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Digital Economy, Technological Innovation and Carbon Productivity

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Abstract
Digital development has become increasingly important in mitigating the pressure on carbon emissions. This paper uses the data of 30 provinces in China from 2010 to 2019, introduces the intermediary effect model, builds a theoretical framework for the technological innovation, carbon, digital economy, and empirically tests the mechanism of the three. The research finds that: (1) Digital economy and technological innovation have a strong positive impact on the improvement of carbon productivity, and the impact of digital economy is significantly higher than that of technological innovation. (2) As an intermediary variable, innovation is the core transmission channel for digital economy to develop China's carbon productivity, effectively transmitting the impact of digital economy development to carbon productivity. (3) The impact of digital economy on carbon productivity in different regions is different. The most obvious impact is in the east.

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Keywords: economy; technological innovation Carbon productivity; intermediary effect

1. Introduction

The problem of global climate change caused by carbon emissions is becoming more and more serious. Extreme weather, land drought, pests and diseases, forest fires and other natural disasters occur frequently. Countries around the world take multiple measures to effectively mitigate global warming. The problems about environment caused by carbon emissions have a significant impact on people's lives and social development, causing huge economic losses. China is trying to find the balance between economic development, environmental pollution and social progress, hoping to achieve optimal output at the minimum cost of resources and environment. China promises to achieve carbon peak and carbon neutral by 2030 and 2060 respectively. To achieve this goal, we must pay close attention to carbon productivity. Because carbon productivity has been used as an important bridge to connect economic growth and control carbon emissions since it was proposed. Choosing the path of improving carbon productivity to reduce carbon emissions is an inevitable choice to achieve low-carbon and high-quality development.

In recent decades, China's economy has developed rapidly. After going through the agricultural and industrial economic development stage mainly supported by land, labor, capital and technology, China's economy has moved towards the economic stage with digitalization as the core. Digital economy is a new form, it upgrades and reshapes the production, life and governance of society from different dimensions, promotes the diversified development of low-carbon industrial structure, and makes the entire industrial chain more "green". Obviously, the two indicators play an irreplaceable role in low-carbon green development. What is the connection between carbon productivity and digital economy? How does the digital economy affect carbon productivity, and what are the ways and means of impact? Is there any difference in its impact on carbon productivity in different areas? In view of the above issues, this paper studies the impact of digital economy on carbon, which not only has some enlightenment significance for economic development, but also provides empirical evidence for the path choice of achieving the "dual carbon" goal.

2. Ease of Use

In 2020, the scale of China's digital economy will be about 39.3 trillion yuan. In 2021, the scale of the Internet center service market, the scale of the cloud computing market and the scale of the artificial intelligence core industry will respectively exceed

150 billion yuan, 210 billion yuan and 410 billion yuan. The digital economy has become the focus of the global industry. First, the digital economy is a new driving force, and its development is conducive to rapid economic growth. Second, many scholars believe that the digital economy can improve the utilization rate of production resources. Third, digital economy is an essential part for the development of ecological greening.

In essence, technological innovation is conducive to a more rational allocation of economic factors among industries and a continuous improvement of economic and efficiency levels among industrial sectors. China's technology is bound to move to the high-end ranks without the important driving force of digital economy. Therefore, scholars finish many research on how digital economy affects technological innovation from many ways. First of all, many scholars believe that digital economy directly promotes technological innovation through digital industrialization and industrial digitalization. Second, digital economy indirectly acts on technological innovation. Digital economy promotes technological innovation by changing the allocation of capital, innovation, efficiency, labor and other factors among industries. Other studies believe that digital economy is a technology, which can effectively promote the transfer of labor-intensive industrial structure to a high-tech, low-carbon and green industrial structure.

Technological innovation. It is beneficial to reduce carbon emission intensity and improve carbon productivity. Feng & Wu (2022) [1] believed that the reasonable upgrading of industrial structure and technological innovation had a significant positive impact on the improvement of carbon productivity. Compared with the central and western regions, the rationalization of industrial structure and technological innovation has played a more important role in increasing carbon productivity in the eastern region. Wang & Feng (2020) [2] used the total factor productivity estimation method, combined with GEBML-DEA and spatial measurement model, to verify that technological innovation can effectively reduce carbon emission intensity. Liu *et al*. (2021) [3] used the dynamic spatial Dubin model and data from 30 provinces in China to examine The impact of breakthrough low-carbon technology innovation on carbon emissions, and found that breakthrough low-carbon technology innovation can effectively reduce carbon emissions, relieve the pressure of emission reduction. Zhang *et al*. (2022) [4] discussed the internal mechanism of high-tech industries on carbon productivity based on the intermediary effect model, and found that high-tech industries can improve carbon productivity by virtue of economies of scale and total factor productivity.

