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Research on the Impact of Digital Economy on Urban Green Total Factor Productivity

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ABSTRACT

In order to reveal the inherent mechanism of the role of the digital economy in urban green total factor productivity, and provide policy recommendations for achieving the development of the digital economy and urban green development. This article is based on panel data from 274 prefecture level and above cities in China from 2011 to 2020, and empirically analyzes the possible impact and mechanism of the digital economy on urban green total factor productivity. The research results indicate that: (1) the development of the digital economy can promote the improvement of urban green total factor productivity, and for non resource-based cities, high administrative level cities, and southern cities, the role of digital economy in empowering urban green total factor productivity is more significant; (2) The mechanism test shows that the development of digital economy can enhance the level of green innovation, achieve industrial structure upgrading, and thereby improve urban green total factor productivity. In addition, the impact of the digital economy on urban green total factor productivity is constrained by the threshold effect of industrial structure upgrading.

KEYWORDS

Digital economy; Urban green total factor productivity; Mechanism of action

1. INTRODUCTION

Since the outbreak of the global financial crisis in 2008, the economic development of the world has been greatly impacted. The digital economy is gradually becoming a new engine and driving force for economic growth, forming a transformation in various industries dominated by high-tech innovation, which has a profound impact on our way of life and production.

Cai Fang, Chief Expert of the National High end Think Tank of the Chinese Academy of Social Sciences, stated that China's economic development has entered a "new normal". In order to improve the long-term sustainability of economic development, it is necessary to create a competitive environment of "creative destruction", recognize the limitations of traditional stimulus measures, and promote institutional reforms. Therefore, finding new driving forces to enhance the high-quality development and growth of the national economy has become key. The digital economy can not only provide new driving forces for the development of traditional enterprises, but also promote technological changes in various fields through cross integration. Under the new normal, China, as a representative and pioneer of digital economy development, is currently in an important stage of deepening industrial structure adjustment and economic optimization transformation.

2. LITERATURE REVIEW AND RESEARCH HYPOTHESES

2.1. Literature Section

The development of digital economy and green development have become the two major themes of China's current development, which are closely related to the country's high-quality development. The continuous innovation and development of digital technology can help China achieve the common development of digital economy and green economy, thus realizing the goal of high-quality development in China.

Regarding the research on the digital economy, some scholars believe that it can promote the improvement of total factor productivity, mainly through promoting industrial structure upgrading and expanding human capital investment [1]. By measuring the level of development of China's digital economy, it is shown that the digital economy can significantly improve TFP [2]. The digital economy has significant and positive direct and indirect effects on total factor productivity [3]. For the study of green total factor productivity, digital industrialization can enhance GTFP through various channels, with significant heterogeneity in its impact [4]. Digital inclusive finance can promote technological innovation, thereby improving urban GTFP [5]. Technological innovation is an important factor in promoting the improvement of green total factor productivity [6].

The development of the digital economy can not only promote the development of local GTFP, but also have a positive impact on other regions [7]. Scholars have found through empirical analysis that the development of the digital economy contributes to the improvement of regional green total factor productivity. Taking urban data in China as an example, relevant studies have found that the digital economy promotes the development of urban GTFP through green innovation and production efficiency, and this promoting effect varies significantly in different regions [9].

2.2. Research Hypothesis

The Direct Impact of Digital Economy on Urban Green Total Factors

The rapid development of the digital economy can provide better matching mechanisms and innovation incentives for the construction of China's modern economic system [10]. The digital economy and digital industrialization indirectly enhance the efficiency of green economy by optimizing industrial structure, promoting technological innovation, and deepening marketization [11]. The accelerated development of the digital economy improves the production efficiency of enterprises, thereby supporting the development of green total factor productivity in cities [12]. Based on this, this article proposes the following assumptions:

H1: The development of the digital economy can promote the improvement of urban green total factor productivity.

The Indirect Impact of Digital Economy on Urban Green Total Factors

From the perspective of industrial structure upgrading, research has shown that the digital economy can effectively promote industrial structure upgrading. Relevant scholars have used urban data analysis to demonstrate that the digital economy has advanced the industrial structure [13]. The development of the digital economy can promote the optimization and upgrading of industrial structure by enhancing the ability to allocate capital and labor [14]. Therefore, this article proposes the following hypothesis:

H2: The digital economy enhances green total factor productivity through industrial structure upgrading.

