

# ***The Influence of Digital Economy on Carbon Emission under Dual-Carbon Goals: A Perspective on Green Technology Innovation***

Xin Li<sup>1,a,\*</sup>

<sup>1</sup>*School of Economics, Yunnan University, Kunming, China*

*a. 13887531356@163.com*

*\*corresponding author*

**Abstract:** The digital economy and innovation in green technology have become vital factors in boosting sustainable economic activities, achieving the ‘dual-carbon’ goal, and reducing the intensity of carbon emissions. Based on the panel data of 29 provinces in China from 2011 to 2020, this paper analyses the relationship between digital economy, innovation in green technology and the intensity of carbon emissions using the threshold effect model. The results are as follows: the digital economy plays a significantly positive role in reducing regional carbon emission intensity; with the evolution of the development stage of green technological innovation, the influence of the digital economy on carbon emission intensity shows a negative and increasing marginal effect of non-linear characteristics. The influence of digital economy and innovation of green technology on carbon emission intensity shows obvious heterogeneity in different regions, especially in the Northeast and the East, the synergistic effect of the two is more obvious, which can contribute to the carbon emission reduction in the region more effectively. Therefore, the government should adopt differentiated regional digital economy development policies to stimulate enterprises to carry out green innovation, so as to more efficiently promote the digital transformation in enterprise production, and thus achieve China's ‘dual-carbon’ strategic goal.

**Keywords:** digital economy, green technological innovation, carbon emission intensity

## **1. Introduction**

In the current social context, the digital economy has become a key driver of global economic growth, demonstrating robust momentum. By 2023, China's digital economy reached a scale of 53.9 trillion-yuan, accounting for 42.8% of the gross domestic product (GDP). It achieved a nominal growth rate of 7.39% and contributed 66.45% to GDP growth, surpassing the nominal GDP growth rate during the same period [1]. Continuous innovation and the widespread application of digital technologies are reshaping economic development, steering it toward greater efficiency, intelligence, and interconnectivity. The digital economy not only revitalizes traditional industries but also fosters the emergence of new business models, enhances resource allocation efficiency, and drives innovation and collaboration. These developments provide fresh impetus for sustainable global growth and serve as a pivotal force in economic transformation and upgrading across nations.

Under the impetus of the digital economy, green technological innovation has become a cornerstone for advancing sustainable development, playing a critical role in reducing carbon intensity and facilitating green economic transformation. The 'dual-carbon' goals mandate an 18% reduction in carbon dioxide emissions per unit of GDP by 2025 compared to 2020, a reduction of over 65% by 2030 relative to 2005 levels, and the ultimate achievement of carbon neutrality by 2060 [2]. Guided by this goal, green technological innovation is developing rapidly, new energy technologies are increasingly breaking through, and the use efficiency of clean energy, such as solar and wind energy, is constantly improving; the widespread application of green manufacturing technology effectively reduces energy demand and pollution release, and promotes the optimization and upgrading of the industrial structure, thus laying a good foundation for the construction of a green, low-carbon and recycling economic system. The deep integration of digital economy and green technology innovation has opened up new ways to reduce carbon emission intensity. Digital technology has been widely used in many fields such as power systems, industrial and agricultural production, etc., and a digital low-carbon energy ecosystem has been constructed through the integration of energy flow, information flow and value flow. Enterprises are revolutionizing traditional production models by incorporating digital intelligence and green technologies to enhance energy efficiency and unlock new business opportunities. As the digital economy continues to evolve, leveraging green economic growth to meet the 'dual carbon' emission reduction goals has become a national priority. This study examines the interplay between the digital economy, green technology innovation, and carbon emission intensity, offering insights of both theoretical and practical significance.

## **2. Literature Review**

### **2.1. Impact of the Digital Economy on the Achievement of the 'Double Carbon' Goal**

Carbon emissions are an integral part of achieving the 'double carbon' goal and related policymaking, and the digital economy plays a pivotal role in this regard. From a theoretical point of view, the digital economy is closely connected with the achievement of the 'dual-carbon' target. Promoting the optimization and development of the digital economy can give full play to the expansion, accumulation and multiplication effects of digital technology [3], and effectively promote the realization of the 'double carbon' goal. On the one hand, the digital economy, as a new kinetic energy for industrial growth, shows significant positive externalities, and has a positive impact on the improvement of the social economy and efficiency [4], while accelerating the digital transformation of primary, secondary and tertiary industries, forming a 'three-in-one' sharing economic ecological chain [5], in order to support green development and the construction of low-carbon benefits. On the other hand, through digital means to establish a link between supply and consumption, to achieve the organic integration of energy flow, information flow and value flow, so as to build a digital low-carbon energy ecosystem [6], and open up new paths for the development of China's sustainable economy. In addition, the digital economy also shows the enabling effect, through the integration and precise matching of elements, to enhance the ability of enterprise growth and industrial structure optimization [7], thus improving the overall industrial efficiency and competitiveness.

