cannot be coordinated with the development speed of the digital economy, resulting in a widening gap between the development level of the digital economy and the development level of the traditional real economy such as forestry. Therefore, the retardation of the development of the digital economy will inhibit the green total factor productivity of forestry. From the comparison of the regression results of the Eastern and Western "Hu Huanyong line", it can be seen that strengthening innovation ability, improving the coordination of forestry and digital economy development, and accelerating the process of forestry digitalization and networking through the digital economy. Specifically, digital production and processing of forest products can be implemented, knowledge related to forest product production can be popularized, communication between buyers and sellers can be increased through informatization, and the forest product sales market can be expanded, so as to better integrate the digital economy and forestry, so as to extend the positive impact range of the digital economy on forestry green total factor productivity, and better play the promoting role of the digital economy.

Thirdly, promote the coordinated development of the digital economy among regions. For the development of digital economy and the economic development level of more backward regions, policy support should be provided to promote the digital economy in the backward regions to better promote the development of forestry and other real economies; for the economic development level of the middle region, it should promote technological innovation, increase support for talent training and talent introduction, and progress industrial transformation and upgrading so that they can get through the bottleneck period of the digital economy and forestry integration as soon as possible. Economically developed regions should be encouraged to increase their degree of openness and external exchanges, promote innovation, and take the lead in the development of the digital economy and the integration of the digital economy with forestry.

Fourth, encourage regions with a low integration degree in the digital economy and forestry to actively learn from the experience of surrounding regions with a high development degree in the digital economy, and rationally use the resources of surrounding areas. On the one hand, promote the development of local digital economies, so that forestry production can use the traditional production resources or digital information resources of surrounding areas. On the other hand, it promotes the relocation of forest-related industries to high-level areas of the digital economy as far as possible to improve the level of industrial digitalization, and better play the spatial spillover effect of the digital economy on forestry green total factor productivity.

5.4. Shortcomings and Outlook

Although this study contributes to an improved understanding of the relationship between the digital economy and green total factor productivity in forestry, there are still some gaps that require further research.

Firstly, this study focuses only on the relationship between the digital economy and the level of green total factor productivity in forestry in 277 major urban areas in China. Our results may differ significantly from those of other regions in China.

Secondly, because the sample was selected from within China, we recommend caution in applying our findings to other regions, and further evidence is needed to determine whether the findings of this study can be applied to other regions, as economic development, forest resources, environmental conditions, and demographic and institutional characteristics may differ between regions. Therefore, our results should be interpreted with caution. More efforts should be made to study the change in forestry green total factor productivity and its temporal and spatial development trend among regions with different forestry development bases, main types of regional forestry, and social and economic characteristics.

In addition, the digital economy is a broad concept; directly or indirectly using data to guide resources to play a role in the economy belongs to its category. In order to fully grasp the impact of the digital economy on forestry green total factor productivity, it is worthwhile to further improve the measurement method of the development level of the digital economy in future studies, and to comprehensively consider the impact of various factors included in the digital economy on forestry green total factor productivity. We hope that future studies will start from this perspective.

