Impact of the Digital Economy on the Carbon Emissions of China’s Logistics Industry

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Abstract: As a new type of economy, the digital economy has become an important driver of economic changes and the direction of future economic development, as well as an important way to reduce carbon emissions in the logistics industry. Promoting carbon emissions reduction in the logistics industry with the digital economy has great practical significance. This paper analyzes the mechanism through which the digital economy impacts carbon emissions of the logistics industry, and then, based on provincial panel data from 2005 to 2019 in China, a nonlinear regression model and a quantile regression model are used to empirically test the digital economy’s impact on the carbon emissions of the logistics industry. The results show that there is a U-shaped correlation between the digital economy and carbon emissions of China’s logistics industry, and it is in the first half of the U-shaped correlation. The development of the digital economy has both a significant inhibitory and evolutionary effect on the carbon emissions of the logistics industry. With the increase in quantiles, the marginal impact of digital economy development on carbon emission reduction in China’s logistics industry decreases.

Keywords: digital economy; carbon emissions; logistics industry

1. Introduction

Carbon emissions and the climate problems they cause have become the focus of global attention. As the largest carbon emitter in the world, China proposed in September 2020 the strategic goal of achieving carbon peaking by 2030 and carbon neutrality by 2060. It is China’s active responsibility to promote the building of a community of a shared future for humankind and a living community between man and nature; it is also an inherent requirement for China’s economy to achieve green and sustainable development. Promoting carbon emissions reduction in the logistics industry is an important part of China’s “dual carbon” target, which is conducive to the development of the logistics industry as well as to China’s construction of a green and low-carbon circular economy system and high-quality development. As a new type of economy, the digital economy has become an important force in promoting economic transformation and the direction of future economic development; it has also become a new driving force for carbon emissions reduction in the logistics industry and an important way to achieve the “dual carbon” target. It is of great practical significance to promote carbon emissions reduction in the logistics industry through the digital economy. Therefore, what is the mechanism through which the digital economy impacts the carbon emissions of the logistics industry? Does it have a positive effect or a negative effect? How much impact has the digital economy had on the carbon emissions of China’s logistics industry? These questions are addressed in this paper.

Research on the impact of the digital economy on the carbon emissions of the logistics industry mainly focuses on the following aspects:

The first is research on the digital economy. The digital economy refers to a series of economic activities that take data resources as key production factors, modern information
networks as important carriers and the effective use of information and communication technology as important driving forces for efficiency improvement and economic structure optimization [1]. It is a new economic type that accelerates the reconstruction of economic development and governance models. Scholars who have studied the measurement methods of the digital economy include Xu and Zhang (2020), who used direct measurement methods for research [2]; Wang et al. (2021), who used the comprehensive index system method to evaluate the development scale of China’s digital economy [3]; and Luo et al. (2021) and Yang and Zhang (2019), who designed the framework and compilation plan of China’s digital economy satellite account [4,5]. Others have evaluated the digital economy in different regions and analyzed the impact of the digital economy on the overall economy [6–8].

The second is research on the carbon emissions of the logistics industry. The logistics industry is a composite service industry integrating transportation, warehousing, freight forwarding, information, and other industries, and it is a basic, strategic and leading industry supporting the development of the national economy [9]. The carbon emissions of the logistics industry are the general term for greenhouse-gas emissions in logistics activities, which are mainly derived from energy consumption during transportation [10]. The logistics industry has large amounts of energy consumption and carbon emissions. Many scholars have used the IPCC carbon emission coefficient method, input–output method, data envelopment analysis method, factor decomposition method, and econometric analysis method to study the carbon emissions of the logistics industry and its influencing factors. Zhang et al. (2021) used the GDIM decomposition method [11], and Deng et al. (2020) used the PCA-DEA-Tobit method to analyze the carbon emissions of the logistics industry and its influencing factors [12].

The third is research on the impact of the digital economy on the carbon emissions of the logistics industry. From the perspective of digital industrialization, although the development of the digital industry will result in a certain amount of energy consumption, the digital industry is a technology-intensive and environmentally friendly industry, and its environmental impact is relatively small compared to other industries [13]. From the perspective of industrial digitalization, the digital economy is becoming an important engine for driving the development of low-carbon industries [14], promoting the green and low-carbon circular development of regional economies [15], and achieving energy conservation, consumption reduction, emissions reduction, and efficiency enhancement [16]. The logistics internet, big data, cloud services and artificial intelligence promote the development of smart logistics and modern logistics through intelligent planning and resource sharing, and drive energy conservation and carbon reduction in the logistics industry [17].

The existing research has laid the research foundation for this paper, but it has insufficient theoretical research and empirical analysis on the impact of the digital economy on the carbon emissions of the logistics industry, which does not match the urgent need for carbon emissions reduction in China’s logistics industry. In view of this, the main contributions of this study are as follows: (1) In terms of the research perspective, this paper explores the issue of carbon emissions reduction in China’s logistics industry from the perspective of the digital economy and evaluates the development level of China’s provincial digital economy from the perspective of the development foundation, efficiency and momentum. (2) In terms of research methods, this paper constructs an evaluation index system for the development level of the digital economy in China’s provinces and uses the entropy method to measure it; it uses the quantile regression model to analyze the marginal impact of the digital economy on the carbon emissions of the logistics industry. (3) In terms of research content, we theoretically analyze the impact mechanism of the digital economy on the carbon emissions of the logistics industry and empirically verify the specific effect of the digital economy on the carbon emissions of the logistics industry, which are relatively rare in existing research.

The rest of this paper is organized as follows. Section 2 analyzes the impact mechanism of the digital economy on the carbon emissions of the logistics industry and presents
the hypothesis. Section 3 presents the methodology and data analysis, with a detailed introduction to the research methodology, variable selection, and data sources. Section 4 empirically analyzes the specific impact of the digital economy on the carbon emissions of China’s logistics industry, including the benchmark regression results and the quantile regression results. Section 5 gives the conclusions, policy implications, and limitations of the paper.

