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Has the Development of The Digital Economy Reduced the Growth Rate of Carbon Emissions?

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Abstract: Against the backdrop of the "30 · 60" dual carbon target, low-carbon development and the progress of the digital economy are the focus of attention at home and abroad. The digital economy has become an important driving force for high-quality economic development in China. This article studies panel data at the provincial level in China from 2011 to 2018, empirically testing the negative correlation between the development of the digital economy and the growth rate of carbon emissions, and verifying the mechanism effect of green technology innovation, Finally, the situation in the eastern, central, and western regions was discussed through sample analysis and robustness testing was conducted. Based on the above research conclusions, the following insights can be drawn: firstly, improve the speed and quality of digital economy development; Secondly, focus on the development of green innovative technologies.

Keywords: Digital Economy, Carbon Emission, Growth rate.

1. Introduction

The data from the "2022 World Energy Statistics Report" shows that the global emissions of carbon dioxide are still growing at a rate of 5.9% per year. As a major carbon emitter, China's carbon emission situation is severe, striving to achieve carbon peak by 2030 and carbon neutrality by 2060. However, there is currently a serious imbalance in regional development in our country. In order to achieve the carbon peak, the carbon structure and economic structure still face major challenges. Under the challenge of the COVID-19 outbreak in 2020, the digital economy has emerged as a new driving force for economic recovery. The "China Digital Economy Development Trend Industry Report"[1] shows that in 2021, China's digital economy scale reached 45.5 trillion, accounting for as high as 39.8% of GDP. The digital economy is becoming a new driving force for the rapid recovery and development of our country's economy. China has elevated the development of the digital economy to a national strategy, and the report of the 20th National Congress of the Party also proposed "accelerating the development of the digital economy" and "accelerating the construction of digital China". Unlike the traditional economy, the digital economy has characteristics such as a wide range of involvement and high permeability. The digital economy has promoted the transformation of the economy from an industrial form to an intelligent form. The digital economy represents the future direction of economic development and profoundly affects important carbon-emitting industries including manufacturing. Under the background of carbon peaking, the impact of the digital economy on carbon emissions has attracted much attention. However, what kind of impact does the digital economy have on carbon emissions? There is no consensus in academia yet. Therefore, this article starts with the growth rate of carbon emissions to explore the impact of the digital economy on the growth rate of carbon emissions. Whether or not research on whether the digital economy has alleviated the growth rate of carbon emissions is not only an objective need for the development of the digital economy, but also an inevitable requirement for China to fully implement the "3060" plan. The digital economy is an economic system based on information and digital technology. The OECD defines it as a series of economic activities driven by effective use of information and communication technology with modern information networks as an important carrier. The economy and environment have always been key topics in academic research. Since the rapid development of the digital economy, many scholars have explored the relationship between the digital economy and environment. Williams (2011) believes that the digital industry itself is a high-energy-consuming industry that relies on many infrastructure constructions, and developing a digital industry will bring great environmental burdens[2]. Yang Gangqiang et al (2023) also mentioned when analyzing digital industries that data centers and cloud servers are key sources of carbon footprints, and electricity consumed by data center operations reached twice that of annual power generation at Three Gorges Dam[3]. It seems that digital economies seem to increase environmental burdens instead, but in fact, not only does it reflect energy consumption in terms of developing a digital economy, but it also helps transform ways economic development occurs. The internet and big data are important manifestations of a digital economy; related research mostly believes that they show "environmental benefits". Jie Chunyan et al (2017) researched from three aspects: dynamic environmental monitoring, informatization of government environmental regulation, and deepening social public participation in environmental protection; they found that internet technology development can significantly improve environmental quality[4]. Xu Xianchun et al (2019) believe that big data development provides an important path for China's green development; it helps optimize industrial transformation at provincial level and demand structure; it can provide important guarantees for green production and green life[5]. From a carbon emission perspective, Xie Wenqian (2022) believes that from an industrial structure upgrade perspective, a digital economy has a significant inhibitory effect on carbon emissions[6]. Yi Ziyu et al (2022) found that while developing technology in a digital industry will increase carbon emission intensity, it can enable upstream and downstream industrial technology innovation to achieve energy conservation and emission reduction[7]. It can be seen that existing literature discussions have not reached consensus; China's total carbon emissions are still increasing year by year; pollution industry transfer may be a key influencing factor; if growth rates for carbon emissions are reduced due to impacts from a digital economy, fundamentally speaking it still helps achieve peaking carbon emissions.