Author Contributions: Conceptualization, Z.M.; methodology, Z.M., H.X. and H.C.; software, H.C. and J.L.; validation, H.C., Z.M. and H.X.; formal analysis, Z.M. and H.C.; investigation, Z.M., H.C., and W.C.; resources, W.C.; data curation, Z.M., H.C., H.X. and W.C.; writing—original draft preparation, W.C., H.C., Z.M. and H.X.; writing—review and editing, H.C., Z.M., H.X. and J.L.; visualization, H.C., Z.M., H.X. and J.L.; supervision, W.C.; project administration, W.C.; funding acquisition, W.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by "the Fundamental Research Funds for the Central Universities" No. 2023SKY01: Research on the supply capacity and efficiency of ecological service products in state-owned forest farms under the background of dual carbon strategy.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Song, Z.; Liu, H.; Strömberg, C.A.; Wang, H.; Strong, P.J.; Yang, X.; Wu, Y. Contribution of forests to the carbon sink via biologically-mediated silicate weathering: A case study of China. *Sci. Total Environ.* **2018**, *615*, 1–8. [CrossRef] [PubMed]
2. Dudek, D.J.; Leblanc, A. Offsetting new CO_2 emissions: A rational first greenhouse policy step. *Contemp. Econ. Policy* **1990**, *8*, 29–42. [CrossRef]
3. Chen, C.; Ye, F.; Xiao, H.; Xie, W.; Liu, B.; Wang, L. The digital economy, spatial spillovers and forestry green total factor productivity. *J. Clean. Prod.* **2023**, *405*, 136890. [CrossRef]
4. Xiao, H.; Ning, C.; Xie, F.; Kang, X.; Zhu, S. Influence of rural labor migration behavior on the transfer of forestland. *Nat. Resour. Model.* **2020**, *34*, e12293. [CrossRef]
5. Ning, Y.L.; Shen, W.H.; Song, C.; Zhao, R. Studying on the promotion strategies of high-quality development of forestry industry. *Issues. Agric. Econ.* (In Chinese). **2021**, *494*, 117–122. [CrossRef]
6. Lin, B.; Ge, J. Carbon sinks and output of China's forestry sector: An ecological economic development perspective. *Sci. Total Environ.* **2019**, *655*, 1169–1180. [CrossRef] [PubMed]
7. Ahmed, E.M. Green TFP Intensity Impact on Sustainable East Asian Productivity Growth. *Econ. Anal. Policy* **2012**, *42*, 67–78. [CrossRef]
8. Wu, L.; Zhang, Z.G. Impact and threshold effect of Internet technology upgrade on forestry green total factor productivity: Evidence from China. *J. Clean. Prod.* **2020**, *271*, 122657. [CrossRef]
9. Helvoigt, T.L.; Adams, D.M. A stochastic frontier analysis of technical progress, efficiency change and productivity growth in the Pacific Northwest sawmill industry. *For. Policy Econ.* **2009**, *11*, 280–287. [CrossRef]
10. Hseu, J.S.; Shang, J.K. Productivity changes of pulp and paper industry in OECD countries, 1991-2000: A non-parametric Malmquist approach. *For. Policy Econ.* **2005**, *7*, 411–422. [CrossRef]
11. Lai, Z.Q.; Zhang, Z.H. The super-efficiency DEA analysis of Guangdong forestry input-output. *J. South China Agric. Univ.* **2008**, *4*, 43–48. (In Chinese)
12. Zhong, S.; Wang, H.L. The effect of total factor productivity of forestry industry on CO2 emissions: A spatial econometric analysis of China. *Sci. Rep.* **2021**, *11*, 14200. [CrossRef]
13. Lv, J.H.; Sun, J.Y.; Cai, X.T. Spatial-Temporal Evolution of Green Total Factor Productivity of Forestry in China. *J. Agro-For. Econ. Manag.* (In Chinese). **2022**, *21*, 320–330. [CrossRef]
14. Goldfarb, A.; Tucker, C. Digital Economics. *J. Econ. Lit.* **2019**, *57*, 3–43. [CrossRef]
15. Niu, F.J. The Role of the Digital Economy in Rebuilding and Maintaining Social Governance Mechanisms. *Front. Public Health* **2022**, *9*, 819727. [CrossRef]
16. Chen, P.Y. Is the digital economy driving clean energy development?—New evidence from 276 cities in China. *J. Clean. Prod.* **2022**, *372*, 133783. [CrossRef]

