

The Impact of Digital Economy Development on Green Technology Innovation

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Abstract: In recent years, China has accelerated the transformation of old and new driving forces, promoting high-quality economic development. How to ensure high-quality economic development while reducing energy consumption and promoting sustainable economic development under the new development pattern has become an important research topic. Through literature review both domestically and internationally, it has been found that research on the impact of digital economy on the development of green technology and the influencing factors of green economy and green finance is a hot topic in the academic community. On this basis, this article will delve into the path of the impact of the digital economy on green technology innovation. Based on panel data from 241 prefecture level cities in China from 2011 to 2022, it will empirically explore the relationship between the digital economy and green technology innovation, and use the mediation effect model to focus on identifying the mechanism of urban financial development level. The study found that the digital economy has become an important force in promoting green technology innovation. The level of financial development is the key intermediary for its effectiveness; The impact of digital economy development on green technology innovation has strong heterogeneity. Therefore, it is necessary to vigorously develop the digital economy, promote regional coordinated development, accelerate the transformation of green economy, and accelerate the development of green economy.

Keywords: Digital economy, Green technology innovation, Financial development level, Mechanism of action.

1. Introduction

Under the new development pattern, the five development concepts guide high-quality economic development and have become a strategic direction for promoting the transformation of China's economic development momentum. With the continuous development of the economy, the deterioration of environmental resources has become irreversible. Under the conditions of continuous development of science and technology, how to reduce the consumption and sacrifice of resources in economic development through technological innovation has become a necessary way to achieve China's sustainable development goals. At the same time, with the deeper and wider penetration and integration of the digital economy and the real economy, the digital economy has become an important driving force and support for achieving the transformation of old and new driving forces. How to scientifically evaluate the green development effects brought by the digital economy under the new development concept has become an inevitable requirement for achieving sustainable economic development in China. Therefore, identify the impact relationship and mechanism between the two, proposing relevant optimization measures and suggestions, and providing new ideas for achieving green economic development in China.

2. Theoretical Analysis and Research Hypotheses

The research on the impact of digital economy on green technology innovation and development, as well as the influencing factors on green economy and green finance, has been a hot topic in the academic community in recent years.

2.1. The Direct Impact of Digital Economy on Green Technology Innovation

Many scholars have concluded through empirical analysis that the development of the digital economy is conducive to promoting green technology innovation. Zhang Xiuwen analyzed the impact of the digital economy on green technology innovation, green industrial structure upgrading, and green consumption demand release, and elaborated on the positive role of the digital economy in achieving sustainable development goals. Zhu Qiaoqiao established a moderated mediation effect model based on a multi-dimensional collaborative perspective to explore the impact and mechanism of the digital economy on green total factor productivity. Research has found that the development of the digital economy has significantly improved the level of green total factor productivity, and the conclusion still holds after robustness tests such as selecting historical data as instrumental variables and using the establishment of the "National Big Data Comprehensive Experimental Zone" as an exogenous policy shock. Green technology innovation plays a mediating role in this process, and the impact mechanism is positively regulated by government environmental support and public environmental concern. Sun Quansheng believes that the digital economy can provide empowerment for improving the efficiency of green technology innovation. The internal modes of empowerment are automated production and information management, and the execution of the internal modes requires three specific operational modes: digital technology upgrading, all-round collaborative cooperation, and standardized thinking. Zhou Caiyun believe that the digital economy can improve energy efficiency by promoting green technology innovation, and the improvement of green technology innovation level can help cities cross the second threshold of the digital economy,

achieving a win-win situation between digital economy development and energy efficiency improvement.

In addition, the impact of the digital economy on green technology innovation is also influenced by factors such as regional resource endowments, industry development, and urban infrastructure construction. This results in significant differences in the impact of the digital economy on green technology innovation in regions with different levels of development, leading to uneven technological development. In areas where the development of the digital economy is relatively lagging behind, in order to keep up with the trend of the times and seize new opportunities for development, efforts are often concentrated on developing regional infrastructure construction. However, due to insufficient technological foundation, this process inevitably leads to problems such as low resource utilization efficiency and waste, which is not conducive to the innovative development of green technology. For regions with high levels of digital economy development, emerging technologies and ecological environments built around the digital economy are stimulating larger scale digital industrialization and industrial digitization processes, greatly enhancing the empowering effect of digital economy development on green technology innovation. Based on the above analysis, this article proposes the following research hypotheses:

H1a: The development of digital economy can enhance green technology innovation.

