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A Study On The Impact of The Digital Economy on China's Carbon Neutrality Capability

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Abstract. The digital economy is a new economic form driven by digital technology, which contains green and low-carbon effects and can promote the transition to a resource-saving and environmentally friendly society. This paper explores the impact of the digital economy on carbon neutrality capability using panel data from 30 provinces in China between 2013 and 2021and finds that the digital economy has a positive effect on carbon neutrality capability with non-linear characteristics. It has a positive and then a negative effect on carbon reduction capability, as well as a positive effect on carbon removal capability. The digital economy can aid various societal actors in enhancing carbon neutrality capability by promoting corporate technological innovation, encouraging public green consumption, and adjusting government environmental regulations.

Keywords: Digital economy; carbon neutrality capability; technological innovation; green consumption; environmental regulation.

1. Introduction

At present, climate warming continues, and the climate issue has become a serious challenge that the world has to face. China, as a responsible big country, has clearly proposed to actively and steadily promote carbon peak carbon neutral. Embarking on the "dual carbon" journey, on time, quality and efficiently out of China's own green sustainable development road is a hot topic being discussed by all walks of life. In this regard, academics have actively explored, scholars from multiple dimensions and combined with the reality of China's national conditions to explore the realization of the "dual carbon" goal of the path, in which the digital economy to the rapid pace of development, radiation, the degree of influence of a wide range of deep striking and related to the overall situation of the country's development has become a general trend. The digital economy brings digital productivity that can promote changes in production and lifestyle and promote the development of society towards resource-saving and environment-friendly. In line with the development trend of the digital economy, taking advantage of the momentum to promote the realization of carbon neutrality is a choice in line with the reality of the national situation. Digital economy is based on digital technology, with data elements as the core, so we can make use of the changes brought by the development of digital economy, such as new technologies and new elements, to stimulate and make full use of the green and low-carbon effect, mobilize the government, enterprises, and the public's low-carbon and environmental protection initiative, so that the digital economy can become a new engine of leading the economic development, and also become the new weapon of low-carbon and sustainable development. Therefore, it is necessary to systematically explore and empirically test the specific realization path of the digital economy to the goal of carbon neutrality, so as to provide reference for the current digital road to enhance carbon neutrality.

2. Literature Review

At present, carbon neutrality has become the climate governance goal of many countries in the world, but the expression of this goal varies from country to country, and there are also differences in the connotation. The expressions related to carbon neutrality include net zero, zero carbon, climate neutrality, absolute emission reduction, etc. The differences are manifested in the scope of the covered gases and the accounting rules, etc., and there are a number of countries with the same expression,

but there are still differences in their specific connotations, and the international expression of "net zero" is more frequent, i.e., net zero carbon dioxide emissions. Rosenbloom and Meadowcroft [1] point out that the various sectors of society are closely related to greenhouse gas emissions, so the realization of the "net-zero" goal requires the joint efforts of society. Promoting the realization of the net-zero goal will involve a full range of changes in policy, technology, and social practices, such as incentives for technological innovation of new low-carbon products [2], and low-carbon guidance for personal behavior and lifestyle [3].

The digital economy, with digital technology as its core driving force, helps predict, analyze and track product life cycles [4], enhances the ability to organize production, supply, logistics and recycling, and maximizes the use of the product life cycle [5], thus helping the economy to shift from the linear process of production, use and disposal to the circular sustainable process of recycling and reuse, and to achieve the goal of "net-zero" through the promotion of low-carbon development by means of the circular economy. When discussing the basic path of carbon neutrality with the help of digital economy, scholars mostly focus on the two aspects of carbon neutrality, i.e., reducing carbon emissions and increasing carbon sinks, which are summarized as "controlling the increment" and "reducing the stock". In order to achieve China's green, low-carbon and sustainable development, the digital economy, as a means and a tool, can promote the green transformation of production and lifestyle, optimize the energy structure and improve the efficiency of energy use in terms of emission reduction; in terms of carbon sinks, it can enhance the capacity of carbon sinks in the natural environment and improve the technology of carbon sinks. The project of realizing the goal of carbon neutrality through the digital economy is systematic, huge and complex, and requires the digital transformation of all fields of society to help the generation, enhancement and transformation of the green consciousness of all social subjects, and ultimately the formation of a good situation in which all the members of the society work together to promote green development.