2. Mechanism Analysis

The impact of the digital economy on the carbon emissions of the logistics industry is complex. On the one hand, the digital economy increases the carbon emissions of the logistics industry. The application of digital technologies and digital platforms is premised on the consumption of a certain amount of energy [18]. The mining, generation, calculation, storage, transmission and processing of logistics big data, the internet, the internet of things, the internet of vehicles, artificial intelligence, e-commerce systems, geographic information systems, multimodal transport systems, online retail information systems, intelligent distribution systems, distribution management systems, supply chain management systems, transportation management systems, and other applications are based on power consumption as the premise and guarantee. Roads, railways, aviation, waterway and pipeline transportation, the operation of bus stations, railway stations, ports, airports, logistics parks, storage centers, distribution centers, logistics centers, logistics transfer stations, etc., the operation of cargo transportation equipment, cargo distribution, the use of sorting equipment, cargo processing equipment, cargo storage equipment, loading and unloading handling equipment, cargo measuring equipment, maintenance and inspection equipment, ventilation and lighting equipment, fire safety equipment, labor protection equipment, and supporting electronic information equipment must consume electricity, raw coal, gasoline, kerosene, diesel, fuel oil, natural gas, and other energy sources, which increases the carbon emissions of the logistics industry. On the other hand, the digital economy reduces the carbon emissions of the logistics industry. The digital economy exerts network, innovation, and efficiency effects to drive carbon emissions reduction in the logistics industry. The impact mechanism is as follows:

The digital economy has a network effect on reducing the carbon emissions of the logistics industry. First, the network effect of the digital economy reduces some logistics activities and drives carbon emissions reduction in the logistics industry. As a producer service industry, the logistics industry is accompanied by the whole process of enterprise production [19]. Raw material procurement requires the participation of raw material logistics, procurement logistics, fuel logistics, parts logistics, and auxiliary material logistics. Production requires the participation of production logistics, which involves multiple logistics links, such as transportation, warehousing, packaging, loading and unloading, handling, distribution processing, and information processing. If waste or recyclable materials are generated in production, the participation of waste logistics, and recyclable logistics are needed. Commodity sales require the participation of sales logistics and third-party logistics. The application of a digital network enables enterprises to realize the advance planning, real-time sharing [20], and precise connection of logistics information; realizes flexible, efficient, and precise management and control of logistics activities; reduces a large number of unnecessary logistics activities and drives carbon emissions reduction in the logistics industry. The network effect of the digital economy enables consumers to browse, modify, and share logistics information in a timely manner [21], reduces offline logistics activities, and reduces the carbon emissions of the logistics industry. Second, the digital economy contributes to the integration and network coordination of all aspects of logistics through network effects and drives carbon emission reduction in the logistics industry. The application of tracking and tracing systems, global positioning systems, geographic information systems, multimodal transport systems, online retail information systems, e-commerce systems, intelligent distribution systems, distribution management systems, supply chain management systems, transportation management systems, automation tech-
technology, artificial intelligence technology, radio frequency identification technology, infrared technology, smart label technology, video visualization technology, data mining technology, and information processing technology lead to the integrated connection and networked collaboration of various logistics links. The dynamic matching of logistics supply and demand promotes the precision, intelligence, and green and low-carbon development of the logistics industry and drives the industry’s carbon emissions reduction.

The digital economy has an innovative effect on reducing the carbon emissions of the logistics industry. First, the digital economy drives the development and application of logistics technology, improves the level of green, low-carbon and energy-saving technologies, and reduces the carbon emissions of the logistics industry. The digital economy is an important part of the national economy, and innovation is its essential feature. Digital technology drives knowledge accumulation, information integration, and resource sharing; reduces the cost of knowledge search, storage, processing, and transmission; accumulates innovative resources; and lays the foundation for technological carbon reduction [22]. The use of digital platforms and digital technologies optimizes the allocation of innovation resources [23], reduces the irrational behavior of technology research and development, predicts innovation risks, reduces innovation costs, improves innovation speed and research and development success rates, promotes technological progress through the calculation and analysis of massive information, and drives carbon emissions reduction in the logistics industry through technological linkages and technological spillovers. Second, the digital economy contributes to the optimization and upgrading of the logistics industry through innovation effects and reduces its carbon emissions. The digital economy has the characteristics of openness, strong connectivity, sharing and multiplication. The use of big data, cloud computing, and artificial intelligence promotes the sharing and creation of open logistics knowledge; improves the open innovation and collaboration of logistics enterprises; improves the ability of open innovation, collaborative innovation, combined innovation, incremental innovation, subversive innovation, and cluster innovation of logistics enterprises; improves the integration and innovation between the logistics industry and other industries; drives technology-intensive, data-driven, and innovation-driven transformation of the logistics industry; promotes the transformation of traditional logistics to smart logistics, modern logistics, and digital logistics; drives the optimization and upgrading of the logistics industry; and reduces the carbon emissions of the logistics industry.

The digital economy has an efficiency effect on reducing the carbon emissions of the logistics industry. First, the digital economy improves energy utilization efficiency and reduces the carbon emissions of the logistics industry. The application of digital technology promotes the replacement of fossil energy by green, low-carbon, and clean energy; improves the development and use of renewable energy; helps the construction of green transportation and green logistics systems; improves energy efficiency [24]; and drives carbon emissions reduction in the logistics industry. Big data, cloud computing, and e-commerce reduce the costs of communication, search, transactions, and logistics reduce information asymmetry and improve energy efficiency [25]. The application of the internet, the internet of things, and the internet of vehicles has made the demand for logistics infinitely enlarged and has also greatly improved the logistics supply capacity, bringing economies of scale in the logistics industry, improving energy efficiency, and reducing carbon emissions. Second, the digital economy helps optimize the allocation of logistics resources, improves the efficiency of logistics elements and reduces the carbon emissions of the logistics industry. Online education, online training, and distance teaching all help improve the learning ability, competitiveness, technology application, and innovation ability of logistics practitioners, promote the accumulation of knowledge and human capital, and improve the labor productivity of the logistics industry. Digital capital, internet capital, and digital finance optimize the flow of logistics capital and improve the efficiency of logistics capital investment. The digital transformation of logistics infrastructure improves its utilization rate and sharing rate. The digital economy promotes the agglomeration and diffusion of logistics resources, promotes the free flow of logistics elements, optimizes the
allocation of logistics resources, reduces logistics costs, and ultimately improves the total factor productivity of the logistics industry. The efficient use of logistics factors and the improvement of total factor productivity both drive carbon emissions reduction in the logistics industry.