H1b: The impact of digital economy development on green technology innovation has strong heterogeneity.

2.2. The Mechanism of the Impact of Digital Economy on Green Technology Innovation

Firstly, the digital economy has created favorable conditions for the improvement of regional financial development level. The development of the digital economy has not only changed the form and methods of financial services, expanded the scope of financial services, improved the types of financial services, and improved a series of problems such as information asymmetry, complex approval procedures, and insufficient risk management in the financial services market. At the same time, the digital economy has provided more efficient and convenient services for financial institutions, greatly improving the efficiency of financial services. The application of digital technology has also made the processing of financial data and risk management more precise and automated, reducing human errors and fraudulent behavior.

The improvement of financial development level provides a guarantee for green technology innovation. For innovative behavior, the most important thing is the initial capital investment. The improvement of financial development level can better promote the optimized allocation of financial resources in the field of innovation, thereby promoting regional innovation development. On the one hand, the improvement of financial development level is conducive to reducing the cost of green technology innovation. By providing more efficient and convenient financial services to innovative entities, financial institutions can effectively reduce various costs incurred by innovative entities in preparing funds in the early stage, effectively solve financing difficulties, provide a good financial environment, and enable more entities to participate in innovation activities. On the other hand, the improvement of financial development level

is conducive to enhancing society's willingness to consume green products. The level of financial development effectively enhances the consumption level of residents. With the continuous accumulation of wealth, residents will gradually increase their consumption of green products, which can also stimulate the willingness of innovative entities to innovate green technologies and promote the development of the green technology market. Based on the above analysis, this article proposes the following assumptions:

H2: Digital Economy Promotes Green Technology Innovation by Improving Financial Development Level

3. Variable Selection and Description

To reveal the effects and mechanisms of digital economy empowering green technology innovation, this article selects the following variables for empirical analysis.

3.1. The Dependent Variable

Green Technology Innovation (Gti). Drawing on the method of Qi Shaozhou (2018), select each city's annual plan. The ratio of the number of green patents applied for to the total number of patent applications represents the status of green technology innovation.

3.2. Explanatory Variable Digital

Digital level of economic development. This article uses the method of Zhao Tao (2020) and adopts, Internet penetration rate, relevant employees, relevant business output, mobile phone penetration rate and China's digital inclusive financial index. By using principal component analysis, the data of the above 5 indicators were standardized and dimension-ally reduced to obtain the comprehensive development index of the digital economy in the region.

3.3. Mediating Variable

Financial development level (Fin). The commonly used indicators in the academic community to measure the level of financial development are Ge and Mai. This article takes into account the optional nature of data and, based on the definition of Gorge index, uses financial asset measurement indicators for deposit and loan data in various regions. Based on this, the ratio of annual deposit and loan balance data of financial institutions in each region to the nominal GDP of the region in the same year is calculated to measure the level of financial development in the region.

3.4. Adjusting the Variable

In the selection of control variables, this article sets five control variables. Urban Development Level (CGDP) is used to measure the level of urban economic development, and we choose regional per capital GDP as the measurement indicator. The industrial structure also has a certain impact on the development of green economy in a region. Therefore, we choose the proportion of the overall production value of the secondary industry to the regional GDP as the indicator of its industrial structure level (STR); the degree of government intervention (GOV) refers to the power of the government to allocate natural resources. Reasonable and moderate government intervention can also affect the development of green technology innovation. This article uses the ratio of regional general public finance expenditure to the region's gross domestic product as an indicator to measure the degree of government intervention; The degree of opening up to the

outside world (OFF): Since the reform and opening up, China has continuously increased its economic openness to enhance international competitiveness. Exchange and learning of new technologies with foreign countries can help the region win a place in international competition. This article uses the ratio of foreign investment used by the region to the region's gross domestic product as a measurement standard; Research capability (RC) is the most direct factor affecting the level of green technology innovation in a region. The higher level of research in a region plays an important role in green

technology innovation. This article selects the logarithm of the number of universities in the city to measure.

This article uses data from 241 cities from 2011 to 2022, and uses interpolation to fill in missing data. In order to eliminate the influence of outliers, a 1% level truncation was performed. The relevant data comes from the China Urban Statistical Yearbook, Wind database, Environmental Statistical Yearbook, etc. The descriptive statistics of each variable are shown in Table 1.