Empirical research on the digital economy's role in achieving 'dual-carbon' goals focuses on two main areas. The first examines factors influencing these goals. For example, Li et al. [8] found that the digital economy boosts green innovation by optimizing manufacturing structures and advancing green technologies. Similarly, Sun and Li [9] showed that green innovation drives high-quality, low-carbon development. The second area focuses on methods to evaluate progress. Single-model approaches, like those by Li and Hou [10], highlight how the digital economy reduces carbon

emissions through innovation, industrial upgrades, energy optimization, and resource efficiency. Yu et al. [11] developed a framework to assess digital economy growth using dimensions like infrastructure, economy popularity, and resource usage. Combined approaches, such as Fei Wei et al. [12], reveal an inverted U-shaped relationship between the digital economy and carbon emissions. Zheng et al. [13] found regional disparities in digital economy development across China, with higher levels in the east and no single factor driving high carbon emissions.

## **2.2. Impact of Green Technology Innovations on the Achievement of the ‘Dual-Carbon’ Goal**

Innovation in green technology plays a significant role in achieving the ‘dual-carbon’ target, both directly and indirectly. The pathways through which the digital economy and green technological innovation influence carbon emissions are complex. Regarding the ‘direct effect’ of reducing carbon emissions, green technology innovation can effectively promote the attainment of the ‘dual-carbon’ goal. It demonstrates significant carbon reduction outcomes at the city level while generating positive spatial spillovers to neighboring cities [14]. Additionally, in city clusters with higher levels of comprehensive development, the growth rate of carbon emissions is notably lower than that of clusters with lower levels of development [15]. As for the ‘indirect effect,’ green technology innovation promotes the growth of new types of productivity and stimulates further technological advancements. These innovations empower the low-carbon economy and facilitate high-quality growth in low-carbon practices. From a more segmented perspective, some studies have argued that different types of green technological innovation have different degrees of impact, for example, the role played by inventive green technological innovation is different from that of practical green technological innovation, with the former accounting for a greater proportion of the intermediary effect [16].

Green technological innovation serves as a vital bridge for the digital economy to achieve low-carbon societal development, reduce carbon emissions, and enhance carbon utilization. At the national level, environmental regulations implemented by governments can effectively improve energy efficiency and promote the adoption of green, innovative technologies [17]. Moreover, the impact of digitalization on green technological breakthroughs becomes more significant when environmental regulations are stricter and industries are more competitive [18]. At the industry level, the digital economy accelerates the development of high-quality, eco-friendly industries both within and across regions [19]. For example, it enhances industrial green innovation capacity by driving structural upgrades in the manufacturing sector and fostering green technology development in businesses [8]. Furthermore, the digital economy aids industries in transitioning to green intelligence through resource optimization and other strategies. At the corporate level, the digital economy directly enhances corporate green technology innovation (CGTI) [20], enabling businesses to achieve green development and reduce costs through green technological advancements [21]. This is complemented by the technological dividend effect, reflected in green technological breakthrough capacity and green total factor productivity [22]. For instance, digital development—driven by big data, cloud computing, and other technologies—can significantly increase enterprise labor demand [23] and boost green technological innovation by optimizing human capital, attracting media attention, and alleviating financial constraints [18]. However, some studies present contrasting views. They suggest that the relationship between carbon emission efficiency and green technology innovation lacks an effective mechanism, resulting in negligible impacts [24]. Additionally, while the digital economy contributes significantly to overall carbon emissions, the positive effect of green technology innovation in mitigating this impact is weakened [25].

The existing research primarily focuses on how the digital economy and green technological innovation impact the "dual-carbon" goal. This includes empirical and theoretical studies, as well as

investigations into influencing factors and evaluation methods. Multi-perspective assessments from government, industry, and entrepreneurship highlight both the direct and indirect benefits of green technology innovation and the essential role of the digital economy in achieving the "dual-carbon" aim. However, there is a lack of consensus and research on the mechanisms linking carbon emission efficiency and green innovation. This paper aims to address these gaps by exploring the complex relationship between carbon emissions, green technology innovation, and the digital economy, while providing a robust theoretical foundation and practical recommendations for achieving the "dual-carbon" goal.