Based on the above analysis, this paper posits that the digital economy not only increases the carbon emissions of the logistics industry but also leads to a reduction in carbon emissions of the logistics industry, and the latter is the key issue. The digital economy has a complex impact on the carbon emissions of the logistics industry, and there may be a nonlinear correlation between the two. Therefore, this paper proposes the following hypotheses:

**Hypothesis 1.** The digital economy reduces the carbon emissions of the logistics industry.

**Hypothesis 2.** The digital economy has a nonlinear impact on the carbon emissions of the logistics industry.

### 3. Methodology and Data

#### 3.1. Models

**3.1.1. Benchmark Regression Model**

To test the impact of the digital economy on the carbon emissions of China’s logistics industry, based on the work by Chao et al. (2020) [26], the panel mixed-effects model, fixed-effects model, and random-effects model are used to conduct empirical tests, and the benchmark regression model is set as follows:

\[
LC_{it} = \alpha_0 + \alpha_1 DIG_{it} + \varphi D_{it} + \varepsilon_{it}
\]  

(1)

where \( LC \) is the carbon emissions of China’s logistics industry. \( DIG \) represents China’s digital economy. \( i \) is the province in China, \( t \) is the year and \( D \) is the control variable. \( \alpha_0, \alpha_1 \) and \( \varphi \) are the parameters to be estimated, and \( \varepsilon \) is a random error.

To further verify whether there is a nonlinear correlation between the digital economy and the carbon emissions of the logistics industry, we make reference to scholars’ research on the nonlinear correlation between the digital economy and carbon emissions [27,28]. The digital economy and its square term are incorporated into the model and the nonlinear regression model is constructed as follows:

\[
LC_{it} = \beta_0 + \beta_1 DIG_{it} + \beta_2 DIG^2_{it} + \varphi D_{it} + \varepsilon_{it}
\]  

(2)

where \( DIG^2 \) represents the square term of the digital economy in China, and \( \beta_0, \beta_1, \) and \( \beta_2 \) are the parameters to be estimated.

**3.1.2. Quantile Regression Model**

In 1978, Koenker and Basett proposed the quantile regression model [29]. Compared with the traditional OLS regression method, the quantile regression model has the advantages of fewer constraints, avoiding outliers, and more robust estimation results. It can more comprehensively analyze the marginal impact of the digital economy on the carbon emissions of the logistics industry. Considering that the impact of the digital economy on the carbon emissions of China’s logistics industry may not be uniform, the quantile regression model can be used to measure the varying impact intensity of the digital economy on the carbon emissions of China’s logistics industry under different carbon emissions states. That is, the marginal impact of the digital economy on the carbon emissions of China’s logistics industry at different quantiles can be determined through the significance test and the parameters to be estimated that explore the evolution of the digital economy on the carbon emissions of the logistics industry. Therefore, based on Zhang et al. (2015) [30], the quantile regression model is set as follows:
Quant_p(LC_{it}|DIG_{it}) = \gamma_0 + \gamma'_pDIG_{it} + \varphi D \tag{3}

where Quant_p(LC_{it}|DIG_{it}) represents the carbon emissions of China’s logistics industry at the p-th quantile under the condition of a given development level of the digital economy, and \(\gamma_0\) and \(\gamma'_p\) are the parameters to be estimated. To analyze the marginal impact of the digital economy on the carbon emissions of China’s logistics industry in detail, we selected five quantiles: 0.10, 0.25, 0.5, 0.75, and 0.90.

3.2. Variables and Data

3.2.1. Variables

The explained variable in this paper is the carbon emissions of the logistics industry. Based on the work by Zhang et al. (2013) [31], the consumption of raw coal, gasoline, kerosene, diesel, fuel oil, natural gas, and electricity in the logistics industry is converted into standard coal and added to the total energy consumption of the logistics industry. Then, the carbon emissions formula is used to calculate the carbon dioxide emissions of the logistics industry as the value of the carbon emissions of that industry. The formula is:

\[ LC = \sum_{i=1}^{7} A_i B_i \tag{4} \]

where \(LC\) represents the total carbon dioxide emissions of the logistics industry, \(i\) is the \(i\)th energy consumed by the logistics industry, \(1 \leq i \leq 7\), \(A_i\) represents the consumption of the \(i\)th energy source in the logistics industry and \(B_i\) represents the carbon emissions coefficient of the \(i\)th energy source in the logistics industry. According to the “IPCC Guidelines for National Greenhouse Gas Emissions Inventory 2006”, the carbon emissions factors for raw coal, gasoline, kerosene, diesel, fuel oil, natural gas and electricity are 0.7559, 0.5538, 0.5741, 0.5821, 0.6185, 0.4483, and 2.2132 kg carbon/kg standard coal, respectively.

The explanatory variable is the digital economy. To analyze the nonlinear impact of the digital economy on the carbon emissions of China’s logistics industry, we used the square term of the digital economy as an explanatory variable. According to the definition of the digital economy and the availability of relevant data, this paper constructs an evaluation index system of China’s digital economy from the following three aspects: development foundation, development efficiency and development momentum, as shown in Table 1.

<table>
<thead>
<tr>
<th>First-Level Indicators</th>
<th>Second-Level Indicators</th>
<th>Measurement Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development foundation</td>
<td>Internet</td>
<td>Internet broadband access users (10,000 households)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Long-distance optical cable line length (10,000 km)</td>
</tr>
<tr>
<td>Mobile phone</td>
<td></td>
<td>End-of-year mobile phone users (10,000)</td>
</tr>
<tr>
<td>Development efficiency</td>
<td>Input indicator</td>
<td>Number of employees in computer, communication and other electronic equipment manufacturing industry (10,000 people)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of employees in information transmission, software and information technology services (10,000 people)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Physical capital stock of computer, communication and other electronic equipment manufacturing industry (RMB 100 million)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Physical capital stock of information transmission, software and information technology services (RMB 100 million)</td>
</tr>
<tr>
<td>Output indicator</td>
<td></td>
<td>Main business income of computer, communication and other electronic equipment manufacturing industry (RMB 100 million)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total telecom business (RMB 100 million)</td>
</tr>
<tr>
<td>Development momentum</td>
<td>Innovation</td>
<td>Technology market turnover (RMB 100 million)</td>
</tr>
<tr>
<td></td>
<td>Talent</td>
<td>Human capital</td>
</tr>
<tr>
<td></td>
<td>Institutional</td>
<td>Institutional Index</td>
</tr>
</tbody>
</table>