From the perspective of green innovation, it can reduce the negative impact on the environment through technological innovation and drive the healthy development of cities [15]. The development of digital economy can optimize the allocation of factor resources, promote industrial upgrading, and improve the level of urban green innovation. Therefore, this article proposes the following hypothesis:

H3: The digital economy enhances green total factor productivity through green innovation.

The Nonlinear Spillover Effect of Digital Economy on Urban Green Total Factors

According to Metcalfe's Law, the network economy has high penetration rate and strong externalities, and the value of the digital economy is influenced by multiple factors, which means that the impact of the digital economy on urban green total factor productivity may be nonlinear. The regional scale and institutional environment have threshold effects on the impact of digital economy on industrial GTFP, showing a marginal increasing characteristic [16]. So, this article proposes the following hypotheses:

H4: The impact of the digital economy on urban green total factor productivity is constrained by the threshold effect of green innovation.

H5: The impact of the digital economy on urban green total factor productivity is constrained by the threshold effect of industrial structure upgrading.

3. MODEL SETTING AND VARIABLE SELECTION

3.1. Model Setting

Benchmark regression model:

This article studies the impact of the digital economy on green total factor productivity, with green total factor productivity as the dependent variable and the digital economy as the explanatory variable. The model is as follows:

$$GTFPit=\alpha+\beta DEit+\gamma Zit+\mu i+\theta t+\varepsilon it$$

Among them, i represents the city, t represents the year, *GTFPit* represents green total factor productivity, *DEit* represents the level of digital economy development, and Zit is the control variable. μi is the city dummy variable, θt is the year dummy variable, and εit is the random error term.

Mediation effect model:

$$GTFPit=\alpha 1+\beta 1DEit+\gamma 1Zit+\mu i+\theta t+\varepsilon it$$

$$IMsit=\alpha 2+\beta 2DEit+\gamma 2Zit+\mu i+\theta t+\varepsilon it$$

$$GTFPit=\alpha 3+\beta 3DEit+\eta IMsit+\gamma 3Zit+\mu i+\theta t+\varepsilon it$$

Among them, IMsit represents the mediating variables of this article, namely the level of green innovation and industrial structure upgrading.

Threshold effect model:

This article uses a panel threshold regression model to further investigate possible nonlinear spillover effects. The threshold model constructed is as follows:

$$GTFPit=\alpha 4+\beta 4DEitI_{(qit\leq c1)}+\beta 5DEitI_{(c1\leq qit\leq c2)}+\beta 6DEitI_{(qit\geq c3)}+\mu i+\theta t+\varepsilon it$$

3.2. Variable Selection

Explained variable:

Green Total Factor Productivity (GTFP). Based on existing research, this article uses the GML index calculated by the super efficiency SBM model based on unexpected output to measure green total factor productivity. DEA generally believes that producing more output with fewer resources is an efficient production method. If we consider unexpected output, we do not want to produce more industrial waste regardless of the input. Therefore, the most efficient production method in today's society must be green production, which means producing more expected output with less input and less unexpected output. The measurement method of using the super-efficient SBM model with unexpected output can fully reflect green development. The specific indicators and their meanings are shown in the table below.

Table 1. Green Total Factor Productivity Indicators

First level indicator	Secondary indicators	Meaning of indicators
Investment indicators	Labor input	Number of employees in the unit at the end of the year
	Capital investment	Capital stock
	Energy investment	Regional electricity consumption
Output indicators	Expected output	Real GDP
	Unexpected output	Industrial wastewater discharge volume
		Industrial smoke and dust emissions
		Industrial sulfur dioxide emissions

Explanatory variables:

Digital Economy Indicators (DE). Mainly drawing on Zhao Tao's research, the proportion of computer service and software practitioners is determined by the number of information transmission, computer service and software industry practitioners and the number of urban private and individual practitioners. The China Inclusive Finance Index adopts data from Peking University's Digital Inclusive Finance Index, with specific indicators as follows.