### 3. Theoretical Models and Hypothesis

The carbon intensity indicator is vital for evaluating the environmental impact of businesses, sectors, or regions, as well as the relationship between economic growth and greenhouse gas emissions. The digital economy emphasizes digital data and knowledge as key outputs, with digital innovation as the driving force and modern information networks as essential transporters. A defining characteristic of the digital economy is its use of data and information as public goods. By integrating digital technology with the real economy, the digital economy can optimize traditional industries and enhance industrial digital intelligence, fostering a new economic model. It can also leverage the synergistic effects of technology, market dynamics, policy, and talent by using knowledge and information as primary drivers of economic development through effective data integration and interoperability.

Furthermore, the digital economy has a big impact on how the industrial framework is optimized. It can enhance intelligent production to encourage the use of new energy technologies and reduce emissions by boosting energy efficiency and optimizing industrial structure. The digital economy can, for instance, straight use the storage of vast amounts of data for analysis, support businesses in making accurate decisions, achieve accurate production energy management, and decrease energy wasteful use; ideal digital infrastructure can enhance the digital economy's coverage and application depth, offer robust support for the digital evolution of various sectors, and encourage the rapid growth of low-carbon industries, such as the service sector, which lowers emissions of carbon intensity. Additionally, the growth of the digital economy can further foster financial innovation, increase funding for the environmental preservation sector, and fortify a nation's efforts to implement ecological conservation and low-carbon policies. Therefore, this paper proposes hypothesis 1.

H1: Regional carbon emission intensity can be decreased with the help of the digital economy.

The impact of green technology innovation on regional carbon intensity evolves as the digital economy matures. Initially, innovation may reduce carbon emissions primarily through increased energy inputs, higher environmental costs, and enhanced factory efficiency. As green technology innovation advances, its role becomes more complex, contributing to lower carbon intensity through changes in energy consumption, synergies with digital economy growth, and significant modifications to manufacturing systems. For example, certain indicators might initially lead to a decrease in carbon emissions, followed by an increase, reflecting intricate transformation patterns. This variability arises from the differing mechanisms through which green technology interacts with other factors at various stages. Therefore, this paper proposes Hypothesis 2.

H2: The influence of the digital economy on the intensity of emissions of carbon in each location exhibits a non-linear feature as innovation in green technologies progresses to different stages.

Building an environmentally friendly and carbon-free system of commerce in China can be aided by the rapid expansion of the digital economy and innovations in green technologies. There are disparities in the advancement of digital commerce and innovation in green technologies across different areas of China due to a variety of factors, including economic level, extent of digital progress,

innovation capacity, and scientific and technological investment. This phenomenon of uneven and uncoordinated progress also occurs and affects the intensity of carbon emissions in various areas.

According to industrial structure theory, regions with high economic levels and advanced digitization can leverage digital technology to reshape industrial processes, promote low-carbon industrial evolution, and enhance renewable energy productivity through environmentally friendly innovations. Conversely, areas with limited digital development struggle to optimize their industrial structures, remaining constrained by high-carbon industries. Additionally, insufficient scientific innovation capabilities restrict their ability to reduce pollutants and lower energy consumption, making industrial transformation difficult. Factor endowment theory suggests that regions rich in resources can accelerate the development and implementation of green solutions by utilizing capital, green technologies, and creative talent. These regions can also use digital tools to optimize energy consumption and explore new energy sources. In contrast, resource-poor areas face challenges in overcoming reliance on conventional energy sources, introducing innovative green technologies, and adjusting their energy structures, complicating efforts to control carbon emissions. Therefore, this paper proposes Hypothesis 3.

H3: The impact of innovation in green technologies and the digital economy on regional intensity of carbon emissions varies by location.

## 4. Model Setting and Description of Variables

### 4.1. Research Design

#### 4.1.1. Basic Regression Model

In accordance with this paper's changeable settings and study goal, the following baseline regression model is first constructed:

$$Car_{it} = \alpha_0 + \alpha_1 GTI_{it} + \alpha_2 Dig_{it} + \alpha_3 GTI_{it}^2 + \theta_p Controls_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (1)$$

In model (1),  $Car$  is the degree of reduction in carbon emissions,  $GTI$  is the invention in green technology;  $GTI_{it}^2$  is the square term of invention in green technology;  $Dig$  is the degree of growth of the digital economy;  $Controls_{it}$  is the control variable;  $i$  represents the province;  $t$  represents the year;  $\alpha$  is the coefficient that needs to be calculated;  $\theta_p$  is the estimated coefficient of each control variable;  $\mu_i$  is the province fixed effect;  $\delta_t$  is the time fixed effect;  $\varepsilon_{it}$  represents the random error term. If  $\alpha_2$  is negative and passes the significance test, suggesting that the digital economy has a considerable impact on reducing emissions of carbon.