Nowadays, more than 120 countries and regions around the world have proposed carbon neutrality targets. The buffer period from carbon peaking to carbon neutrality in Western developed countries is mostly 40-70 years, while China only has a 30-year transition period. Moreover, China's high-carbon path dependence formed over a long period of time has a large inertia, especially the factors of heavy economic industries, energy bias towards coal, and low efficiency, which bring severe challenges to the realization of the "dual carbon" goal. In terms of industrial structure, coal, cement, and steel are globally recognized high-carbon industries, and China's cement production and steel production account for 60% and 50% of the world's total respectively. Therefore, China faces a more urgent time and greater resistance to achieve the "dual carbon" strategic goal.

As an important driving force to help green low-carbon development, the digital economy is a new economic form born in the process of a new round of technological revolution and industrial transformation. It is promoting profound changes in economic and social development and production and lifestyle, injecting new momentum into achieving the "dual carbon" goal. With the iterative optimization of digital technology, the digital economy can promote the green low-carbon transformation of traditional industries through technological progress, gradually reduce carbon emissions, and use carbon sink technology to reduce the concentration of greenhouse gases in the atmosphere, enabling and enhancing the achievement of the "dual carbon" goal. Therefore, under the background of comprehensively implementing the "dual carbon" strategy, it is necessary to incorporate digital economy and green low-carbon development into the research framework.

In the context of accelerating evolution in a new round of technological revolution, the digital economy as a powerful tool to promote coordinated development of digitization and greening has gradually entered the research field of academia. Through sorting out existing literature, it is found that scholars' research focuses mainly on the impact of digital economy on urban green development, industrial green total factor productivity, rural household agricultural green low-carbon transformation, carbon emissions and other sub-fields. The above research results have enlightening significance for playing a positive effect on green sustainable development by digital economy and lay a good foundation for this paper.

Therefore, this article focuses on growth rates for carbon emissions due to impacts from a digital economy rather than just focusing on carbon emissions themselves; it conducts empirical analysis on provincial-level data from 2012 to 2019. Possible innovations in this article include: first, establishing an empirical model to explore impacts from a provincial-level perspective in China regarding how a digital economy affects growth rates for carbon emissions; this supplements existing research; secondly, due to obvious phenomena regarding industrial transfer existing in China, this article focuses on whether impacts from a digital economy on growth rates for carbon emissions show regional heterogeneity.

2. Theoretical Analysis and Research Hypotheses

2.1. The Impact of the Digital Economy on the Growth Rate of Carbon Emissions

The impact of the digital economy on the growth rate of carbon emissions is mainly reflected in the following three aspects: First, an important feature of the digital economy is the industrialization of digital industries[8], which are dominated by internet and information service companies. These companies themselves have a higher level of greening compared to traditional industries. Even if the construction is difficult at the beginning of development, digital industries have environmentally friendly characteristics in the long run. Second, the development of the digital economy will promote industrial digitization[8], accelerate the intelligent and green development of traditional industries, make the operation efficiency of traditional industries higher, and this digital transformation makes the utilization rate of information in industries higher, which helps to achieve cross-industry integration development, strengthen the connection between industries[9], reduce energy consumption waste, and reduce the growth rate of carbon emissions. Third, the development of the digital economy is conducive to the establishment and improvement of the carbon market, which helps to reduce carbon emissions. To establish a perfect carbon trading market, it is inseparable from emission detection, reporting and verification technology[10].