Table 2. Digital Economy Indicators

First level indicator	Secondary indicators	Meaning of indicators
Digital Economy	Digital Industrialization	Proportion of computer service & software professionals
		Internet users per 100 people
		Number of mobile phone users per 100 people
		Proportion of computer service & software professionals
	Industrial digitalization	China Inclusive Finance Index

For the calculation of digital economy indicators, this article uses the entropy weight method to objectively assign weights for measurement.

Mediating variables and threshold variables:

The intermediary and threshold variables in this article are green innovation and industrial structure upgrading. For green innovation, the logarithm of the total number of green patents applied for by prefecture level cities each year is taken as 1;

In terms of industrial structure upgrading, industrial structure upgrading is represented by industrial structure upgrading, which refers to the ratio of the output value of the city's tertiary industry to that of the secondary industry.

Control variables: This article adds the following other variables that affect the experiment: level of openness to the outside world (OPEN), expressed in terms of total exports; Urbanization level (UL), expressed as the proportion of urban population to total population; Economic development level (ED), indicated by per capita GDP; Government investment (FI), expressed as general public budget expenditure of the government; Educational level expenditure (EL), expressed as the ratio of local education expenditure to general public budget; The level of science and technology (ST) is expressed as the ratio of local science and technology expenditures to the general public budget.

3.3. Data Sources

The data is sourced from the "China Urban Statistical Yearbook", statistical yearbooks of various cities, and national economic and social development statistical bulletins of each city.

4. EMPIRICAL TESTING AND ANALYSIS

4.1. Benchmark Regression Analysis

Firstly, conduct benchmark regression analysis, with only the green total factor productivity variable and control variable added to column 1, and the core variable digital economy variable added to columns 2 to 5. As shown in the figure, after adding control variables, city fixed effects, and year fixed effects, it can be seen from column 5 that the regression coefficient of digital economy DE is 0.22, which is significantly positive. This indicates that the digital economy can have a positive effect on urban green total factor productivity, that is, the development of digital economy can improve urban green total factor productivity. Columns 2 to 4 show the results of single factor fixed effects, and the DE coefficient remains significantly positive, indicating the robustness of this conclusion. Assuming that it is verified.

Table 3. The results of the benchmark regression analysis.

	one	two	three	four	five
	GTFP				
DE		0.52^{***}	0.41^{***}	0.02^{***}	0.22^{*}
ED	0.32^{***}	0.05^{***}	0.11^{***}	0.41^{***}	0.90
OPEN	-0.14	-0.28	0.07	-0.23^{***}	-0.54^{**}
UL	0.00	-0.00	0.19	0.23^{**}	0.31
FI	-0.00^{***}	-0.05^{**}	-0.40^{***}	-0.78^{**}	-0.02
EL	-0.31^{*}	-0.43^{*}	-0.77	-0.41	-0.03
ST	-0.52	-0.26	-0.30	-0.37	-0.72
Urban fixed effects	no	no	no	yes	yes
Fixed year effect	no	no	yes	no	yes
N	2740				

4.2. Robustness Check

(1) Change the core explanatory variable

Use principal component analysis to re measure the level of development of the digital economy, and test its robustness by changing the measurement method of the core explanatory variables. The regression results of measuring the level of digital economy development using principal component analysis are shown in column 1. From the results, it can be seen that the regression coefficient of DE is significant and positive. After changing the calculation method of digital economy development, the core results of this article are still robust.

(2) Adjust the experimental year

Adjust the experimental year to 2017-2021 and perform regression again. As shown in column 2. After changing the year variable, the DE regression coefficient remained significantly positive, consistent with the baseline regression results.

Table 4. The results of the robustness check.

	Principal Component Analysis	Adjust year
DE	0.42^{**}	0.33^{**}
control variable	yes	yes
city	yes	yes
particular year	yes	yes

4.3. Endogeneity Test

This article uses the instrumental variable method to alleviate potential endogeneity issues. The historical fixed telephone numbers meet both the requirements of relevance and exclusivity. Therefore, this article selects the fixed telephone numbers per 100 people in each city in 1984 as the instrumental variable for the digital economy index. The two-stage least squares method was used for testing, and the regression results are shown in the table.

Table 5. The results of the endogeneity test.