#### 4.1.2. Threshold Effect Model

The degree of innovative green technology development is used as a threshold variable to build a threshold effect model, as indicated in equation (3), with the aim to explore further the process of the influence on the digital economy under different stages of growth.

$$Car_{it} = \alpha_0 + \alpha_1 Dig_{it} \times I(GTI_{it} \leq \beta_1) + \alpha_2 Dig_{it} \times I(\beta_1 < GTI_{it} \leq \beta_2) + \alpha_3 Dig_{it} \times I(GTI_{it} > \beta_2) + \theta Controls_{it} + \mu_i + \delta_t + \varepsilon_{it} \quad (2)$$

where  $GTI_{it}$  denotes the threshold variable,  $\beta$  is the threshold value,  $I(\cdot)$  is an indicator function taking the value of 1 or 0, and  $Controls_{it}$  is a collection of control variables that align with the variables in the baseline regression model.

## 4.2. Variable Selection

### 4.2.1. Explained Variable

For the purpose of to reach the carbon peak carbon neutral aim, China has suggested implementing a dual-control system of greenhouse gas emissions, with intensive control serving as the primary objective and complete control as a supplement [26], this paper takes carbon intensity (CI) as an indicator for measuring low-carbon development.

Referring to related studies [27-28], the 2006 IPCC Guidelines for National Greenhouse Gas Inventories are employed to calculate carbon dioxide emissions. The total emissions of carbon dioxide are derived from the sum of the emission coefficient and the energy consumption results for each energy type. Eight petroleum-based products were selected for analysis, including coal, energy coke, crude oil, paraffin, diesel, petrol, fuel oil, and natural gas. The carbon intensity for each province is calculated as the ratio of its gross domestic product (GDP) to its total carbon emissions [29]. The formula for calculating carbon intensity can be summarized as follows:

$$CI_i = TCE_i / GDP \quad (3)$$

$$TCE_i = \sum_{j=1}^n TCE_{ij} \quad (4)$$

$$TCE_{ij} = E_{ij} \times SCC_j \times CEC_j \times 44/12 \quad (5)$$

Where provinces and energy kinds are represented by the letters  $i$  and  $j$ , correspondingly;  $CI_i$  is the carbon intensity;  $TCE_i$  denotes the emissions of carbon dioxide of province  $i$ ;  $TCE_{ij}$  is the carbon dioxide emissions generated by energy source  $j$  in province  $i$ ;  $E_{ij}$  is the amount of energy source  $j$  used in province  $i$ ;  $SCC_j$  represents the standard reduced coal coefficient for power supply  $j$ ;  $CEC_j$  is the emission of carbon coefficient for power supply  $j$ . Carbon dioxide's molecular ratio is 44/12.

### 4.2.2. Core Explanatory Variable

Following the methodology of Zhao et al. [30], this paper establishes a framework for measuring the digital economy, considering data availability and scientific principles. The assessment focuses on two key components: the expansion of the internet and the inclusion of digital financial services. To evaluate the degree of progress in the internet-based economy, indicators across four dimensions are calculated using principal component analysis. This approach helps determine the weights of each measure, facilitating an understanding of the digital economy's development level. The first-level indicators are constructed from 18 variables, encompassing three components: digital infrastructure, digital industrialization, and digital innovation capacity.

Table 1: Indicators for measuring the digital economy.

| Level 1 indicators                                   | Level 2 indicators                       | Description of indicators                                         |
|------------------------------------------------------|------------------------------------------|-------------------------------------------------------------------|
| The overall development of the digital economy index | Internet penetration rate                | Per 100 people with broadband Internet access                     |
|                                                      | Internet related professionals           | Percentage of workers in computer service and software industries |
|                                                      | Internet-related output                  | Per capita total telecommunications business                      |
|                                                      | Mobile Internet users                    | Number of mobile phone subscribers per 100 people                 |
|                                                      | Inclusive development of digital finance | China Digital Inclusive Finance Index                             |

#### 4.2.3. Threshold Variable

Green patents represent the results of innovation, providing a direct reflection of efforts and outputs in green technology. The number of applications can indicate the activity and direction of innovation in this field. While various complex factors, such as approval processes and time delays, influence patent issuance, the quantity of applications tends to be more consistent and time-sensitive, making it a more accurate measure of current advancements in sustainable technology. Based on the research by Huang et al. [31], this study opts to use the annual number of green patent applications filed in the sample provinces as an indicator of the degree of innovation in green technology. This approach enables a clear assessment of innovation efforts and activity within the context of sustainability.