To achieve the peak carbon goal, it is urgent to scientifically handle the dialectical relationship between development and emission reduction, explore a new path of green low-carbon development, effectively control the increase of greenhouse gas emissions, and promote the green transformation of economic society in high-quality development. As a new driving force for green low-carbon development, the digital economy is a new economic form with data as the core, modern information network as the key carrier, and intelligence as an important feature. It can promote the industrial structure from capital and labor-intensive to digital and technology-intensive transformation. This helps to reduce industrial energy consumption and carbon emission intensity, get rid of the dependence of economic growth on high energy consumption and high emission development paths, and provide new opportunities for the timely realization of the "dual carbon" goal. According to data from the World Economic Forum, it is estimated that by 2030, the application of information and communication technology (ICT) in various industries will reduce carbon emissions by up to 12.1 billion tons. In summary, the digital economy mainly promotes industrial structure transformation and upgrading through industrial digitization and digital industrialization, reduces total carbon emissions and intensity, and helps green low-carbon development.

From the perspective of industrial digitization, big data, Internet of Things and other important foundations driving the development of the digital economy can help enterprises deepen "intelligent +" technological transformation and low-carbon process innovation, carry out full-chain digital transformation of traditional industries, and continuously improve energy-saving and carbon-reducing levels. In the era of digital economy, traditional high-energy-consuming industries are supported by digital technology to build resource recycling platforms and energy management platforms. They can comprehensively monitor the operation and energy consumption emission situation of key equipment through data collection, storage, analysis and management, improve the convenience and accuracy of carbon emission data acquisition, statistics, calculation. This is beneficial to help governments, enterprises and other subjects efficiently obtain carbon index information, accelerate the realization of real-time, digitalization and automation of carbon emission accounting, enhance the intelligent level of carbon emission tracking and carbon asset management, provide data support for orderly promotion of "dual carbon" work. Not only that, but also the continuous integration of digital technology with traditional industries can force enterprises to transform digitally, accelerate the flexible, networked and low-carbon transformation and upgrading of enterprise production operations, optimize resource allocation, reduce total carbon emissions in production links, promote carbon emission performance improvement. Under "Metcalfe's Law", digital technology embedded in traditional high-energy-consuming industries can lead enterprises to innovate green processes, continuously improve green manufacturing systems, enhance enterprises' low-carbon development capabilities throughout their life cycle, thereby helping to achieve "dual carbon" goals with industrial green low-carbon transformation. For example, not only is it beneficial for digital agriculture development to realize full-process traceability and panoramic visualization of breeding, processing, sales and other links but also it can reduce pesticide fertilizer usage with water-saving irrigation and precision fertilization technologies to reduce agricultural production's carbon footprint for realizing agricultural low-carbon development and "dual carbon" goals.

From the perspective of digital industrialization: The development of information communication technology (ICT) industry can promote industrial structure digitization transformation upgrade which has a significant positive externality on economic society green low-carbon development and "dual carbon" goal. Specifically speaking: The continuous expansion of information communication technology (ICT) industry scale will further enrich ICT product types which will prompt ICT products equipment market prices to rapidly decline. Under this circumstance: ICT products equipment will realize replacement for other products equipment in a certain sense which will release "big wisdom cloud" technology diffusion overflow effect on other industry sectors driving industry structure intelligent change. That is to say: Digital industrialization uses modern information technology's integration commercial application as internal driving force which can realize production process's automation intelligent transformation cultivating economic growth new momentum. This is beneficial for strengthening information communication technology (ICT) industry's technical association structural association with traditional industries prompting high energy consumption intensity high carbon emission factor-driven development mode to turn into low energy consumption intensity.

The application of digital technology provides a channel to solve these problems. Based on the above analysis, this article proposes the following hypothesis H1.

H1: The development of the digital economy can reduce the growth rate of carbon emissions.