Table1. Descriptive statistics

Variable	Variable symbols	Sample quantity	Average value	Standard deviation	Minimum value	Maximum value
Green technology innovation	Gti	3103	0.080	0.071	0.056	0.333
Digital economy	Digital	3103	0.334	0.360	0.109	0.687
Financial development level	Fin	3103	2.569	2.234	1.244	7.218
Industrial structure level	STR	3103	12.244	11.220	7.639	38.220
Urban development level	CGDP	3103	0.106	0.049	0.147	0.730
External development level	OFF	3103	1.401	1.386	1.053	4.174
Research capability	RC	3103	0.204	0.176	0.101	0.625
Government intervention level	GOV	3103	5.413	4.497	3.244	17.366

4. Empirical Analysis

This section combines the selection of variables in the previous section, and based on hypothesis reasoning, constructs an econometric model to test the effect of digital economy development on green technology innovation.

4.1. Benchmark Regression Analysis

The benchmark regression results of the development of digital economy on green technology innovation are shown in Table 2. In the regression process, this article compares the fitting degree and coefficient significance between the random effects model and the fixed effects model, and concludes that the fixed effects model is more suitable. Model (1) studies the relationship between digital economy and green technology innovation without adding control variables, while Model (2) studies the regression of digital economy development with green technology benchmarks without adding control variables.

The results indicate that the impact of the digital economy on green technology innovation in model (1) is positive and significant at the 10% level. In the process of the development of the digital economy, information sharing and automation have been greatly improved. After the digital economy has formed a certain scale, the widespread coverage of digital technology, automated management, and data networks has greatly improved the efficiency and speed of resource matching, reduced unnecessary resource waste, and improved resource utilization. The impact of the development of the digital economy on green technology innovation is precisely demonstrated through this way to promote the development of the green economy. Therefore, the H1 hypothesis is verified.

From the regression results of controlling variables, it can be seen that scientific research ability can significantly promote the development of green technology. On the one hand, the continuous improvement of education level can cultivate more scientific research talents. At the same time, under quality education, people's environmental awareness

gradually increases, which is conducive to strengthening the ability of related technological innovation; On the other hand, the improvement of scientific research capabilities can acquire more technologies, efficiently innovate and drive the development of green technologies. At the same time, government intervention and urban development level also significantly affect the innovative development of green technology. The government strengthens the guidance and incentive system for green technology innovation, providing a good environment for technological innovation; the higher the level of development, the more resources a city possesses, and therefore, it is more capable of promoting the transformation of technological innovation achievements.

The impact of industrial structure and level of openness on green technology innovation is positive, but not significant. The reason may be that with the development of science and technology, China has deepened its supply side reform. However, overall, the proportion of traditional industries with high energy consumption and outdated technology is still relatively high. The innovative application of technology is not achieved overnight and requires time to change, so the impact effect is not so obvious; as for the level of opening up to the outside world, environmental pollution caused by industrial development has become a global problem focus. Both foreign and domestic green technologies have their own immature development areas, and technological barriers and boundaries have not been broken and integrated, so the impact effect is not very obvious.

Table 2. Benchmark regression results

Variable	Model (1)	Model (2)
	Gti	Gti
Digital	0.018* (1.96)	0.008** (0.88)
STR		0.014 (0.30)
OFF		0.036 (4.45)
RC		0.078*** (0.87)
GOV		0.015*** (1.11)
CGDP		0.002** (3.14)
Constant term	0.086*** (26.03)	0.073*** (11.92)
N	3103	3103
Fixed effects	Yes	Yes
P	0.000	0.000

Notes: statistics in parentheses; *p< 0.1, **p< 0.05, ***p< 0.01, the following table is the same.

4.2. Robustness Testing

Firstly, replace the explanatory variable. The development of the digital economy is an important engine for promoting high-quality economic development. Use software to crawl words related to digital economy development from government work reports of various cities, and calculate their frequency to reflect the status of a city's digital economy development. Therefore, this article replaces the previous explanatory variable of the level of digital economy development with the frequency of words related to digital economy development, and conducts robustness tests. The regression results and their significance are basically consistent with the benchmark regression results.

Secondly, the instrumental variable method. In order to eliminate heterogeneity issues caused by causal relationships and missing important variables, this article uses the interaction terms of the number of telephones per 10000 people in each city in 1984 and the network penetration rate in each city from 2011 to 2022, and constructs an instrumental variable replacement model for digital economy development that changes over time and region. After using instrumental variables, the overall regression results of the model were consistent with the benchmark model. At the same time, the selected instrumental variables passed the under identification test, weak instrumental variable test, and over identification test, and the research conclusions were robust.