#### 4.2.4. Control Variable

Environmental regulation (Er) can encourage businesses to implement cleaner methods of manufacturing and lower pollution levels, as well as encourage the modernization of industrial structures and the efficient use of energy to meet the goal of lowering the release of carbon dioxide. According to Xiao and Zeng [28], it is determined by dividing the value contributed by the secondary sector in each province by the investment made in pollution from industry management.

The degree of regional urbanization (urban) can alter industrial structure, energy consumption, population agglomeration, and other factors that impact the utilization of energy and, in turn, the intensity of greenhouse gas emissions. This publication makes reference to the research of Cao et al. [32], who chose to assess it by dividing the entire population of each province by the number of urbanized residents.

Per capital road area (PROAD) refers to the research of Wu et al. [15] and uses the per capital road area in each province to measure.

#### 4.2.5. Data Source and Descriptive Statistics

This paper uses panel data from 29 Chinese provinces (not including Tibet, Hong Kong, Macao, and Taiwan) from 2011 to 2020. Some of emission of carbon data came from China Carbon Accounting Databases (CEADs)[33], while the majority came from China Energy Statistics Yearbook, China Statistics Yearbook, China Information Yearbook, etc. in various years .

Table 2: Variable descriptive statistics

| Variable | Mean   | Std Dev | Max    | Min     |
|----------|--------|---------|--------|---------|
| lnCI     | 1.8307 | 0.7451  | 3.4407 | -0.3236 |
| Dig      | 0.9512 | 1.2935  | 7.4158 | -1.0270 |
| GTI      | 0.6347 | 0.8868  | 5.6195 | 0.0027  |
| Er       | 0.2860 | 0.2850  | 2.4509 | 0.0044  |
| lnurban  | 4.0627 | 0.2007  | 4.4951 | 3.5565  |
| lnPROAD  | 1.6196 | 0.4158  | 2.5356 | 0.0955  |

The maximum value of carbon emission intensity is 3.4407, the minimum value is -0.3236, and the average value is 1.8307, which is more inclined to the maximum value and has a large data fluctuation range. The statistical results show that there exist substantial variations in carbon emission intensity among different provinces, with some having larger carbon emission intensity than others. The degree of green technological innovation varies from province to province, with some having a greater degree of innovation activity, a higher output of achievements, and strong advances in science and technology. The digital economy, road area per capita, and environmental regulation all differ

significantly, suggesting that different provinces have varying levels of support for safeguarding the environment and economic growth.

## 5. Analysis of Empirical Results

### 5.1. Benchmark Regression Analysis

The variance inflation factor test is performed in this paper before the formal regression evaluation, and the results show that there is no multicollinearity in the model because each variable's VIF value is considerably below 10. The model is then used to progressively add the control variables, and regression analyses are performed on the relationships between emissions of carbon intensity, digital economy, green innovative technology, and the remaining control variables.

Table 3: Tests for multicollinearity.

| Variable | VIF  | 1/VIF  |
|----------|------|--------|
| lnUrban  | 3.36 | 0.2974 |
| Dig      | 2.56 | 0.3913 |
| lnPROAD  | 2.16 | 0.4636 |
| GTI      | 1.59 | 0.6294 |
| Er       | 1.17 | 0.8529 |

The findings from the baseline regression analysis of factors influencing carbon emissions at the provincial level are summarized in Table 4. The results for the primary explanatory variable—digital economy—are presented in Column (1). The regression coefficients for the digital economy are consistently negative across all columns, and with the gradual inclusion of control factors, all coefficients pass the 1% significance level. This indicates that as the digital economy develops, the intensity of regional carbon emissions decreases, supporting Hypothesis 1. In Column (2), the variable for environmentally friendly methods innovation is added, showing a negative regression value. The significance of this variable increases with the addition of more controls, suggesting that green technology innovation positively impacts the reduction of carbon intensity. Regarding control variables, most regression coefficients for environmental restrictions introduced in Column (3) are significantly negative, indicating a negative relationship between environmental regulation intensity and carbon emissions. The regional urbanization level (lnurban) becomes significantly negative in Column (6), illustrating that urbanization can lead to a decrease in carbon emission rates under certain conditions. Additionally, the extent of government interference, introduced in Column (6), has a significantly positive coefficient. This may imply that the nature and style of government intervention affect business production choices. For example, regulations aimed at encouraging increased production could lead to higher carbon dioxide emissions.