2.2. Digital Economy and Green Technology Innovation

Do One of the important features of the digital economy is its innovativeness brought by it. The digital economy is conducive to continuous integration and development of green technologies by various enterprises and research institutes. The digital economy has given birth to a large number of emerging industries through extensive use of digital technology, attracting a large number of high-tech and highly educated talents to gather[11], which is conducive to regional green technology innovation development. Digital technology has broken down information barriers, enabling enterprises to better capture market demand for low-carbon products, making enterprises more closely connected with universities and research institutes; new technologies can be applied faster[12], promoting improvement in green technology innovation levels. Green technology innovation is widely used in enterprises, can promote enterprises to improve energy conservation and emission reduction levels, help industrial structure transition towards a green direction, reduce growth speed for carbon emissions from its source, and ultimately achieve peaking carbon emissions[13]. Green technology innovation has expanded development and application scope for renewable energy such as wind energy and photovoltaics in energy utilization fields; it directly reduces carbon emissions and effectively reduces carbon emissions[14]. Based on this analysis, this article proposes hypothesis H2.

H2: The digital economy reduces growth rates for carbon emissions through green technology innovation.

3. Research Design and Data Description

3.1. Model Setting

In order to explore the impact of the digital economy on the growth rate of carbon emissions, this paper uses 30 provinces in China as samples and constructs a benchmark regression equation as follows:

$$PCO2_{i,t} = \alpha_0 + \alpha_1 Dig_{i,t} + \alpha_c Control_{i,t} + \mu_i + \delta_t + \varepsilon_{i,t} \quad (1)$$

$PCO2_{i,t}$ represents the carbon emission growth rate of province i at time t , $Dig_{i,t}$ represents the level of digital economy development of province i at time t , $Control_{i,t}$ represents a set of control variables, μ_i is the fixed effect of the province, δ_t is the fixed effect of time, $\varepsilon_{i,t}$ is the random disturbance term. α_1 is the core coefficient considered in this paper. If α_1 is significantly less than 0, it indicates that the higher the level of digital economy development, the more conducive it is to reducing the growth rate of carbon emissions.

In order to explore the mediating role of green technology innovation in the impact of digital economy on carbon emission growth rate, it is generally believed that there may be a series of problems with the traditional three-step method of mediating mechanism test. According to econometric principles, unless experimental interventions only affect relevant mediators and no other mediators, experimental analysis of mediators will be inaccurate. Considering that the impact of digital economy may affect carbon emission growth rate through multiple mediators, this paper will adopt the common practice of current scholars and only test the impact from explanatory variables to mediating variables. The model is constructed as follows:

$$Med_{i,t} = \beta_0 + \beta_1 Dig_{i,t} + \beta_c Control_{i,t} + \mu_i + \delta_t + \varepsilon_{i,t} \quad (2)$$

$Med_{i,t}$ represents the value of the mediating variable in province i at time t , which refers to green technology innovation in this paper. The other variables are consistent with the above. β_1 is the core coefficient considered. If β_1 is significantly greater than 0, it indicates that the higher the level of digital economy development, the more conducive it is to improving green technology innovation, and thus more conducive to reducing the growth rate of carbon emissions.

3.2. Variables and Data Description

Digital Economy Development Level (*Dig*): Following the practice of Zhao Tao et al. (2020), from five aspects: Internet penetration rate, number of people employed in the Internet-related industry, output related to the Internet, number of mobile Internet users, and development of digital financial inclusion. They are represented by the number of Internet users per hundred people, the proportion of computer service and software employees, per capita total telecommunications services, the number of mobile phone users per hundred people, and the China Digital Financial Inclusion Index. After standardizing the data of these indicators, they are dimensionally reduced using principal component analysis to obtain the level of digital economy development. The original data of these indicators can be obtained from the "China City Statistical Yearbook", and after summing up, provincial data is obtained. The Digital Financial Inclusion Index is compiled by Peking University's Financial Research Center and Ant Financial Services Group.