Table 1. The evaluation index system of China’s digital economy.
The steps to measure the development level of China’s digital economy are as follows: First, the entropy method is used to measure the development foundation and development momentum of the digital economy, and the data envelopment analysis method is used to measure the development efficiency of the digital economy. Then, based on the measurement values of the development foundation, development efficiency and development momentum of the digital economy, the entropy method is used to measure the development level of China’s digital economy. All the measurement methods in this section are as follows:

The first is the entropy method. In 1948, Shannon introduced entropy into information theory and used information entropy to objectively weight each evaluation index [32]. The entropy method has the advantages of strong objectivity, simple calculation, wide applicability, and high accuracy. Therefore, it is widely used in many disciplines and fields. Based on the work by Liu et al. (2018) [33], the calculation steps of the entropy method are set as follows:

In the first step, the original index matrix is set as follows:

\[
X = \begin{pmatrix}
X_{11} & \cdots & X_{1j} \\
\vdots & \ddots & \vdots \\
X_{i1} & \cdots & X_{ij}
\end{pmatrix}
\]  

(5)

In the matrix, \(X_{ij}\) represents the observation value of the \(i\)th evaluation object on the \(j\)th index, \(0 \leq i \leq n\), and \(0 \leq j \leq m\). All data are standardized. Since all indicators are positive indicators, the positive extreme value method is adopted. The formula is as follows:

\[
X'_{ij} = \frac{X_{ij} - \min(X_{ij})}{\max(X_{ij}) - \min(X_{ij})}
\]  

(6)

\(X'_{ij}\) is the standardized index value, \(\min(X_{ij})\) is the minimum value within the group and \(\max(X_{ij})\) is the maximum value within the group.

In the second step, calculate the power function \(P_{ij}\), which is the proportion of the \(j\)th index in the \(i\)th evaluation object, and its formula is as follows:

\[
P_{ij} = \frac{X_{ij}}{\sum_{i=1}^{n} X_{ij}}
\]  

(7)

In the third step, calculate the entropy value \(e_j\) and the difference coefficient \(d_j\), and their solution formulas are as follows:

\[
e_j = -\frac{1}{\ln n} \sum_{i=1}^{n} P \ln(P)
\]  

(8)

\[
d_j = 1 - e_j
\]  

(9)

In the fourth step, calculate the index weight \(W_j\) and the comprehensive evaluation value \(Z_i\), and the formulas are as follows:

\[
W_j = \frac{d_j}{\sum_{j=1}^{m} d_j}
\]  

(10)

\[
Z_i = \sum_{j=1}^{m} W_j \times X_{ij}
\]  

(11)

In the formula, the larger the value of \(Z_i\), the more important the \(i\)th index, while the smaller the value of \(Z_i\), the less important the \(i\)th index, \(0 \leq Z_i \leq 1\).

The second is the DEA model. In 1978, Charnes, Cooper and Rhodes proposed the data envelopment analysis method (DEA model) [34], which is a nonparametric analysis method based on “relative efficiency”. The DEA model has the advantages of not needing
to set the specific form of the production function and can measure the efficiency value of multiple inputs and multiple outputs. In this paper, the DEA model is used to measure the development efficiency of the digital economy, and the linear programming formula of the DEA-CCR model is:

\[
\min \theta \\
\text{Subject to} \\
\sum_{j=1}^{t} \lambda_j X_j \leq \theta X_0 \\
\sum_{j=1}^{t} \lambda_j Y_j \geq Y_0 \\
\lambda_j \geq 0 \\
j = 1, 2, \ldots, t
\]

where \(\theta\) represents the development efficiency of the digital economy, \(j\) is the decision unit, \(X\) and \(Y\) are input and output vectors, and \(\lambda\) represents weight vectors. The larger the value of \(\theta\), the higher the efficiency, while the smaller the value of \(\theta\), the lower the efficiency, \(0 \leq \theta \leq 1\). DEA-SOLVER 5.0 software is used to measure the development efficiency of the digital economy.

The third is the perpetual inventory method. In 1951, Goldsmith proposed using the perpetual inventory method to estimate the physical capital stock, arguing that the current capital stock is the weighted sum of the investment levels in the past periods [35]. Based on the work by to Liu et al. (2015) [36], the perpetual inventory method is used to measure the physical capital stock of the computer, communication and other electronic equipment manufacturing industries, as well as the physical capital stock of the information transmission, software and information technology service industries, and its formulas are as follows:

\[
K_t = IN_t + (1 - \delta)K_{t-1} \\
K_0 = IN_0 / (g + \delta)
\]

where \(K_t\) stands for the physical capital stock in period \(t\), \(IN_t\) stands for fixed assets in period \(t\), \(g\) is the average growth rate of investment in fixed assets, and \(\delta\) is the depreciation rate. Based on the work by He et al. (2019) [37], \(\delta = 15%\) is used, and the base period is 2004.

The fourth is the average years of education method. Referring to Huang et al. (2015) [38], the average education years method is used to measure the level of human capital, and the calculation formula is set as:

\[
H_{it} = \frac{6prim_{it} + 9mid_{it} + 12hig_{it} + 16uni_{it}}{emp_{it}}
\]

where \(H\) stands for human capital in China, \(prim_{it}\), \(mid_{it}\), \(hig_{it}\) and \(uni_{it}\) represent the number of persons with primary school, junior high school, high school, college education, and above among the employed persons in year \(t\) in province \(i\) in China and \(emp_{it}\) represents the total number of employed persons in province \(i\) in year \(t\).

The fifth is the measurement method of the institutional index. Based on the work by Liu et al. (2008) [39], institutions are divided into three types: property rights diversification, state-controlled capital and opening to the outside world, which assign 40%, 20% and 40% of the proportions and are measured by the proportion of the total industrial output value of nonstate-owned enterprises of the total industrial output value of industrial enterprises above a designated size, the proportion of nonfinancial revenue in GDP and the proportion of total import and export in GDP, respectively.