17. Li, X.Y.; Liang, X.P.; Yu, T.; Ruan, S.J.; Fan, R. Research on the Integration of Cultural Tourism Industry Driven by Digital Economy in the Context of COVID-19-Based on the Data of 31 Chinese Provinces. *Front. Public Health* **2022**, *10*, 780476. [CrossRef]
18. Qiu, Z.X.; Zhou, Y.H. Productivity: An Analysis Based on National Big Data Comprehensive Pilot Zone. *J. Financ. Econ.* (In Chinese). **2021**, *47*, 4–17. [CrossRef]
19. Pan, W.R.; Xie, T.; Wang, Z.W.; Ma, L.S. Digital economy: An innovation driver for total factor productivity. *J. Bus. Res.* **2022**, *139*, 303–311. [CrossRef]
20. Zhang, Y. Digital economy, spillover effect and total factor productivity improvement. *Guizhou Soc. Sci.* (In Chinese). **2021**, *3*, 139–145. [CrossRef]
21. Yang, H.M.; Jiang, L. Digital Economy, Spatial Effects and Total Factor Productivity. *Stat. Res.* (In Chinese). **2021**, *38*, 3–15. [CrossRef]
22. Fan, X.; Yin, Q.S. Does Digital Finance Promote Green Total Factor Productivity? *J. Shanxi Univ. (Philos. Soc. Sci. Ed.)* (In Chinese). **2021**, *44*, 109–119. [CrossRef]
23. Zhou, X.H.; Liu, Y.Y.; Peng, L.Y. Development of Digital Economy and Improvement of Green Total Factor Productivity. *Shanghai J. Econ.* (In Chinese). **2021**, *399*, 51–63. [CrossRef]
24. Liu, Y.; Yang, Y.; Li, H.; Zhong, K. Digital Economy Development, Industrial Structure Upgrading and Green Total Factor Productivity: Empirical Evidence from China's Cities. *Int. J. Environ. Res. Public Health* **2022**, *19*, 2414. [CrossRef]
25. Zhao, C.; Liu, Z.; Yan, X. Does the Digital Economy Increase Green TFP in Cities? *Int. J. Environ. Res. Public Health* **2023**, *20*, 1442. [CrossRef] [PubMed]
26. Lyu, Y.; Wang, W.; Wu, Y.; Zhang, J. How does digital economy affect green total factor productivity? Evidence from China. *Sci. Total. Environ.* **2023**, *857*, 159428. [CrossRef]
27. Jia, X. Digital Economy, Factor Allocation, and Sustainable Agricultural Development: The Perspective of Labor and Capital Misallocation. *Sustainability* **2023**, *15*, 4418. [CrossRef]
28. Hu, J.; Li, X. Construction and Optimization of Green Supply Chain Management Mode of Agricultural Enterprises in the Digital Economy. *Int. J. Inf. Syst. Supply Chain Manag.* **2021**, *15*, 1–18. [CrossRef]
29. Balcerzak, A.P.; Pietrzak, M.B. Digital Economy in Visegrad Countries. Multiple-criteria Decision Analysis at Regional Level in The Years 2012 and 2015. *J. Compet.* **2017**, *9*, 5–18. [CrossRef]
30. Chen, X.H.; Li, Y.Y.; Song, L.J.; Wang, Y.J. Theoretical framework and research prospect of digital economy. *J. Manag. World* **2022**, *38*, 208. (In Chinese) [CrossRef]
31. Wu, L.; Zhang, Z.G. Research on three-dimensional technology-industry-operation development path of "Internet + Forestry" in China. *World For. Res.* **2018**, *31*, 1–7. (In Chinese) [CrossRef]
32. Fu, H.N.; Li, X.C. Digital Economy Drives Agricultural Modernization in China: Mechanism and Effects. *J. South China Agric. Univ. (Soc. Sci. Ed.)* **2023**, *22*, 18–31. (In Chinese)
33. Ma, Z.; Liu, T.; Li, J.; Liu, Z.; Chen, W. Spatial Effect Analysis of Forestry Technology Innovation on Forestry Industry Economic Growth. *Forests* **2023**, *14*, 557. [CrossRef]
34. Bonsu, N.O. Towards a circular and low-carbon economy: Insights from the transitioning to electric vehicles and net zero economy. *J. Clean. Prod.* **2020**, *256*, 120659. [CrossRef]
35. Shi, D.; Sun, G.L. The Influence of the Integration of Digital Economy and Real Economy on Green Innovation. *Reform* **2023**, *348*, 1–13. (In Chinese)
36. Johnson, J.S.; Friend, S.B.; Lee, H.S. Big Data Facilitation, Utilization, and Monetization: Exploring the 3Vs in a New Product Development Process. *J. Prod. Innov. Manag.* **2017**, *34*, 640–658. [CrossRef]
37. Liu, X.Z.; Zhu, S.Y.; Zhou, H.M. Does the Development of Digital Economy in the Yangtze River Economic Belt Promote Regional Green Innovation. *Study Pract.* **2022**, *464*, 21–29. (In Chinese) [CrossRef]
38. Kahouli, B.; Hamdi, B.; Nafla, A.; Chabaane, N. Investigating the relationship between ICT, green energy, total factor productivity, and ecological footprint: Empirical evidence from Saudi Arabia. *Energy Strat. Rev.* **2022**, *42*, 100871. [CrossRef]
39. Lun, X.B.; Liu, Y. Digital government, digital economy and green technology. *J. Shanxi Univ. Financ. Econ.* **2022**, *44*, 1–13. (In Chinese) [CrossRef]
40. Haucap, J. Competition and Competition Policy in a Data-Driven Economy. *Intereconomics* **2019**, *54*, 201–208. [CrossRef]
41. Wen, Z.; Ye, B. Analyses of Mediating Effects: The Development of Methods and Models. *Adv. Psychol. Sci.* **2014**, *22*, 731–745. (In Chinese) [CrossRef]
42. Wei, X.J.; Zhang, M.X. Empirical Study on Mechanism of Factors Influencing Chinese Forestry Industrial Agglomeration—Based on Spatial Durbin Model (SDM). *Resour. Dev. Mark.* **2018**, *34*, 1731–1737. (In Chinese) [CrossRef]
43. Tone, K. A slacks-based measure of super-efficiency in data envelopment analysis. *Eur. J. Oper. Res.* **2002**, *143*, 32–41. [CrossRef]
44. Zhao, T.; Zhang, Z.; Liang, S.K. Digital Economy, Entrepreneurship, and High-Quality Economic Development: Empirical Evidence from Urban China. *J. Manag. World* **2020**, *36*, 65–76. (In Chinese)
45. Huang, D.P.; Zhu, X.Y. Comprehensive evaluation and space-time evolution of China's digital economy development level. *Stat. Decis.* **2022**, *38*, 103–107. (In Chinese) [CrossRef]
46. Dong, Z.Q.; Wang, H. Local-Neighborhood Effect of Green Technology of Environmental Regulation. *China Ind. Econ.* **2019**, *370*, 100–118. (In Chinese) [CrossRef]