Carbon Emission Growth Rate ($PCO2_{i,t}$): The annual growth rate is calculated using the carbon dioxide emissions of each province in China each year. The provincial carbon dioxide emissions in China come from the China Carbon Accounting Database (CEADs), .

Green Innovation (*Gre*): Considering that the number of green patent applications cannot well represent the actual green innovation ability, this paper uses the sum of the number of green invention patent authorizations and green utility model patent authorizations in each province each year to represent green innovation ability. The data comes from the China Research Data Service Platform (CNRDs).

Control Variables: Includes four control variables, namely government intervention level (*gov*): represented by the ratio of general budget expenditure to GDP; foreign investment (*fi*): represented by foreign investment/billion dollars; structure of tertiary industry and secondary industry (*str*): obtained by tertiary industry added value: secondary industry added value (billion yuan); total population (*peo*): represented by population sampling survey population. All of the above data comes from provincial data in the "China Statistical Yearbook".

4. Empirical Test

4.1. Descriptive Statistics

Basic descriptive statistics are performed on the data used in this paper. The time span of each data is from 2011 to 2019. See Table 1:

Table 1. Descriptive Statistics of Variables

Variables name	Unit	Sample Size	Mean	sd	Min	Max
Digital Economy Development Index (dig)	-	270	0.341	0.150	0.0773	0.895
Carbon Emission Growth Rate (pco2)	-	270	0.0293	0.0683	-0.153	0.428
Government Intervention Degree (gov)	-	270	0.264	0.115	0.120	0.758
Foreign Investment (fi)	Billion/USD	270	82.82	79.43	0.0446	357.6
Population Quantity (peo)	Pre/Thousand People	270	4589	2824	568	12489
Industrial Structure (str)	-	270	1.292	0.712	0.527	5.234
Green Patent Authorization Number (gre)	-	270	3822	4947	25	33685

According to the descriptive statistics, it can be found that there is a large gap in the calculated digital economy development index among the main variables, indicating that there is a large gap in the development of the digital economy in various provinces in China. The carbon emission growth rate has both positive and negative values, indicating that the level of carbon pollution control in various provinces is different and is also limited by industrial structure issues. In terms of the ratio of industrial structure, it can be seen that the value of the tertiary industry added value to the secondary industry added value in the highest province has already exceeded 5, while some western regions still have the secondary industry added value surpassing the tertiary industry, which is closely related to the internal provincial transfer of polluting industries in China. In terms of the number of green patent authorizations, there is a large gap in the green technology innovation capabilities of various provinces, and the standard deviation is extremely high. The unbalanced development of China's innovation capabilities is still a major issue in pollution prevention and control.

4.2. Benchmark Regression and Mechanism Test

Columns (1) - (5) of Table 2 report the results of the benchmark regression model set in the second part after adding control variables respectively: It can be found that the coefficient of the measured digital economy development index is significantly negative and the absolute value of the coefficient increases after adding control variables in succession, growing from 0.118 to 0.119. Although the increase is not significant, it remains significant at the 1% level overall, and R2 continues to increase and the regression effect improves. This indicates that the higher the level of digital economy development, the lower the carbon emission increment rate in China's provinces, and they have a negative impact relationship. Hypothesis H1: The development of the digital economy can reduce the carbon emission growth rate is confirmed.

Among other control variables, the coefficient of population quantity is significantly negative, indicating that the higher the population, the lower the carbon emission increment rate. Common sense and existing scholars' research show that the more population, the more carbon emissions, but this study shows that the more population, the lower the carbon emission growth rate. This indicates that in cities with large populations, although total carbon emissions are high, provinces with high population agglomeration have higher development levels and pay more attention to carbon emission control, so carbon emission growth is low; The coefficient of foreign investment is negative, indicating that areas with high foreign investment may have a lower carbon emission growth rate, but the result is not significant and has a low impact level; The coefficient on industrial structure is significantly negative, indicating that cities with a higher proportion of tertiary industry have a lower carbon emission growth rate. Since tertiary industry tends to be more environmentally friendly compared to secondary industry, this is consistent with our reality; However, it is not significant on government intervention level, indicating that government intervention actually has a small impact on carbon emission growth rate. The reason is that in practice, government interference in carbon emissions is mainly through issuing documents rather than financial means.