In summary, scholars have explored the digital economy and carbon neutrality, but since the carbon neutrality targets of various countries are mainly formally proposed after 2017, the academic research on the impact of the digital economy on carbon neutrality is still in its infancy. Compared with the existing literature, the possible contributions of this paper are: (1) to add the carbon removal perspective to the existing basis of studying the impact of the digital economy on carbon emissions, and to empirically test the mechanism of the digital economy's effect on carbon neutrality; (2) based on the connotative division of dimensions of carbon neutrality, to further explore the nonlinear and heterogeneous characteristics of the impact effect; (3) based on the framework of mechanism analysis of each social subject, we explore the subjective initiative and synergistic effect played by enterprises, the public and the government in the digital economy empowering green and low carbon.

3. Data and Methodology

3.1. Data

This paper utilizes panel data from 30 provinces in China from 2013-2021 for empirical analysis. The explanatory variable is carbon neutralization capacity (*tan*). Satisfying the principles of data availability, systematicity, research relevance and scientificity, according to the definition of carbon neutral capacity, and based on the reference to the "Establishment of a Sound Carbon Peak Carbon Neutral Standard Measurement System Implementation Program" and the existing research, the entropy weighting method is used to assign weights to ultimately measure and obtain the level of carbon neutral capacity. The core explanatory variable is the digital economy (*dig*). The digital economy has gone through a long history of development and research, and the connotation is constantly changing and enriched. In this paper, according to the connotation of the digital economy, the entropy weighting method is used to give weight, and ultimately the level of development of the digital economy is measured. This paper selects seven variables as control variables, namely, the proportion of utilized foreign capital, fiscal decentralization, fiscal dependence, consumption scale, human capital, advanced industrial structure and rationalization of industrial structure.

3.2. Methodology

3.2.1. Benchmark regression model

Overall to explore the impact of the digital economy on carbon neutral capacity, an econometric model is constructed as follows:

$$tan_{it} = \alpha_0 + \alpha_1 dig_{it} + \alpha_c Z_{it} + \omega_i + \sigma_t + \varepsilon_{it} \quad (1)$$

Where *i* is the region, *t* is the year, *tan* is the carbon neutral capacity, *dig* is the digital economy, *Z* are the control variables, α_0 is the intercept term, ω_i is the province fixed effect, σ_t is the time fixed effect, ε_{it} is the residual term.

3.2.2. Sub-dimensional regression model

Based on the fact that the connotation of carbon neutral capacity involves both carbon emission reduction and carbon removal, it is necessary to explore the differential impact of the digital economy on the sub-dimensions of carbon neutral capacity, and construct an econometric model as follows:

$$cpai_{it} = \alpha_0 + \alpha_1 dig_{it} + \alpha_2 dig^2_{it} + \alpha_c Z_{it} + \omega_i + \sigma_t + \varepsilon_{it} \quad (2)$$

$$cyc_{it} = \alpha_0 + \alpha_1 dig_{it} + \alpha_c Z_{it} + \omega_i + \sigma_t + \varepsilon_{it} \quad (3)$$

Where *cpai* and *cyc* are the sub-dimensions of carbon neutral capacity (carbon reduction capacity and carbon removal capacity), dig^2 is the squared term of the digital economy.

3.2.3. Threshold effect model

Considering the impact of the digital economy on carbon neutrality under different scenario levels, referring to Hansen's threshold test model, the threshold model is constructed as follows:

$$tan_{it}=\theta_0+\theta_1 dig_{it}\times I(Q_{it}\leq\rho_1)+\theta_2 dig_{it}\times I(\rho_1<Q_{it}\leq\rho_2)+\theta_3 dig_{it}\times I(\rho_2<Q_{it})+\theta_c Z_{it}+\omega_i+\sigma_t+\varepsilon_{it} \quad (4)$$

where *I(.)* is the threshold variable and ρ denotes the threshold value.

4. Results

4.1. Benchmark regression results

The Hausman test was conducted, and the results rejected the original hypothesis, i.e., the fixed effects model was chosen to explore the direct impact of the digital economy on carbon neutral capacity, and the regression was conducted using robust standard errors. The regression results are shown in column (1) and column (2) of Table 1, which shows that the regression coefficient of digital economy on carbon neutralization capacity is significantly positive regardless of whether control variables are added or not, i.e., digital economy can significantly enhance carbon neutralization capacity.

Table 1 Benchmark regression results

	(1)	(2)
	tan	tan
dig	0.417***	0.443***
	(7.44)	(5.70)
Control Variable	No	Yes
Province Fixed Effect	Yes	Yes
Year Fixed Effect	Yes	Yes
Intercept Term	0.272***	-0.114
	(39.01)	(-0.21)
N	270	270
R^2	0.738	0.756

Note: Numbers in brackets are t-values. *, **, *** denote statistical significance at the 0.1, 0.05, and 0.01 levels, respectively.