Table 4: Regression results of the impact of green technology innovation and digital economy on regional carbon emission intensity.

| Variable | lnCI                   |                        |                        |                        |                        |                        |
|----------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|
|          | (1)                    | (2)                    | (3)                    | (4)                    | (5)                    | (6)                    |
| Dig      | -0.3001***<br>(0.0776) | -0.2840***<br>(0.0777) | -0.2854***<br>(0.0792) | -0.3245***<br>(0.0659) | -0.3167***<br>(0.0630) | -0.2955***<br>(0.0608) |
| GTI      |                        | -0.0278<br>(0.0263)    | -0.0223<br>(0.0246)    | -0.0445*<br>(0.0251)   | -0.0605**<br>(0.0263)  | -0.1961**<br>(0.0901)  |
| GTI2     |                        |                        |                        |                        |                        | 0.0222*<br>(0.0122)    |

Table 4: (continued).

|                |                       |                       |                       |                       |                       |                       |
|----------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| Er             |                       |                       | -0.0611<br>(0.0408)   | -0.0775**<br>(0.0337) | -.0624**<br>(0.0293)  | -0.0476*<br>(0.0275)  |
| lnurban        |                       |                       |                       | -0.9644**<br>(0.4293) | -0.4927<br>(0.5257)   | -0.5145<br>(0.5049)   |
| lnPROAD        |                       |                       |                       |                       | -0.3002**<br>(0.1391) | -0.3229**<br>(0.1411) |
| Constant term  | 2.0935***<br>(0.0402) | 2.1039***<br>(0.0370) | 2.1180***<br>(0.0391) | 5.9257**<br>(1.6942)  | 4.4648**<br>(1.9456)  | 4.6093**<br>(1.8700)  |
| Time fixed     |                       |                       |                       | Yes                   |                       |                       |
| Province fixed |                       |                       |                       |                       |                       |                       |
| R <sup>2</sup> | 0.8197                | 0.8218                | 0.8236                | 0.8373                | 0.8444                | 0.8502                |
| N              |                       |                       |                       | 290                   |                       |                       |

Note: Robust standard errors are in parentheses; \*\*\*, \*\*, and \* denote significance levels of 1%, 5%, and 10%, respectively, as in the table below.

## 5.2. Threshold Effect Test

In the context of the digital economy, innovative green technology is used as a threshold variable to analyze how different levels of advancement in green technological innovation affect greenhouse gas intensity. Prior to conducting the regression analysis, the significance and validity of the panel thresholds are evaluated through 300 bootstrap samples. The findings, as shown in Table 5, indicate that the model exhibits a single threshold effect. This conclusion is supported by test results that demonstrate significant thresholds at both the 10% and 5% confidence levels. In contrast, tests for double or triple thresholds do not yield notable results. This suggests that variations in the advancement of green technological innovation have a distinct and measurable impact on greenhouse gas intensity, reinforcing the importance of innovative practices within the digital economy. Table 6 shows that as green technology advances, the digital economy has a definite detrimental impact on regional carbon emissions when its threshold variable level is smaller than 3.371. With a coefficient ranging from -0.0491 to -0.1330, the negative effect is amplified when the threshold variable is higher than 3.371. Per capita road area (lnPROAD), regional urbanization level (lnurban), and environmental regulation (Er) are all negative and significant at least 5%, suggesting that they can reduce the extent of carbon emissions. The findings support hypothesis 2 and demonstrate that the negative impact of the digital economy on regional carbon emission intensity is amplified when the background of the digital economy is taken into account.

Table 5: Threshold Test impact of the development of innovative green technologies within the framework of the digital economy.

| Threshold Variable                            | Model            | Threshold | F-statistic value | P-value | BS count | Threshold value |        |        | Confidence interval |
|-----------------------------------------------|------------------|-----------|-------------------|---------|----------|-----------------|--------|--------|---------------------|
|                                               |                  |           |                   |         |          | 1%              | 5%     | 10%    |                     |
| Green Technology Innovation Development Level | Single threshold | 3.371     | 46.87**           | 0.010   | 300      | 45.947          | 33.120 | 28.080 | [0.8545,0.8943]     |

Note: The P-values and F-critical values in the estimates of the threshold models in the table are the results of 'bootstrap self-sampling' 300 times and stand for 1%, 5%, and 10% statistical significance, respectively.