Table 2. Regression Results

Variables	pco2					gre
	(1)	(2)	(3)	(4)	(5)	(6)
dig	-0.118***	0.122***	-0.117***	-0.120***	-0.119***	3.303***
peo		-0.016***	-0.014***	-0.015***	-0.016***	0.052**
fi			-0.003	-0.003	-0.005	0.163***
str				-0.01*	-0.01*	-0.145*
gov					-0.042	-4.879***
Constant Term	0.070***	0.238***	0.231***	0.256***	0.277***	6.721***
Regional Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Number of Variables	270	270	270	270	270	270
R-sq	0.0719	0.1478	0.1529	0.1633	0.1649	0.8097

Note: ***, **, and * represent passing the test at the significance levels of 1%, 5%, and 10% respectively.

Column (6) of Table 2 reports the results of the green innovation mediation regression model set in the second part after adding control variables: The coefficient of the digital economy development level on green technology innovation is significantly positive, indicating that the improvement of the digital economy level helps stimulate green technology innovation, and then reduces the carbon emission growth rate according to the theoretical analysis part above, verifying H2: The mechanism effect of green technology innovation. Among other control variables, population quantity and foreign investment both show strong significance, indicating that population agglomeration and foreign investment both contribute to green technology innovation; A special finding is that in government intervention, the coefficient is significantly negative, indicating that the degree of government intervention not only cannot promote green innovation but will reduce the overall level of green innovation.

4.3. Heterogeneity Analysis

Table 3 reports the sub-sample regression results after dividing the sample into eastern, central, and western regions: In the sub-sample regression, we mainly focus on the coefficients and significance of the core explanatory variable, i.e., the level of digital economy development. The negative impact of the level of digital economy development on carbon growth rate is more pronounced in the western and central regions than in the eastern region. The absolute values of the coefficients in the western and eastern regions are about 0.21, while in the eastern region it is only 0.052 with a lower level of significance. This is consistent with the uneven development levels in the eastern, central, and western regions of our country. The western and central regions have more polluting industries and a lower level of digital economy development compared to the eastern region, so the effects of digital economy development are more pronounced; The eastern region itself has a higher level of digital economy development and some polluting industries have been partially transferred.

Table 3. Heterogeneity Results

Variables	pco2		
	West	Mid	East
dig	-0.213**	-0.208**	-0.052*
peo	-0.024**	-0.014*	-0.005
fi	0.001	0.001	-0.017*
str	-0.027	-0.073*	-0.009
gov	0.011	0.197	-0.136
Constant Term	0.387***	0.266*	0.216***
Regional Fixed Effects	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes
Number of Variables	99	72	99
R-sq	0.2266	0.1528	0.1356

Note: ***, **, and * represent passing the test at the significance levels of 1%, 5%, and 10% respectively.

4.4. Robustness Test

To further test the negative linear relationship between the digital economy and the growth rate of carbon emissions, this paper conducts a robustness test by changing the dependent variable, selecting instrumental variables, and changing the measurement method of the digital economy.

(1) Replace the dependent variable with per capita carbon emissions, calculate the carbon emission growth rate, and further observe whether the conclusion holds after replacing the variable. Column (1) of Table 4 is the regression result of the digital economy on the growth rate of per capita carbon emissions, which is basically consistent with the previous results, proving that the results are robust.