4.2. Sub-Dimensional Analysis

The regression results of the digital economy on the sub-dimension of carbon neutral capacity are listed in Table 2. Column (1) shows the regression results of the digital economy on the carbon emission reduction capacity, and the coefficient of the squared term is significantly negative, which means that the digital economy has a non-linear effect of low-level promotion and high-level inhibition on the carbon emission reduction capacity. The value of the digital economy turning point for promotion to inhibition is 0.563, i.e., 0.450/(2×0.400), and only two regions, Beijing and Shanghai, cross this value in 2021, so that most of China is still in the stage of the growth of carbon emission reduction capacity promoted by the digital economy, and the carbon reduction impacts such as the greening effect of the data elements and the energy efficiency enhancement effect of the digital economy are larger than the carbon reduction effects brought by it. The carbon reduction impact of the greening effect of data elements and the energy efficiency improvement effect brought by the digital economy is greater than the carbon increase impact brought by its own and indirect demand-induced expansion effect. Column (2) shows the regression results of the digital economy on carbon removal capacity, and the regression coefficient is significantly positive, that is, the digital economy can enhance carbon removal capacity.

Table 2 Results of the sub-dimensional impact analysis

	(1)	(2)
	cpai	cyc
dig	0.450** (2.06)	0.780*** (7.58)
dig^2	-0.400*** (-2.92)	
Control Variable	Yes	Yes
Province Fixed Effect	Yes	Yes
Year Fixed Effect	Yes	Yes
Intercept Term	-0.306 (-0.74)	0.040 (0.04)
N	270	270
R^2	0.771	0.656

Note: Numbers in brackets are t-values. *, **, *** denote statistical significance at the 0.1, 0.05, and 0.01 levels, respectively.

4.3. Nonlinear analysis

4.3.1. Carbon neutral capacity as a threshold variable

The number of thresholds was first identified, and a double threshold effect was found. Then the double threshold effect model is regressed, and the regression results are listed in Table 3, and the two thresholds of carbon neutral capacity are 0.314 and 0.435 respectively. From 2019 to 2021, the regions whose carbon neutral capacity level is always greater than 0.435 include Beijing, Jiangsu, Zhejiang, etc., mostly provinces in the eastern region. From 2013 to 2021, the average value of carbon neutral capacity is below 0.314 in Inner Mongolia, Guangxi, Yunnan, etc., mostly in western provinces. As shown in column (1) of Table 3, as the level of carbon neutrality crosses the two thresholds, the effect of the digital economy on carbon neutrality changes from insignificant to significant, and the regression coefficient grows from 0.254 to 0.415 at the significant level, i.e., with the increase of the level of carbon neutrality, the effect of the digital economy on carbon neutrality shows a non-linear characteristic of gradually increasing, and the effect of the digital economy on carbon neutrality increases with the increase of the level of carbon neutrality.

Table 3 Double threshold effect regression results

		(1)			(2)
		tan			tan
dig	tan≤0.314	-0.011 (-0.13)	dig	cyc≤0.270	0.095 (1.40)
	0.314<tan≤0.435	0.254*** (4.10)		0.270<cyc≤0.319	0.288*** (4.58)
	Tan>0.435	0.415*** (7.38)		Cyc>0.319	0.421*** (6.79)
Intercept Term		-0.408 (-1.16)	Intercept Term		-0.482 (-1.43)
N		270	N		270
R^2		0.796	R^2		0.813

Note: Numbers in brackets are t-values. *, **, *** denote statistical significance at the 0.1, 0.05, and 0.01 levels, respectively.

4.3.2. Carbon emission reduction capacity as a threshold variable

First identify the number of thresholds, the test results are listed in Table 4, none of the threshold effects are significant. That is, with the enhancement of the level of carbon emission reduction capacity, the impact of the digital economy on carbon neutral capacity does not have a non-linear characteristic.