The control variables are economic development and its square term, industrial structure, environmental regulation, technological innovation, and opening to the outside world. The first is economic development and its square term. On the one hand, a series of environmental impacts brought by economic development increase the carbon emissions of the logistics industry. On the other hand, a higher level of economic development
establishes the material foundation for strengthening ecological and ecological protection, improving environmental quality and promoting technological carbon reduction and providing technical, financial and institutional support for carbon reduction in the logistics industry. According to the environmental Kuznets curve, economic growth and environmental pollution have an inverted U-shaped correlation [40], so economic development and its square term are used as control variables for analysis. The second is industrial structure. The optimization and upgrading of the industrial structure gives full play to the structural dividend, promotes the rational distribution of industrial departments, limits the development of high-pollution, high-energy-consuming, and high-emission industries, and promotes the development of green, low-carbon, recycling, and high-tech industries. It also promotes the green and low-carbon transformation of the logistics industry through industrial linkages and regional linkages [41] and reduces the carbon emissions of the logistics industry. The third is environmental regulation. Environmental regulation can improve environmental productivity [42]. The increase in the intensity of environmental regulation forces the innovation of environmental protection technology and energy-saving technology, promotes the replacement of fossil energy by green and clean energy, promotes the replacement of fossil energy by renewable energy, and promotes the replacement of low-energy-consuming and low-emission industries with high-energy-consuming and high-emission industries. This replacement forces the logistics industry to switch to green and low-carbon, reducing its carbon emissions. The fourth is technological innovation. The improvement of technological innovation, especially in the areas of low-carbon and green energy-saving technologies, enhances the development and utilization efficiency of renewable energy [43], energy use efficiency, resource use efficiency, and total factor productivity, and promotes technical energy savings, carbon reduction, and efficiency enhancement in the logistics industry. The fifth is opening to the outside world. Opening to the outside world can reduce carbon emissions [44], it expands the boundaries of the logistics market and helps the logistics industry to optimize the allocation of resources within a larger market scope. Competition and cooperation related to energy conservation and emission reduction in the logistics industry reduce its carbon emissions.

The selection information of all variables is shown in Table 2.

<table>
<thead>
<tr>
<th>Variables Types</th>
<th>Variable Names</th>
<th>Measurement Indicators</th>
<th>Symbols</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explained variable</td>
<td>Carbon emissions of the logistics industry</td>
<td>The total carbon dioxide emissions of the logistics industry (million tons)</td>
<td>LC</td>
</tr>
<tr>
<td>Explanatory variables</td>
<td>Digital economy</td>
<td>Digital economy</td>
<td>DIG</td>
</tr>
<tr>
<td></td>
<td>Square term of the digital economy</td>
<td>Square term of the digital economy</td>
<td>DIG(^2)</td>
</tr>
<tr>
<td></td>
<td>Economic development</td>
<td>GDP per capita (RMB 10,000)</td>
<td>PGDP</td>
</tr>
<tr>
<td></td>
<td>Square term of the economic development</td>
<td>The square of GDP per capita</td>
<td>PGDP(^2)</td>
</tr>
<tr>
<td>Control variables</td>
<td>Industrial structure</td>
<td>The proportion of the output value of the secondary industry to GDP (%)</td>
<td>IS</td>
</tr>
<tr>
<td></td>
<td>Environmental regulation</td>
<td>The proportion of completed industrial pollution control investment in industrial added value (%)</td>
<td>ER</td>
</tr>
<tr>
<td></td>
<td>Technological innovation</td>
<td>Number of authorized patent applications (10,000 items)</td>
<td>TECH</td>
</tr>
<tr>
<td></td>
<td>Opening to the outside world</td>
<td>The proportion of total imports and exports to GDP (%)</td>
<td>OPEN</td>
</tr>
</tbody>
</table>

Table 2. Variable selection.
3.2.2. Data

The regional scope of this study is 30 provinces in China (excluding Hong Kong, Macao, Taiwan and Tibet), and the time frame is 2005–2019. Data come from the China Statistical Yearbook, China Logistics Yearbook, China Industrial Statistical Yearbook, China Tertiary Industry Statistical Yearbook, China Fixed Asset Investment Statistical Yearbook, China Investment Statistical Yearbook, China Labor Statistics Yearbook, China Statistical Yearbook of Population and Employment, and Provincial Statistical Yearbooks. The descriptive statistics of the variables are shown in Table 3.

Table 3. Descriptive statistics.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Max</th>
<th>Min</th>
<th>Mean</th>
<th>Std. Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC</td>
<td>32.116</td>
<td>0.294</td>
<td>8.166</td>
<td>5.237</td>
</tr>
<tr>
<td>DIG</td>
<td>0.735</td>
<td>0.054</td>
<td>0.201</td>
<td>0.110</td>
</tr>
<tr>
<td>DIG^2</td>
<td>0.540</td>
<td>0.003</td>
<td>0.053</td>
<td>0.067</td>
</tr>
<tr>
<td>PGDP</td>
<td>16.456</td>
<td>0.522</td>
<td>4.058</td>
<td>2.672</td>
</tr>
<tr>
<td>PGDP^2</td>
<td>270.810</td>
<td>0.272</td>
<td>23.602</td>
<td>35.110</td>
</tr>
<tr>
<td>IS</td>
<td>61.960</td>
<td>15.989</td>
<td>43.107</td>
<td>8.312</td>
</tr>
<tr>
<td>ER</td>
<td>3.098</td>
<td>0.017</td>
<td>0.437</td>
<td>0.371</td>
</tr>
<tr>
<td>TECH</td>
<td>52.739</td>
<td>0.008</td>
<td>3.614</td>
<td>6.341</td>
</tr>
<tr>
<td>OPEN</td>
<td>166.397</td>
<td>1.146</td>
<td>30.610</td>
<td>33.916</td>
</tr>
</tbody>
</table>

To eliminate the bias caused by dimensional differences, all the variables were standardized by the extreme value method. The positive extreme value method is used to standardize positive indicators, and the negative extreme value method is used to standardize negative indicators. The formulas are as follows:

\[ x'_{ij} = \frac{[x_{ij} - \min(x_{ij})]}{[\max(x_{ij}) - \min(x_{ij})]} \]  

where i is the province in China, j is the index, \( x'_{ij} \) is the standardized value, and the value range is [0, 1]. \( x_{ij} \) is the original value, \( \min(X_{ij}) \) is the minimum value, and \( \max(X_{ij}) \) is the maximum value. The data used in the following analyses were standardized.

4. Results

4.1. Benchmark Regression Results

Based on the panel data of 30 provinces in China from 2005 to 2019, to show the correlation between the digital economy and the carbon emissions of the logistics industry, scatter plots of the correlations between the digital economy and the carbon emissions of China’s logistics industry are shown in Figure 1.