(2) Select instrumental variables. Following Zhao Tao's (2020) approach, we use historical postal data from 1984 as an instrumental variable for the digital economy development index. On one hand, as an extension of traditional communication technology, historical telecommunications infrastructure influences subsequent internet technology applications in terms of technical level and usage habits, satisfying relevance. On the other hand, the impact of telecommunications tools such as landline phones on economic development gradually weakens as their usage frequency decreases, satisfying exclusivity. However, there is a problem that this data is cross-sectional and cannot be directly used for panel econometric analysis. Referring to its processing method, we construct an interaction term between the number of internet users nationwide in the previous year and the number of telephones per 10,000 people in each province in 1984 as an instrumental variable for the digital economy index. The results are shown in column (2) of Table 4, proving that our regression results are robust.

(3) The digital economy development index in this paper is measured by principal component analysis. After changing to entropy method, the regression results are shown in column 3 of Table 4, confirming that our regression results are robust.

Table 4. Robustness Results

Variables	(1) Growth Rate of Per Capita Carbon Emissions	(2) Instrumental Variable	(3) Entropy Method Digital Economy Index
dig	-0.1259**	-3.234***	-0.1744***
Sample Size	270	270	270
R-sq	0.1397	0.4233	0.1624

Note: ***, **, and * represent passing the test at the significance levels of 1%, 5%, and 10% respectively.

5. Conclusion

This paper studies the impact of the digital economy on the growth rate of carbon emissions at the provincial level and draws the following conclusions:

First, there is a significant negative correlation between the digital economy and the growth rate of carbon emissions, i.e., the development of the digital economy will significantly reduce the growth rate of carbon emissions.

Second, the digital economy can reduce the growth rate of carbon emissions by promoting green technology innovation, with green innovation playing a positive role.

Third, the negative correlation between the digital economy and the growth rate of carbon emissions is more pronounced in the western and central regions of China than in the eastern region.

Based on these research conclusions, we propose the following insights:

Improve the speed and quality of digital economy development. We need to accelerate the development of the digital economy, which includes digital industrialization and industrial digitization. Currently, there is a large gap in the level of digital economy development between eastern, central, and western China. We need to increase infrastructure construction in central and western regions that can support digital technology and platforms, such as base stations, data centers, applications of artificial intelligence, etc., to promote digital transformation. At the same time, we need to pay attention to energy-saving and emission-reducing technologies in digitization, improve energy utilization efficiency, enhance the quality of digital economy development, and focus on talent cultivation in digital economy-related education fields.

Pay attention to the development of green innovation technology. This study finds that green technology innovation is a powerful mechanism for the impact of digital economy development on carbon emission growth rate. While promoting efficient development of the digital economy, we should also pay attention to the development and follow-up of related innovative technologies. The government should play a good role in management, supervision, and regulation to form an efficient operating development system with macro governance and micro implementation.

To enhance the speed and quality of digital economy development, it's crucial to expedite the progression of the digital economy, which encompasses both digital industrialization and industrial digitization. Presently, there's a significant disparity in the level of digital economy development between eastern, central, and western China. It's necessary to augment infrastructure construction in central and western regions that can support digital technology and platforms. This includes base stations, data centers, and applications of artificial intelligence, among others, to foster digital transformation. Simultaneously, we need to pay heed to energy-saving and emission-reducing technologies in digitization, improve energy utilization efficiency, enhance the quality of digital economy development, and concentrate on talent cultivation in digital economy-related education fields.

Moreover, it's important to focus on the development of green innovation technology. This study reveals that green technology innovation is a potent mechanism for the impact of digital economy development on carbon emission growth rate. While promoting efficient development of the digital economy, we should also pay attention to the development and follow-up of related innovative technologies. The government should play a good role in management, supervision, and regulation to form an efficient operating development system with macro governance and micro implementation.

In summary, achieving a balance between rapid digital economic growth and environmental sustainability requires a multi-faceted approach. This includes accelerating the digitization of industries, improving infrastructure in less developed regions, promoting energy-efficient technologies, and fostering innovation in green technologies. Furthermore, government regulation and oversight play a crucial role in ensuring that these developments are carried out in a manner that is beneficial to both the economy and the environment.

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