	DE	GTFP
DE		0.22^{***}
Iv	0.19^{**}	
F		17.19^{***}
LM		7.84^{***}

The first column shows the regression results of the instrumental variable in the first stage. The regression coefficient between instrumental variable IV and digital economy DE is 0.19, which is significantly positive, indicating a significant positive relationship between instrumental variables and the development of the digital economy. The second column shows the regression results of the second stage of instrumental variables, and it can be seen that both the Kleiberen PaapWaldrkF and Kleiberen PaaprkLM statistics are significant. Therefore, the hypothesis of insufficient identification of instrumental variables and weak instrumental variables is rejected. The regression coefficient between DE and GTFP in the second stage is still significantly positive, indicating that after addressing endogeneity issues, the development of the digital economy can still improve green total factor productivity.

4.4. Heterogeneity Analysis

(1) Heterogeneity of Resource Cities

Resource based cities may have varying impacts of the digital economy on green total factor productivity due to their resources, regions, and other factors. According to the National Sustainable Development Plan for Resource based Cities, this article divides 274 cities into 165 non resource based cities and 109 resource based cities, and conducts a regression analysis. Columns 1 and 2 in the table show the regression results for non resource-based cities and resource-based cities, respectively. The results indicate that for non resource based cities, the regression coefficient of digital economy is significantly positive, indicating that the development of digital economy in non resource based cities can improve green total factor productivity, while the impact of digital economy development on green total factor productivity in resource-based cities is not significant.

Table 6. The results of the heterogeneity of resource cities.

	one	two
DE	0.16^{***}	-0.04
control variable	yes	yes
city	yes	yes
particular year	yes	yes

(2) Heterogeneity of administrative levels

This article categorizes municipalities, provincial capitals, and vice provincial cities into high administrative level cities based on their administrative levels, while other prefecture level cities are classified as general administrative level cities. As shown in the table, columns 1 and 2 respectively represent the impact of digital economy on GTFP in two administrative level cities. The regression results show that regardless of the administrative level of the city, the regression coefficient is significantly positive. However, the regression coefficient of cities with high administrative levels is higher than that of cities with general administrative levels, indicating that the digital economy can empower the improvement of green total factor productivity in cities, and the promotion effect of cities with high administrative levels is more significant.

Table 7. The results of the heterogeneity of administrative levels.

	High administrative level city	General administrative level city
DE	0.38^{***}	0.17^{***}
control variable	yes	yes
city	yes	yes
particular year	yes	yes

(3) Differences between North and South Regions

With the further southward shift of the national economic center, this article divides 274 prefecture level cities into 125 northern cities and 149 southern cities based on the criteria of economic geography, and conducts a regression analysis. The regression results are as follows. The first column reports the regression results for the northern region, with a regression coefficient of 0.04 for DE, which is not significant; The second column reports the regression results of the southern region, and it can be seen that the regression coefficient of DE is significantly positive, indicating that the development of digital economy in southern cities can empower urban green total factor productivity, while it is not significant in the north.

Table 8. The results of the Differences between north and south regions.

	one	two
DE	0.04	0.09^{**}
control variable	yes	yes
city	yes	yes
particular year	yes	yes

5. MECHANISM TESTING

5.1. Intermediary Effect Test

This article explores the possible mediating mechanisms of the impact of urban digital economy on urban green total factor productivity from two aspects: green innovation level and industrial structure upgrading. The inspection results are shown in the table.

Table 9. The results of the Intermediary effect.

	GI	GTFP	IU	GTFP
DE	5.30^{***}	2.11^{***}	3.05^{***}	0.76^{***}
GI		0.00^{**}		
IU				0.24^{***}
control variable	yes	yes	yes	yes
city	yes	yes	yes	yes
particular year	yes	yes	yes	yes

(1) Green Innovation Level Mechanism

Column 2 shows the mediating effect of green innovation level (GI). From column 1, it can be seen that the regression coefficient of DE on GI is 5.30, which is significantly positive, indicating that the development of the digital economy can empower green innovation. In the two columns, both the regression coefficients of DE and GI for GTFP are significantly positive, indicating that the digital economy can improve GTFP by enhancing the level of green innovation. Hypothesis 2 has been verified.