5. Analysis of Impact Mechanisms and Heterogeneity

The level of financial development is an important path for digital economy to affect green technology innovation. Based on this, this article constructs a mediation effect model for further testing.

5.1. Analysis of Mediation Effect Model

Model (3) indicates that the development of the digital economy has a promoting and enhancing effect on green technology innovation. The digital economy can enhance information sharing, enhance industrial collaborative development, enhance knowledge spillover efficiency, enhance technological empowerment to improve regional green technology innovation capabilities, and promote green economic development. Model (5) examines the impact of digital economy development on green technology innovation after incorporating the intermediate variable of financial development level. The results showed that after considering the mediating variables, the direction of the impact of the digital economy on green technology innovation did not change, and its value was larger than the benchmark model, proving the mediating role of financial development level. Therefore, the H2 hypothesis was validated.

Table 3. Inspection of intermediary mechanisms

Variable	Model (3)	Model (4)	Model (5)
	Gti	Gti	Gti
Digital	0.008** (0.88)		0.011** (1.05)
Fin		0.003*** (3.98)	0.012*** (4.02)
Constant term	0.073*** (11.92)	0.080*** (13.82)	0.083*** (12.58)
Sample size	3103	3103	3103
Control variable	Yes	Yes	Yes
Fixed effects	Yes	Yes	Yes
P	0.000	0.000	0.000

5.2. Heterogeneity Analysis

The heterogeneous impact of the digital economy as a new form of economy has also received widespread attention from the academic community. This article further explores the heterogeneous impact of digital economy development on green technology innovation from two perspectives: geographical location differences and urban level differences.

Firstly, geographical differences. This article divides cities into four regional modules based on their different regions, namely the eastern region, central region, western region, and northeastern region. Regression operations are then carried out sequentially, and the results are shown in Table 4, Models (6) - (9). We can see that the effect of the eastern region is the most obvious, which may be because the talent and technology resources in the eastern region are relatively concentrated, and various guarantee policies and systems are also relatively complete. A large number of market entities have achieved digital empowerment and have a certain innovation foundation, so their driving ability for green technology innovation is stronger. The impact effect of the central region is also significant. In recent years, the central region has invested a lot of resources in the development of the digital economy. As the trend of the times, it is necessary to firmly grasp this development opportunity and improve the quality of regional economic development. Therefore, the central region has great potential to promote green technology innovation. On the other hand, in the western and northeastern regions, although the impact on green technology innovation

is positive, it is not significant. The reason may be that in recent years, the western region has focused on implementing the national strategic policy of "counting in the east and counting in the west", and has invested a large amount of resources in infrastructure construction. The scale is relatively large, which will to some extent affect the development of green technology innovation and hinder the green development of the economy; Compared to other regions, the Northeast region is slightly disadvantaged in terms of resources and faces many constraints in developing the digital economy. To develop the digital economy, it is necessary to address these influencing factors and create a suitable development environment. This is a challenging task, and the lack of motivation makes it even more difficult to achieve the development goal of green technology innovation.

Secondly, there are differences at the city level. The level of a city determines its level of resource allocation, attraction to talent, and support for industrial development. In the context of rapid development of the digital economy, higher

city levels are more conducive to the development of green technology innovation. Therefore, this article divides the sample cities into two modules: central cities and non-central cities. The central cities include provincial capital cities and sub provincial cities, while non-central cities include cities other than central cities. Regression analysis is conducted sequentially, and the results are shown in models (10) - (11). It can be seen that the impact of digital economy development on cities at different levels has significant differences. Central cities have more development dividends, with advantages in technological innovation, talent introduction, infrastructure, and policy support compared to non-central cities. Moreover, their economic foundation is good, and with the development opportunities of the digital economy, a virtuous cycle of development is formed, which makes market entities more willing to technological innovation and more efficient in resource allocation. The above analysis can demonstrate that the impact of digital economy development on green technology innovation has regional heterogeneity, and the H1 hypothesis has been fully validated.