Table 6: Regression analysis of the threshold model for the development of innovative green technologies within the framework of the digital economy.

| Variable                                 | Coefficient estimates  | 95% confidence interval |
|------------------------------------------|------------------------|-------------------------|
| $Dig_{it} \times I(GTI_{it} \leq 3.371)$ | -0.0491**<br>(0.0200)  | [-0.0886,-0.0096]       |
| $Dig_{it} \times I(GTI_{it} > 3.371)$    | -0.1330***<br>(0.0143) | [-0.1613,-0.1046]       |
| Er                                       | -0.0897**<br>(0.0360)  | [-0.1607,-0.0186]       |
| lnurban                                  | -1.4074***<br>(0.2463) | [-1.8926,-0.9223]       |
| lnPROAD                                  | -0.2028**<br>(0.0957)  | [-0.3913,-0.0143]       |
| Constant term                            | 7.9912***<br>(0.9001)  | [6.2187,9.7638]         |

### 5.3. Robustness Test

This study employs three methods to validate the accuracy of the previously mentioned results. **Lagging Explanatory Variables:** The first approach addresses the endogeneity issue by lagging the explanatory variables by one period. This adjustment accounts for temporal lag and dynamic effects. The findings reveal a strong correlation between each province's carbon emissions and its digital economy at the 1% significance level. **Data Reduction:** The second technique involves shrinking the dataset to enhance robustness and mitigate the influence of extreme values on the analysis results. **Incorporating Additional Control Variables:** The third approach adds new control variables to the initial model, specifically including thermal power generation (thermpower) [12] and per capita gross domestic product (pgdp). The estimation outcomes, as shown in Table 7, indicate that the impact of the digital economy on reducing regional carbon emissions remains consistent with the benchmark regression findings. Overall, the robustness and endogeneity tests reinforce the reliability of the empirical findings and conclusions drawn from the research.

Table 7: Results of the endogeneity and robustness tests.

| Variable | Core explanatory variable lagged one period | Tailoring                  | Addition of control variables |
|----------|---------------------------------------------|----------------------------|-------------------------------|
| Dig      | -0.3332***<br>(0.0776)                      | -<br>0.3167***<br>(0.0630) | -0.2228***<br>(0.0654)        |
| GTI      |                                             | -0.0605**<br>(0.0263)      | -0.0904**<br>(0.0328)         |
| GTI_1    | -0.0488*<br>(0.0248)                        |                            |                               |
| Er       | -0.0797**<br>(0.0370)                       | -0.0624**<br>(0.0292)      | -0.0729***<br>(0.0228)        |
| lnurban  | -0.5150<br>(0.5654)                         | -0.4926<br>(0.5257)        | 0.2545<br>(0.6984)            |
| lnPROAD  | -0.2893*<br>(0.1467)                        | -0.3001**<br>(0.1391)      | -0.1696<br>(0.1148)           |

Table 7: (continued).

|                |          |          |          |
|----------------|----------|----------|----------|
| Pgdp           |          |          | 1.650*   |
|                |          |          | (0.8690) |
| thermpower     |          |          | 1.642*** |
|                |          |          | (0.4030) |
| Constant       | 4.5078** | 4.4648** | 0.6342   |
| term           | (2.1155) | (1.9455) | (2.9562) |
| Time fixed     |          |          |          |
| Province       |          | Yes      |          |
| fixed          |          |          |          |
| R <sup>2</sup> | 0.8372   | 0.8444   | 0.8788   |
| N              |          | 290      |          |

#### 5.4. Heterogeneity Analysis

The impact of innovative green technologies and the digital economy on carbon emission intensity across China's central, western, northeastern, and eastern regions is summarized in Table 8. In the eastern region, the synergy between green technological innovation and the growth of the digital economy effectively reduces carbon emission intensity. Conversely, in the northeastern region, while both the digital economy and innovative green technology are present, they contribute to an increase in carbon emissions. This is largely due to the region's reliance on traditional industries, which face challenges related to the costs of technological transformation and equipment upgrades. In the central and western regions, the combined effects of the digital economy and innovative green technologies are insufficient to significantly alter carbon emission intensity. This suggests that these regions have not yet reached a critical "threshold" where digital transformation can effectively reduce emissions.

Overall, the findings indicate that the eastern region benefits from industrial integration and effective policy guidance, showcasing how digital economy-driven innovation can lead to lower carbon emissions. In contrast, the northeastern region's challenges highlight the complexities of integrating new technologies within established industries. The negligible impact observed in the central and western regions reinforces the notion of notable regional variations in the relationship between the digital economy, innovative green technologies, and carbon emission levels, thus validating Hypothesis 3.