Table 4 Threshold effect test results

Threshold variable	Threshold type	F-statistic	P-value	10% critical value level	5% critical value level	1% critical value level
Carbon Emission Reduction Capacity	Single Threshold	12.20	0.287	16.218	19.842	29.234
	Double Threshold	8.08	0.473	15.002	17.032	25.553
	Triple Threshold	8.71	0.610	17.638	21.182	26.773

4.3.3. Carbon removal capacity as a threshold variable

The number of thresholds was first identified, and a double threshold effect was found to exist. Then the double-threshold effect model is regressed, and the regression results are listed in Table 3, the two thresholds of carbon removal capacity are 0.270 and 0.319 respectively. during the study period, the regions with carbon removal capacity levels greater than 0.319 include Zhejiang, Beijing, Jiangsu and Hebei, mostly provinces in the eastern region. from 2013 to 2021, the carbon removal capacity level averaged below 0.270 include Yunnan, Xinjiang and Shaanxi, mostly provinces in the central and western regions. As shown in column (2) of Table 3, as the level of carbon removal capacity crosses the two thresholds, the effect of digital economy on carbon neutral capacity changes from insignificant to significant, and the regression coefficient grows from 0.288 to 0.421 at the significant

level, i.e., with the increase of the level of carbon removal capacity, the promotion effect of digital economy on carbon neutral capacity shows the nonlinear characteristic of gradual increase.

5. Discussion

5.1. The role of corporate technological innovation

The digital economy enhances carbon neutrality by promoting enterprises to actively realize technological innovation. The digital economy can stimulate the development of green technology, with its own green low-carbon data elements to join the enterprise production, and energy, production and carbon sinks and other technologies, the integration of existing resources, free of space and time constraints, access to knowledge and information sharing and exchange, digestion and absorption of knowledge spillover from other regions, break through the bottlenecks of innovation, resulting in new green and low-carbon technologies, thereby improving the efficiency of energy use, removing excess losses in the production process, reducing the external carbon dioxide emissions. The application of big data and other digital technologies can provide accurate and timely feedback on internal enterprise and external market information, thus integrating data resources, solving the information blind spot of technological innovation, helping enterprises to clarify the direction of technological innovation, and improving the quality of technological innovation on the basis of shortening the cycle of innovation to improve the efficiency of technological innovation, stimulate the enthusiasm of enterprise innovation, and ultimately realize the low-carbon and green transformation of enterprises.

5.2. The role of public green consumption

The digital economy enhances carbon neutrality by promoting the public's preference for green consumption and reducing the consumption of time and energy in the consumption process. Consumers in the purchase of green products, the psychology will generally go through the three processes of cognition, emotion and will, the digital economy can promote public green consumption by influencing the consumer purchase process. In the cognitive link, due to the outstanding environmental problems, the public's pursuit of green environmental protection concepts will drive its attention to the corresponding green products, digital economy to help the public can be more convenient access to low-carbon environmental protection knowledge and green product information; in the emotional link, the dissemination of green product information on the network, so that more consumers will receive the green product knowledge, and then form the corresponding thinking, to produce whether to purchase Intention; in the will link, when consumers have the corresponding social and emotional needs, the digital economy can provide consumers with consumption channels to facilitate their rapid and clear purchase goals and make purchase decisions. Compared with traditional offline consumption, the time, energy, and material costs consumed by the digital economy to participate in the consumption process are reduced. The increase in green consumption by the public guides products to favor the green and low-carbon direction, thus reducing pollution in the links of production, use and disposal and realizing green and low-carbon development. However, after green consumption, based on the moral certificate model in the moral licensing effect, it is difficult to sustain green consumption, because consumers will construct a moral image in the process of green consumption to rationalize the subsequent behavior of reducing green consumption or even overconsumption, which makes the promotional effect of green consumption on the ability of carbon neutrality unsustainable.

5.3. The role of government environmental regulation

The digital economy enhances carbon neutrality by regulating the efficient implementation of environmental regulations by governments. The government has different types of environmental interventions. For command-and-control environmental regulation, the government introduces digital technology to facilitate the collection of environmental information, formulate and improve policies and regulations according to the real situation, and build more transparent and convenient

environmental monitoring and supervision channels in the process of policy implementation, so that it can receive feedback on the effects in time and reasonably grasp the process of policy implementation, thus forcing the "man-made" activities to become low-carbon green at a lower cost and with higher effectiveness. The digital economy has an external influence, with the improvement of the digital economy, the digital economy will provide greater help to the green effect of the command-and-control type of environmental regulation. For market-inspired environmental regulation, through its own carbon-oriented digital transformation, the government guides enterprises to participate in the market activities of green transformation, and builds an interconnected information platform for supply and demand with digital technology to reduce information asymmetry, improve communication efficiency, and then continue to promote the vitality of green finance and optimize the practical application of green credit, carbon trading and other green financial products. However, the principle of market incentive-based environmental regulation is "polluter pays", and enterprises need to choose between the costs and benefits of sewage disposal. When the cost of pollution reduction is greater than the environmental tax, enterprises will tend to choose not to reduce pollution, through the direct payment of environmental taxes to obtain more revenue, at this time the market incentive-type environmental regulation is difficult to play a role in corporate pollution reduction. However, when the development of the digital economy to a certain level, the cost of pollution reduction is less than the environmental tax, the enterprise will be more inclined to control emissions, so as to realize the role of enterprise green production.