Table 4. Heterogeneity analysis

Variable	Model (6)	Model (7)	Model (8)	Model (9)	Model(10)	Model (11)
	Eastern region	Western region	Central region	Northeast region	Central city	Non central cities
	Gti	Gti	Gti	Gti	Gti	Gti
Digital	0.023***	0.013	0.031**	0.002	0.032*	-0.019
	(1.68)	(0.65)	(0.97)	(0.05)	(2.59)	(-0.08)
Constant term	0.044***	0.090***	0.126***	0.038	0.089***	0.071***
	(5.55)	(5.18)	(7.35)	(1.61)	(4.47)	(9.73)
N	1210	936	583	374	317	2786
Fixed effects	control	control	control	control	control	control
control variable	control	control	control	control	control	control
P	0.000	0.000	0.000	0.000	0.000	0.000

6. Suggestions

6.1. Accelerate the Construction of New Infrastructure and Vigorously Develop the Digital Economy

The construction of new infrastructure helps to break through temporal and spatial barriers, achieve more efficient factor circulation, promote digital industrialization and industrial digital development, and provide impetus for empowering green technology innovation and development. Strengthening the construction of new infrastructure requires multiple measures to form a joint force, implementing policies according to local conditions, benchmark advanced industry technology standards, and accelerating the digital and intelligent innovation transformation and upgrading of traditional industries. At the same time, we will continue to increase capital investment, strengthen the application of the digital economy in multiple fields, achieve automated production, improve production efficiency, and gradually achieve the goal of comprehensive construction of the digital economy by building new infrastructure with digital technology as the core.

The construction of new infrastructure cannot be separated from sufficient financial support. The public nature of public goods determines that the government should play the role of an investment subject. While providing sufficient financial security, it is also necessary to coordinate planning,

reasonable layout, strengthen supervision and management, and ensure the quality and progress of construction projects. In addition, it is necessary to strengthen cooperation with social forces, mobilize the power of private capital, and enable more market entities to participate in project construction, jointly promote the equalization of public services, and achieve the sharing of development results by the people. Finally, strengthen the maintenance and updating of new infrastructure, improve the service life of facilities, improve resource utilization efficiency, ensure the long-term development of the digital economy, and assist in the innovation and transformation of green technologies.

6.2. Improve the Market Financial Service System and Stimulate the Vitality of Green Technology Innovation

The development of the digital economy can effectively improve the digital financial environment. The main starting point for innovation for enterprises is to obtain greater benefits. However, green technology innovation has the characteristics of long cycles, large investment, and low conversion rates. Without sufficient financial support, it is difficult for enterprises to persist. Therefore, improving the market financial service system and accelerating the creation of digital financial platforms can effectively alleviate the serious asymmetry of financial credit data, as well as the misapplication and mismatch of financial resources. Digital financial platforms can collect and integrate data from various

parties, achieve rapid matching of information data, achieve real-time tracking, greatly improve the efficiency of enterprise financing and credit, and make market entities more willing to engage in innovative activities. At the same time, we will strengthen institutional openness, optimize financing structure, improve service quality, alleviate financing difficulties and slow financing for green technology innovation enterprises, and provide more practical guarantees for the development of green technology innovation. In addition, the financial services system also needs to develop clear risk management strategies and compliance standards, ensure that all business activities are within a controllable range, establish efficient approval procedures, establish risk prevention mechanisms, strengthen information disclosure requirements, build a more open, transparent, and stable financial services market, and safeguard the development of green technology innovation.

6.3. Implement Regional Differentiated Digital Economy Policies and Accelerate the Realization of Regional Coordinated Development

The impact of digital economy development on green technology innovation development has significant regional differences. Therefore, we need to implement differentiated digital economy policies based on the actual development situation of each region, optimize social distribution mechanisms, improve digital governance methods, continuously narrow the gap between regions, create inclusive and fair development and competition conditions, and promote the unity of fairness and efficiency. Strengthen the cooperation of digital economy between the eastern and western regions, adhere to the combination of promising government and effective market, establish a linkage mechanism between the eastern and western regions, reduce the cost of data transmission between the two, and transform the disadvantage of factors in the western region into a development advantage. Increase investment in infrastructure construction in the Northeast region, expand multi-channel investment sources, lay a solid foundation for development, vigorously promote market cooperation with other regions, and promote regional digital coordinated development. In addition, the digital economy is a systematic engineering project that includes various aspects such as industrial ecology, data elements, technological innovation, and platform enterprise innovation systems. Therefore, it is necessary to strengthen top-level design, tailor measures to local conditions, coordinate the layout of emerging digital industries such as artificial intelligence, big data, and cloud computing, build clusters of digital emerging industries,

promote coordinated development between regions, improve regional digital technology level, reduce technology research and development costs and risks, and promote the improvement of green technology innovation level, promote the comprehensive development of green economy, and help achieve the sustainable development goals of China's economy.

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