Table 8: Heterogeneity analysis of the connection between carbon emission intensity, innovative green technology, and the digital economy.

| Variable | lnCI        |              |                |             |
|----------|-------------|--------------|----------------|-------------|
|          | (1)<br>East | (2)<br>North | (3)<br>Central | (4)<br>West |
| Dig      | -0.1369*    | 0.5458**     | -0.3584        | 0.0518      |
|          | (0.0688)    | (0.1032)     | (0.2219)       | (0.1776)    |
| GTI      | -0.0207     | 0.3092*      | -0.0301        | -0.4258*    |
|          | (0.0184)    | (0.0864)     | (0.2271)       | (0.1904)    |
| Er       | -0.0716     | 0.2284**     | 0.0694         | -0.0593     |
|          | (0.0758)    | (0.0398)     | (0.1188)       | (0.0363)    |
| lnurban  | 1.2665*     | -5.5580*     | -3.4097**      | -1.4693     |
|          | (0.5181)    | (1.8872)     | (1.1410)       | (1.1472)    |
| lnPROAD  | -0.2140*    | 0.4150       | 1.6245**       | -0.5358*    |
|          | (0.0811)    | (0.4108)     | (0.5307)       | (0.2750)    |

Table 8: (continued).

|                |                     |                      |                       |                     |
|----------------|---------------------|----------------------|-----------------------|---------------------|
| Constant term  | -3.0491<br>(2.1543) | 24.6047*<br>(7.8507) | 13.0376**<br>(4.5327) | 8.6865*<br>(4.2464) |
| Time fixed     |                     |                      |                       |                     |
| Province fixed |                     | Yes                  |                       |                     |
| R2             | 0.9083              | 0.9512               | 0.9255                | 0.8825              |
| N              | 100                 | 30                   | 60                    | 100                 |

## 6. Conclusion and Recommendation

### 6.1. Conclusion

The analysis presented in this paper, which utilizes panel data from 29 Chinese provinces from 2011 to 2020 (excluding Tibet, Hong Kong, Macao, and Taiwan), leads to several key conclusions regarding the impact of the digital economy on regional carbon emissions reduction in the context of innovative green technology:

First, the digital economy plays a significant role in reducing regional carbon emission intensity, strongly supporting the achievement of low-carbon objectives. Second, the influence of the digital economy on the intensity of carbon emissions is characterized by a negative and marginal effect that increases nonlinearly with advancements in green technology. Initially, when green technology is still developing, its integration into the local economy helps lower emissions by improving processes such as digital administration and information transfer. However, as innovative green technology becomes more widespread across various industries, its negative impact on emission levels can intensify. Third, the northeastern and eastern regions exhibit a more substantial influence from both the digital economy and innovative green technologies, providing more favorable conditions for effectively reducing regional carbon emissions.

### 6.2. Recommendation

Building an industrial ecosystem for the digital economy will be our first priority. We have advocated for a thorough integration of conventional sectors with the digital economy in accordance with the idea of green progress. By evaluating the channels of digital transformation and introducing digital platform technologies, we can control the production process in real time, precisely deploy resources, enhance product quality, lower the usage of energy for each unit of product, enhance market competitiveness, and form new industrial growth points. actively carry out the government's mandate to provide market instruction, the introduction of relevant policies to attract broad participation of enterprises, promote upstream and downstream cooperation, the establishment of green data standards, the sharing of cutting-edge technology advancements, the best possible distribution of data resources, to create a strong basis for the growth of the digital economy and to fully stimulate the data components of the multiplier effect of sustainable and low-carbon economic growth.

Second, all parties should make concerted efforts to promote green technological innovation. The government has deeply embedded green technology innovation into the national development strategy, precisely focused on key areas and strengthened R&D funding through project and fund systems and other diversified input modes. At the same time, it formulates synergistic policies, establishes cross-sectoral linkage mechanisms, efficiently coordinates resources from all parties, and accelerates the promotion and implementation of demonstration projects; industries rely on cluster building to promote collaborative innovation and resource sharing among enterprises; and financial institutions actively expand their green financial business to inject financial power for the implementation of innovative projects. With the colleges, universities, and scientific research

facilities have a knowledge-spillover impact, the region has strengthened the in-depth integration of industry, academia and research institutes, and accelerated the transformation of innovation results.

Third, the region should make use of its unique factor endowment and resource base to adapt to local conditions, precisely implement policies and achieve integrated regional development, and make the most of the opportunity to fully utilize regional benefits. The eastern area ought to maximise its economic advantages and leadership role, establish upscale innovation hubs in the digital economy, streamline the supply chain, and push goods at the top of the value chain to shift towards green intelligence; cultivate the high-end green consumer market, use big data to precisely locate the target clientele, and inject new vitality into the digital transformation; and establish a system of transfer payments to support the growth of the nation's center and western regions. The northeastern region has formulated a transformation plan for the current situation of heavy industry and set up special funds to urge enterprises to eliminate backward production capacity, use digital technology to reduce consumption and increase efficiency, and build a green and intelligent industrial system to stimulate economic potential. In order to achieve results, the western and central areas take advantage of the chance to draw in investment, transfer digital and green-tech businesses to the east, and work together to train local talent and improve the quality of their products. They also develop wind power, thermal electricity, and various clean energy sources in accordance with local conditions and support green advances in technology.

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