5.4. Synergistic effect of digital economy on China's carbon neutral capacity

The digital economy penetrates the government, enterprises and the public's "carbon reduction and decarbonization" actions with a wide range of radiation, blurs the physical time and space boundaries, and realizes the sharing of information resources, which can help the government's environmental regulation, enterprises' technological innovation and the public's green consumption to produce a good synergy, and efficiently enhance China's carbon neutrality. For the synergy between government environmental regulation and enterprise technological innovation, the command-and-control type and market incentive type environmental regulation force and encourage enterprises to realize technological innovation through administrative or market means, and there exists the Porter's hypothesis effect, which guides enterprises to carry out biased green technological innovation through environmental regulation. For the synergistic effect between enterprise technological innovation and public green consumption, enterprises and the public as the supply and demand parties are linked together, from the supply perspective, the realization of enterprise technological innovation, for the public to provide ways of green consumption, adding convenience; from the demand perspective, the public demand for green consumption can inspire enterprises to research and development of related products, to enhance the enthusiasm of enterprises' technological innovation with broad market prospects and lucrative product profits. For the synergistic effect between public green consumption and government environmental regulation, public green consumption means the improvement of green literacy, the public not only has a green tendency to consume products, but also pay attention to the environmental quality of the city where they are located, and play an external supervisory role in the implementation of government environmental regulation, while the government environmental regulation is government-led, but based on the limited administrative resources, the government will actively mobilize the public to participate in the development and implementation of environmental protection. Public participation, to guide the public green low-carbon life.

6. Summary

Using the panel data of 30 provinces in China from 2013 to 2021, this paper measures the digital economy and carbon neutrality based on the concept of digital economy and carbon neutrality and explores the effect of digital economy on carbon neutrality by constructing a two-way fixed effect model, a threshold effect model, and a mediation effect model, etc., and draws the following conclusions.

Firstly, the ability of digital economy to promote carbon neutrality has two dimensions: carbon emission reduction and carbon removal and has non-linear characteristics. Digital economy can enhance carbon neutral capacity. In terms of carbon emission reduction, the digital economy has a first promotion and then inhibition effect on carbon emission reduction capacity; in terms of carbon removal, the promotion effect of the digital economy on China's carbon removal capacity has been empirically tested. We use the carbon neutralization capacity and carbon removal capacity as the threshold variable to explore its nonlinear effect and find that the digital economy has the nonlinear characteristic of increasing marginal effect on the carbon neutralization capacity. Secondly, the impact of digital economy on carbon neutral capacity cannot be separated from the concerted and synergistic action of the government, enterprises and the public. Existing studies mostly test a single influence path, this paper tries to explore the synergistic relationship among enterprises, the public and the government, and finds that the synergistic relationship does not have a significant effect, which indicates that there is still a huge development potential for the synergistic carbon reduction of each social body.

Based on the conclusions of the study, the following implications can be drawn for promoting the realization of the carbon neutrality goal. First, while the digital economy is firmly recognized as the engine for achieving carbon neutrality, the rebound effect of the digital economy needs to be taken into account. The scale of the increase in carbon emissions from the digital economy should be reduced by means of improving the energy structure, production efficiency, technology and techniques, especially in developed regions, which need to pay attention to the carbon emissions from the infrastructure and income effects of the digital economy itself. Compared with the carbon emission reduction capacity, the carbon removal capacity of all regions is relatively low and needs to be further developed, and it is necessary to promote carbon reduction and carbon removal in parallel to jointly realize the goal of carbon neutrality. Secondly, it is necessary to insist that all social actors work together to promote green and low-carbon development. Mobilize the initiative of the government, enterprises and the public, and fully open up the government's environmental regulation, enterprise technological innovation and public green consumption of the three digital economy on carbon reduction and decarbonization of the influence of the three pathways, but need to pay attention to the sustainability of the public's green consumption, the public should strengthen the public's green literacy, from the perspective of the consumer to emphasize the importance of green low carbon, and cultivate the green benefit to the awareness of their own. At the same time, the synergistic effect of various social actors to enhance carbon neutrality is still mostly at the level of theoretical research, and there is still much room for development in practice.

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