The impact of digital economy on carbon productivity

The digital economy can increase carbon productivity by improving the efficiency of information transfer through technology. The use of advanced digital technology, the integration of data and the reduction of resource consumption at the production end will help reduce the demand and intensity of energy consumption, increase the growth rate of carbon productivity and reduce carbon emissions. Digital economy can also improve carbon productivity through allocation effect, optimizing resource allocation and improving energy utilization efficiency [5]. The application and promotion of digital technology can better understand the trend of the energy market and the trend of price changes, ensure the supply of energy, guide the efficient allocation of energy factors, promote the smooth upgrading and optimization of energy flow, improve the output value increment of unit energy, reduce energy intensity step by step, form a new mode of economic and energy consumption, enhance the integrated development of digital low-carbon. Thus improve carbon productivity. Based on the above analysis, research hypothesis 1 is proposed.

H1: The impact of the digital economy on the improvement of carbon productivity is significant.

The Influence of Digital Economy on Technological Innovation

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From a macro perspective, the digital economy promotes the healthy and efficient development of digital industrialization and industrial digitalization, brings new production factors such as information, technology and data to the industrial development, and improves the industrial technical efficiency and innovation efficiency with the help of universal, enabling technologies and network connectivity effects [6]. This can stimulates the development of emerging industries and reshapes the new form of industrial structure. From a micro perspective, the rapidity, high permeability and improve the industrial proportion relationship, enhance labor productivity, promote the efficiency of information transmission between industrial chains, reduce transaction costs such as information collection, inequality and lag, promote the optimization and improvement of production, transportation, sales and consumption, and achieve the improvement of production efficiency, coordination efficiency and operation efficiency, So as to promote the level of technological innovation. Therefore, research hypothesis 2 is proposed.

H2: The digital economy can significantly promote technological innovation with the help of the technology community integrating multiple technologies.

The intermediary effect of technological innovation between digital economy and carbon productivity

According to the analysis, the development of digital economy will enhance the carbon productivity. As the representative of innovation driven economy, digital economy has promoted technological innovation to an unprecedented height. Digital economy, technological innovation and carbon productivity interact and promote each other, and are closely integrated into an indivisible whole [7]. The development of the digital economy is benefit for the transformation of industrial sectors and the birth of new industries. With the integration and integration effect of the digital economy, the cross-border integration and mode reconstruction of traditional industries are boosted, building a bridge for the coordinated development of the digital economy and low-carbon economy, improving production efficiency, reducing energy efficiency ratio, gradually easing the pressure on carbon emissions, and improving carbon productivity. Based on the above analysis, research hypothesis 3 is proposed.

H3: As an intermediary variable, technological innovation significantly regulates the relationship between the digital economy and carbon productivity.

H4: The intermediary effect of technological innovation has regional heterogeneity.

Index selection and model design

Explained variable: carbon productivity. It refers to the GDP output level per unit of carbon dioxide. This paper refers to relevant international data and the unified standard method recommended by IPCC to calculate the CO2 emissions of all provinces (regions and cities) in China. The formula is as follows:

$$CE_t = E_i \times T_i \times LCV_i \times CEF_i \times O_i \times \frac{44}{12} \quad (1)$$

$$cp = \frac{GDP}{CE} \quad (2)$$

Where, CEt represents the total carbon emissions of a province in year t; Cp is the carbon production rate; GDP is the gross domestic product. Ei, Ti, LCVi, CEFi and Oi represent the consumption of fuel i, coefficient of standard coal, coefficient of low calorific value, carbon emission coefficient and oxidation rate of fuel i respectively; 44/12 is the molecular weight ratio of CO2 to C. The physical quantity of energy consumption is taken from the energy balance sheet. The selected energy includes coal, coke, crude oil, gasoline,