As shown in Figure 1, the linear correlation between the digital economy and the carbon emissions of China’s logistics industry is not obvious, while the nonlinear correlation is more obvious. From the fitting line trend, there is an obvious U-shaped correlation between the digital economy and the carbon emissions of China’s logistics industry. The development level of the digital economy is far from the U-shaped inflection point, and it is in the first half of the U-shaped correlation, which indicates that the digital economy has an obvious negative correlation with the carbon emissions of China’s logistics industry.

To further quantify the relationship between the digital economy and the carbon emissions of China’s logistics industry, we used a panel mixed effect model, fixed effect model, and random effect model to empirically analyze the impact of the digital economy on the carbon emissions of China’s logistics industry. The F test, xttest0 test, and Hausman test are used to identify the best results. It is found that fixed effects are better than random effects and mixed effects, and the results are shown in Column (1) of Table 4. The robustness tests are carried out by using the variable substitution method and subsample analysis method; that is, the core explained variable is replaced by the carbon emissions of the
logistics industry in one lag period, and the 30 provinces are replaced by the eastern provinces in China. The regression results are shown in Columns (2) and (3) of Table 4. The nonlinear regression model is used to further explore the nonlinear impact of the digital economy on the carbon emissions of China’s logistics industry, and the regression results are shown in Column (4) of Table 4. The variable substitution method and subsample analysis method are still used for robustness testing; that is, the number of broadband internet access users is used to substitute the digital economy, and the eastern provinces are used to substitute for 30 provinces in China. The regression results are shown in Columns (5) and (6) of Table 4.

![Figure 1. Scatter plots.](image_url)

Table 4. Benchmark regression results.

<table>
<thead>
<tr>
<th>Variables</th>
<th>(1) Linear Regression</th>
<th>Robustness Test Variable Substitution</th>
<th>Robustness Test Subsample Substitution</th>
<th>Nonlinear Regression</th>
<th>Robustness Test Variable Substitution</th>
<th>Robustness Test Subsample Substitution</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIG</td>
<td>−0.017 (0.029)</td>
<td>−0.032 (0.032)</td>
<td>−0.011 (0.045)</td>
<td>−0.209 *** (0.075)</td>
<td>−0.242 *** (0.083)</td>
<td>−0.834 *** (0.183)</td>
</tr>
<tr>
<td>DIG^2</td>
<td>0.207 ** (0.085)</td>
<td>0.222 ** (0.095)</td>
<td>0.728 *** (0.095)</td>
<td>0.242 *** (0.083)</td>
<td>0.728 *** (0.183)</td>
<td>0.728 *** (0.183)</td>
</tr>
<tr>
<td>PGDP</td>
<td>−0.671 *** (0.042)</td>
<td>−0.742 *** (0.047)</td>
<td>−0.530 *** (0.091)</td>
<td>0.207 ** (0.085)</td>
<td>0.242 *** (0.083)</td>
<td>0.728 *** (0.183)</td>
</tr>
<tr>
<td>PGDP^2</td>
<td>0.395 *** (0.047)</td>
<td>0.427 *** (0.052)</td>
<td>0.283 *** (0.080)</td>
<td>0.326 *** (0.055)</td>
<td>0.242 *** (0.083)</td>
<td>0.728 *** (0.183)</td>
</tr>
<tr>
<td>IS</td>
<td>0.133 *** (0.025)</td>
<td>0.160 *** (0.028)</td>
<td>0.090 (0.059)</td>
<td>0.955 *** (0.025)</td>
<td>0.114 *** (0.028)</td>
<td>0.085 (0.035)</td>
</tr>
<tr>
<td>ER</td>
<td>0.024</td>
<td>0.011</td>
<td>0.009</td>
<td>0.020</td>
<td>0.006</td>
<td>0.013</td>
</tr>
<tr>
<td>TECH</td>
<td>−0.403 *** (0.036)</td>
<td>−0.372 *** (0.040)</td>
<td>−0.412 *** (0.047)</td>
<td>−0.449 *** (0.038)</td>
<td>−0.421 *** (0.042)</td>
<td>−0.508 *** (0.016)</td>
</tr>
<tr>
<td>OPEN</td>
<td>−0.087 *</td>
<td>−0.101 **</td>
<td>−0.036</td>
<td>−0.044</td>
<td>−0.044</td>
<td>0.067</td>
</tr>
<tr>
<td>_cons</td>
<td>0.832 *** (0.045)</td>
<td>0.832 *** (0.050)</td>
<td>0.813 *** (0.055)</td>
<td>0.859 *** (0.038)</td>
<td>0.862 *** (0.042)</td>
<td>0.989 *** (0.050)</td>
</tr>
<tr>
<td>Prob</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

Note: Standard errors are in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1.

It can be concluded from Columns (1) to (3) of Table 4 that the linear correlation between the digital economy and the carbon emissions of the logistics industry is not significant in China. Column (1) shows that the digital economy (DIG) has not passed the significance test; that is, there is no pure linear correlation between the digital economy and the carbon emissions of China’s logistics industry. In the robustness test of Columns (2) and (3), it is found that after replacing the explained variables and subsamples, the digital economy still fails the significance test; thus, the conclusion that there is
no linear correlation between the digital economy and the carbon emissions of China’s logistics industry is robust. It is therefore necessary to verify the nonlinear correlation between the digital economy and the carbon emissions of China’s logistics industry.

As shown in Column (4) of Table 4, the digital economy (DIG) reduces the carbon emissions of China’s logistics industry. The digital economy and its square term (DIG$^2$) passed the significance test at the 1% confidence level, which indicates that the digital economy has a significant nonlinear correlation with the carbon emissions of China’s logistics industry. The coefficient of the digital economy is negative, and the coefficient of the square term of the digital economy is positive, which indicates that there is a significant U-shaped correlation between the digital economy and the carbon emissions of the logistics industry. That is, with the improvement of the digital economy, the carbon emissions in the logistics industry have a U-shaped characteristic of first decreasing and then increasing. The inflection point formula and the denormalization formula are used to calculate the inflection point value, which is 0.398; that is, when the development of the digital economy is lower than 0.398, the digital economy has a significant inhibitory effect on the carbon emissions of the logistics industry. Through data screening, it is found that the value of 94% of the digital economy is on the left side of the inflection point, and the average value of the digital economy development of 0.201 is far below the inflection point value, indicating that the digital economy is in the first half of the U-shaped segment. The digital economy and the carbon emissions of the logistics industry show a monotonically decreasing negative correlation, and the digital economy has a significant inhibitory effect on the carbon emissions of China’s logistics industry. Studies by some scholars have shown that the development of the digital economy has a positive impact on carbon emission reduction [45].