(2) Mechanism for upgrading industrial structure

The fourth column displays the mediating effect of industrial structure upgrading (IU). From the third column, it can be seen that the regression coefficient of DE on IU is 3.05, which is significantly positive, indicating that the development of urban digital economy can empower industrial structure upgrading. The regression coefficients of column 4 DE and IU for GTFP are both significantly positive, indicating that the digital economy can improve GTFP by improving regional industrial structure. Hypothesis 3 has been verified.

5.2. Threshold Effect Test

The article uses 300 self-sampling methods to estimate the F-statistic of the model. The existence of threshold effect is as follows: when the threshold variable is the level of green innovation, both the dual threshold effect and the single threshold effect failed the significance test. When the threshold variable is the advanced industrial structure, both the dual threshold and the single threshold have passed the significance test. This indicates the existence of a dual threshold effect of advanced industrial structure.

Table 10. The results of the Threshold effect 1.

Threshold variable	Explanatory variables	Model	Threshold estimation value			P value
			I	II	III	
IU	DE	single	7.4838			0.0000
		double	6.3008	7.4838		0.0367
		triple	4.9416	6.3008	7.4838	0.8500
GI	DE	single	0.3952			0.5400
		double	0.3952	0.7608		0.5933

The following table shows the regression results with industrial structure upgrading as the threshold variable. It can be seen that when the degree of industrial structure upgrading is lower than the first threshold of 6.30, the regression coefficient is 0.075, indicating significant results; When it is higher than the first threshold of 6.3 and lower than the second threshold of 7.48, the regression coefficient is 0.19; When it is higher than 7.48, the regression coefficient is 0.33, which is significantly positive. The results indicate that as the level of industrial structure upgrading increases, the positive effect of the digital economy on urban green total factor productivity continues to rise, indicating the existence of a non-linear impact of the digital economy on the increasing marginal effect of GTFP.

Table 11. The results of the Threshold effect 2.

		linear model	Dual threshold model
			Threshold value: 6.30 (I) 7.48 (II)
independent variable	DE	0.069^{**}	
	(T≤I)		0.075^{*}
	(I≤T≤II)		0.19^{***}
	(T≥II)		0.33^{***}

Overall, with the improvement of industrial structure upgrading, the promoting effect of green total factor productivity in digital economy cities will become increasingly strong, showing a non-linear growth trend.

6. CONCLUSION AND SUGGESTIONS

The research conclusion is as follows: Firstly, the digital economy can significantly improve urban green total factor productivity, and the experimental results remain robust even after changing the core explanatory variables, adjusting for experimental years, and addressing endogeneity issues. Secondly, from the perspective of heterogeneity, the digital economy can significantly improve the green total factor productivity of non resource-based cities, high administrative level cities, general administrative level cities, and southern cities, but has not significantly improved the green total factor productivity of resource-based cities and northern cities. Thirdly, the digital economy helps to promote the level of green innovation and industrial structure upgrading in cities, empowering urban green total factor productivity through these two channels. In addition, the impact of the digital economy on urban green total factor productivity is also constrained by the threshold effect of industrial structure upgrading.

Based on the above experimental conclusions, this article proposes the following policy recommendations: Firstly, we will continue to vigorously develop the digital economy, improve the integration and progress of the digital economy and green ecology, and make the digital economy an inexhaustible driving force for urban green development. To accelerate digital development, we should improve the construction of urban digital infrastructure, continuously deepen the construction of digital facilities such as big data, artificial intelligence, and cloud computing, and reduce the flow consumption in production and life. In addition, cities with high administrative levels should actively break down digital barriers between cities. Currently, cities with high administrative levels have a high level of digital and green development, and should take the lead in promoting cooperation and collaboration between cities to achieve cross city digital resource sharing, fully leverage the digital economic empowerment of each city, and achieve overall green total factor productivity improvement.

Secondly, improve the level of upgrading urban industrial structure. Promote the digitalization and industrialization of industries, and fully leverage the promoting role of industrial structure upgrading. The government should create a digital development environment, fully integrate the digital economy with the real economy, reduce energy consumption, and decrease dependence on environmental resources. Vigorously promoting the digital transformation of cities, for resource-based cities, they should abandon the production mode that relied mainly on resource consumption in the past, no longer overly rely on local resources, invest funds, attract talent and technology to enter the local area, focus on emerging industries and high-tech industries, achieve the transformation and upgrading of traditional industries, and thereby improve the green total factor productivity level of cities.

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