2. Core explanatory variable: development level of digital economy. This paper decomposes the digital economy index from the four dimensions of informatization, Internet development, network industry practitioners and digital transactions, and selects 12 measurement indicators, such as optical cable density, electronic equipment manufacturing owner business income, mobile phone base station density, technical transformation expenditure of industrial enterprises above designated size, total telecom business, software business income, information technology service income, mobile phone penetration rate The proportion of broadband Internet users, e-commerce sales, e-commerce share, and the total amount of mobile payments, thus designing a digital economy index measurement system to comprehensively measure the level of digital economy in China's provinces (districts, cities). The data are from the China Statistical Yearbook from 2010 to 2020. Using the linear weighting method and combining the 12 indicators selected in this paper, measure the development level of digital economy. The calculation formula is as follows:

$$de = \sum_{j=1}^{12} M_{it} \times N_j \quad (3)$$

Where, j represents the standardized measurement index; Nj represents the weight of the jth measurement index relative to the level of the digital economy. This paper refers to the NBI index weight determination method for weighting.

Data source and description statistics

30 provinces (autonomous regions and municipalities) in China (excluding Tibet, Hong Kong, Macao and Taiwan, China) were selected as the research objects. The descriptive statistical results of each variable are shown in Table 1. In order to more clearly analyze the change trend of the three main variables of digital economy, technological innovation and carbon productivity in 30 provinces (autonomous regions and municipalities) between 2010 and 2019, this paper calculates the average value of these three variables in different provinces (autonomous regions and municipalities) and expresses them in logarithms.

Table 1: Descriptive Statistical Results of Variables

Variable	Observations	Mean value	Standard deviation	Minimum value	Maximum
lncp	300	-0.4169	0.5950	-1.7091	1.2758
lnde	300	0.8095	0.4355	-0.2613	2.0055
lninno	300	8.0024	1.4434	3.7135	10.997
lnurban	300	-0.5832	0.2081	-1.0846	-0.1097
lneef	300	-0.5752	0.1950	-1.1301	0.2510
lnfdi	300	-4.2749	1.1271	-8.4089	-2.5318
lnstr	300	-0.8002	0.2246	-1.3313	-0.1255

Regional heterogeneity test

From the digital economy development level of 30 provinces measured above, there is an obvious digital divide between different regions, which infers that the impact of digital economy on carbon productivity in different regions may be different. In order to test whether the economy has a significant impact on the development of carbon productivity in some regions, this paper divides 30 provinces (regions and cities) into three regions: the eastern region, the central region and the western region ①. The results show that the digital economy has the greatest impact on carbon productivity in the eastern region. The main reason for this result may be that compared with the central and western regions, the eastern regions have relatively high levels of digital economy and technological innovation. The development of digital economy and the improvement of technological innovation have a positive effect on promoting the transformation of industrial structure, which is more conducive to the improvement of carbon productivity; The second is the central region, which has relatively little impact on the western region. This may be due to the large gap between the two area and the eastern regions in R&D, production, commerce and management digitalization. In addition, the problem of digital talent shortage will also restrict the improvement of digital economy on technological innovation.

Conclusions and policy recommendations

According to the research conclusion, digital economy and technological innovation have a significant positive impact on the level of carbon productivity, while the impact on carbon productivity varies greatly in different regions. This paper puts forward the following suggestions: First, tap the development potential of digital economy, improve the level of related industries, and expand the development space of digital economy. Digital economy is becoming an important force that cannot be ignored in the world economy, and digital economy will become a hot field of competition in the world in the future. Therefore, we should expand the development space of the digital economy, strengthen the cooperation between the digital economy and the real economy, improve their development, and introduce more new industries, new formats and new models. Second, consider the regional heterogeneity of digital economy and technological innovation, and coordinate the integrated development of economy and low carbon according to local conditions. The research results show that the role of digital economy and technological innovation in improving carbon productivity in the western and central regions is relatively

weak, which indicates that the development of digital economy in the western and central regions is relatively weak and relevant technologies may need to seek breakthroughs. Therefore, we should make every effort to seize the development opportunities, create a characteristic digital industry, and release the dividend of the digital economy in reducing carbon emissions and improving carbon productivity.

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