As shown in Column (4) of Table 4, among the control variables, first, economic development (PGDP) has a significant inhibitory effect on the carbon emissions of China’s logistics industry. Both economic development and its square term (PGDP$^2$) passed the 1% significance level test, and there is one negative and one positive coefficient, indicating that there is a significant U-shaped correlation between economic development and the carbon emissions of the logistics industry. The absolute value of the coefficient of economic development is significantly larger than its quadratic coefficient, demonstrating that economic development has significant linear and nonlinear inhibitory effects on the carbon emissions of the logistics industry and that the linear inhibitory effect is more prominent. Through data screening, it is found that the value of nearly 100% of the economic development is on the left side of the inflection point of 14.696, and the average value of economic development is 4.058, far below the inflection point value, which illustrates that economic development is in the first half of the U shape; that is, economic development reduces the carbon emissions of China’s logistics industry. Second, technological innovation (TECH) is significantly negative at the 1% confidence level, and the coefficient is $-0.449$, indicating that technological innovation reduces the carbon emissions of the logistics industry. For each unit of technological innovation, the carbon emissions of the logistics industry will be reduced by 0.449 units. Ma et al. (2021) also found that technological innovation can reduce carbon emissions and improve the carbon emissions performance of the logistics industry [46]. Third, industrial structure (IS) passed the significance test, but the coefficient is positive, which demonstrates that there is a positive correlation between the industrial structure and the carbon emissions of the logistics industry; that is, the change in the industrial structure leads to an increase in the carbon emissions of the logistics industry, which may be caused by the unreasonable energy structure. Wang et al. (2019) also found that industrial structure drives the increase in carbon emissions [47]. Fourth, the effects of environmental regulation (ER) and opening to the outside world (OPEN) on the carbon emissions of the logistics industry are not significant, which may be because of insufficient intensity of environmental regulation and insufficient depth of the opening of the logistics industry.
In Columns (5) and (6) of Table 4, although there are differences with the regression results of Column (4) in terms of coefficient values and significance levels, the relationship between the core variables has not changed significantly; thus, it still supports the conclusion that the digital economy has a significant impact on the carbon emissions reduction of the logistics industry. The conclusion of the inhibitory effect proves that the development of the digital economy reduces the carbon emissions of the logistics industry and is basically stable.

4.2. Quantile Regression Results

Based on the provincial data from 2005 to 2019 in China, a quantile regression model and Stata software are used to study the marginal impact of the digital economy on the carbon emissions of China’s logistics industry to explore variations in impact intensity at different quantiles, and the regression results are shown in Columns (1) to (6) of Table 5.

In Columns (1) to (6) of Table 5, the digital economy (DIG) has an inhibitory effect on the carbon emissions of China’s logistics industry. At the five quantiles, the digital economy passed the 1% significance level test, and the coefficients are all negative, indicating a significant inhibitory effect on the carbon emissions of the logistics industry. The marginal impact of the development of the digital economy on carbon emissions reduction in the logistics industry is decreasing. At the five quantiles of 0.1, 0.25, 0.5, 0.75, and 0.9, the coefficients of the digital economy development level are $-0.818$, $-0.808$, $-0.702$, $-0.453$, and $-0.345$, respectively, and the absolute values of the coefficients decrease sequentially, which indicates that there are differences in the impact intensity of the development level of the digital economy on the carbon emissions of the logistics industry at different quantiles. Furthermore, with the continuous increase in quantiles, the impact of the digital economy on the carbon emissions reduction of the logistics industry continues to weaken; that is, the marginal impact shows a decreasing trend.

### Table 5. Quantile regression results.

<table>
<thead>
<tr>
<th>Variables</th>
<th>(1) $p = 0.1$</th>
<th>(2) $p = 0.25$</th>
<th>(3) $p = 0.5$</th>
<th>(4) $p = 0.75$</th>
<th>(5) $p = 0.9$</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIG</td>
<td>$-0.818^{***}$</td>
<td>$-0.808^{***}$</td>
<td>$-0.702^{***}$</td>
<td>$-0.453^{***}$</td>
<td>$-0.345^{***}$</td>
</tr>
<tr>
<td></td>
<td>(0.129)</td>
<td>(0.164)</td>
<td>(0.153)</td>
<td>(0.072)</td>
<td>(0.051)</td>
</tr>
<tr>
<td>PGDP</td>
<td>$-0.673^{***}$</td>
<td>$-0.424^{***}$</td>
<td>$-0.310^{**}$</td>
<td>$-0.436^{***}$</td>
<td>$-0.300^{***}$</td>
</tr>
<tr>
<td></td>
<td>(0.142)</td>
<td>(0.133)</td>
<td>(0.148)</td>
<td>(0.107)</td>
<td>(0.096)</td>
</tr>
<tr>
<td>PGDP$^2$</td>
<td>0.336</td>
<td>0.157</td>
<td>0.489*</td>
<td>0.628**</td>
<td>0.345**</td>
</tr>
<tr>
<td></td>
<td>(0.222)</td>
<td>(0.284)</td>
<td>(0.278)</td>
<td>(0.216)</td>
<td>(0.118)</td>
</tr>
<tr>
<td>IS</td>
<td>$-0.286^{***}$</td>
<td>$-0.244^{***}$</td>
<td>$-0.141^{***}$</td>
<td>$-0.099^{***}$</td>
<td>$-0.119^{***}$</td>
</tr>
<tr>
<td></td>
<td>(0.047)</td>
<td>(0.044)</td>
<td>(0.035)</td>
<td>(0.021)</td>
<td>(0.023)</td>
</tr>
<tr>
<td>ER</td>
<td>$-0.022$</td>
<td>$-0.015$</td>
<td>$-0.029$</td>
<td>$0.109^{**}$</td>
<td>$0.129^{**}$</td>
</tr>
<tr>
<td></td>
<td>(0.027)</td>
<td>(0.065)</td>
<td>(0.048)</td>
<td>(0.050)</td>
<td>(0.036)</td>
</tr>
<tr>
<td>TECH</td>
<td>$-0.054$</td>
<td>$-0.073$</td>
<td>$-0.383^{**}$</td>
<td>$-0.424^{***}$</td>
<td>$-0.462^{***}$</td>
</tr>
<tr>
<td></td>
<td>(0.135)</td>
<td>(0.138)</td>
<td>(0.155)</td>
<td>(0.101)</td>
<td>(0.046)</td>
</tr>
<tr>
<td>OPEN</td>
<td>0.107**</td>
<td>0.075</td>
<td>0.139</td>
<td>0.176**</td>
<td>0.096**</td>
</tr>
<tr>
<td></td>
<td>(0.042)</td>
<td>(0.070)</td>
<td>(0.093)</td>
<td>(0.041)</td>
<td>(0.026)</td>
</tr>
<tr>
<td>_cons</td>
<td>1.091^{***}</td>
<td>1.074^{***}</td>
<td>1.025^{***}</td>
<td>1.009^{***}</td>
<td>1.041^{***}</td>
</tr>
<tr>
<td></td>
<td>(0.027)</td>
<td>(0.024)</td>
<td>(0.025)</td>
<td>(0.016)</td>
<td>(0.018)</td>
</tr>
</tbody>
</table>