47. Xu, J.; Cui, J.B. Low-Carbon Cities and Firms' Green Technological Innovation. *China Ind. Econ.* **2020**, *393*, 178–196. (In Chinese) [CrossRef]
48. Wang, F.; Wang, H.; Liu, C.; Xiong, L.; Qian, Z. The Effect of Green Urbanization on Forestry Green Total Factor Productivity in China: Analysis from a Carbon Neutral Perspective. *Land* **2022**, *11*, 1900. [CrossRef]
49. Zheng, M.; Feng, G.-F.; Jang, C.-L.; Chang, C.-P. Terrorism and green innovation in renewable energy. *Energy Econ.* **2021**, *104*, 105695. [CrossRef]
50. Gao, Y.N.; Zhang, M.C.; Zheng, J.H. Accounting and determinants analysis of China's provincial total factor productivity considering carbon emissions. *China Econ. Rev.* **2021**, *65*, 101576. [CrossRef]
51. Wang, Y.; Sun, X.; Guo, X. Environmental regulation and green productivity growth: Empirical evidence on the Porter Hypothesis from OECD industrial sectors. *Energy Policy* **2019**, *132*, 611–619. [CrossRef]
52. Wu, H.; Hao, Y.; Ren, S. How do environmental regulation and environmental decentralization affect green total factor energy efficiency: Evidence from China. *Energy Econ.* **2020**, *91*, 104880. [CrossRef]
53. Yuan, H.; Feng, Y.; Lee, C.-C.; Cen, Y. How does manufacturing agglomeration affect green economic efficiency? *Energy Econ.* **2020**, *92*, 104944. [CrossRef]
54. Sadorsky, P. Financial development and energy consumption in Central and Eastern European frontier economies. *Energy Policy* **2011**, *39*, 999–1006. [CrossRef]
55. Acheampong, A.O. Modelling for insight: Does financial development improve environmental quality? *Energy Econ.* **2019**, *83*, 156–179. [CrossRef]
56. Zhu, X.A.; Ma, Y.G. Research on the Impact of Digital Economy on Green Total Factor Productivity. *Econ. Probl.* **2022**, *11*, 1–11. (In Chinese)
57. Li, X.Z.; Li, J.Y. Research on the Influence of Digital Economy Development on Urban-rural Income Gap. *J. Agrotech. Econ.* **2022**, *322*, 77–93. (In Chinese) [CrossRef]
58. Mao, F.W.; Zhang, F. The Evolution of Regional Digital Economy in China:1994~2018. *J. Quant. Technol. Econ.* **2022**, *38*, 3–25. (In Chinese) [CrossRef]
59. Chen, Z.; Jia, C. How does environmental regulation affect industrial green productivity of China's cities. *Environ. Dev. Sustain.* **2022**, *25*, 10143–10169. [CrossRef]