Note: Standard errors are in parentheses. $^{***} p < 0.01$, $^{**} p < 0.05$, $^* p < 0.1$.

Among the control variables, economic development and its square term, industrial structure, environmental regulation, technological innovation and opening to the outside world have evolutionary effects on the carbon emissions of China’s logistics industry. First, economic development (PGDP) passed the significance test, and its coefficients are all negative and different, demonstrating that economic development reduces the carbon emissions of the logistics industry; however, at different quantiles of the carbon emissions of the logistics industry, the impact of economic development is also different. The square term of economic development (PGDP$^2$) is significant at the 0.5, 0.75, and 0.9 quantiles,
indicating that the U-shaped relationship between economic development and the carbon emissions reduction of the logistics industry is more prominent in the middle and high quantiles. Second, industrial structure (IS) passed the significance test at all quantiles, which shows that the optimization of the industrial structure reduces the carbon emissions of the logistics industry at different quantiles. The impact of industrial structure on the carbon emissions of the logistics industry is more obvious in the low quantile. Third, technological innovation (TECH) passed the test at the 0.5, 0.75, and 0.9 quantiles, and the absolute value of the coefficient shows an increasing trend. Fourth, at different quantiles, environmental regulation (ER) and opening to the outside world (OPEN) have different impacts on the carbon emissions of the logistics industry; the coefficients at some quantiles are positive, indicating that they have not reduced the carbon emissions of the logistics industry. This may be related to the factors’ insufficient impact on the logistics industry.

The changes in the quantile regression coefficients at different quantiles are displayed graphically, as shown in Figure 2.

As shown in Figure 2, there is a nonlinear correlation between the digital economy and the carbon emissions of China’s logistics industry. In terms of significance, the digital economy (DIG) is significant at all quantiles, indicating that there is a significant correlation between the digital economy and the carbon emissions of China’s logistics industry. In terms of coefficient values, the coefficient values of the digital economy are negative at all quantiles, there is an increasing trend, and the absolute value of the coefficient decreases, which indicates that the digital economy has an inhibitory effect on the carbon emissions of China’s logistics industry, and this inhibitory effect diminishes as the quantile increases.

In the robustness test, we continue to use the variable substitution method; that is, the number of broadband internet access users is used to substitute the digital economy, and the remaining variables remain unchanged. The regression results are shown in Table 6.

From the robustness test results in Table 6, it can be seen that (1) the conclusion that the digital economy has an inhibitory effect on the carbon emissions of China’s logistics industry is robust. At the five quantiles of 0.1, 0.25, 0.5, 0.75, and 0.9, the digital economy passed the 1% significance level test, and the coefficients are all negative, indicating a significant inhibitory effect on the carbon emissions of the logistics industry. (2) The conclusion that the marginal impact of the development of the digital economy on the carbon emission reduction of China’s logistics industry is decreasing is robust. At the 0.1, 0.25, 0.75, and 0.9 quantiles, the coefficients of the digital economy are $-0.956$, $-0.843$, $-0.714$, and $-0.586$, and the absolute values of the coefficients decrease in turn, which shows that the digital economy has an evolutionary effect on the carbon emissions of China’s logistics industry. With the increase in quantiles, the marginal impact of the digital economy decreases.
economy on the carbon emission reduction of the logistics industry generally shows a decreasing trend, which is basically consistent with the analysis conclusions in Table 5.

Table 6. Robustness Test Results.

<table>
<thead>
<tr>
<th>Variables</th>
<th>(1) $p = 0.1$</th>
<th>(2) $p = 0.25$</th>
<th>(3) $p = 0.5$</th>
<th>(4) $p = 0.75$</th>
<th>(5) $p = 0.9$</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIG</td>
<td>$-0.956^{***}$</td>
<td>$-0.843^{***}$</td>
<td>$-0.863^{***}$</td>
<td>$-0.714^{***}$</td>
<td>$-0.586^{***}$</td>
</tr>
<tr>
<td></td>
<td>$(0.113)$</td>
<td>$(0.104)$</td>
<td>$(0.099)$</td>
<td>$(0.111)$</td>
<td>$(0.083)$</td>
</tr>
<tr>
<td>PGDP</td>
<td>$-0.058$</td>
<td>$0.050$</td>
<td>$0.174$</td>
<td>$0.100$</td>
<td>$-0.011$</td>
</tr>
<tr>
<td></td>
<td>$(0.134)$</td>
<td>$(0.107)$</td>
<td>$(0.130)$</td>
<td>$(0.156)$</td>
<td>$(0.116)$</td>
</tr>
<tr>
<td>PGDP$^2$</td>
<td>$0.327^{**}$</td>
<td>$0.309^{**}$</td>
<td>$-0.569^{***}$</td>
<td>$-0.232$</td>
<td>$-0.015$</td>
</tr>
<tr>
<td></td>
<td>$(0.142)$</td>
<td>$(0.130)$</td>
<td>$(0.152)$</td>
<td>$(0.297)$</td>
<td>$(0.240)$</td>
</tr>
<tr>
<td>IS</td>
<td>$-0.166^{***}$</td>
<td>$-0.134^{***}$</td>
<td>$-0.127^{***}$</td>
<td>$-0.049^{**}$</td>
<td>$-0.078^{***}$</td>
</tr>
<tr>
<td></td>
<td>$(0.037)$</td>
<td>$(0.032)$</td>
<td>$(0.039)$</td>
<td>$(0.023)$</td>
<td>$(0.012)$</td>
</tr>
<tr>
<td>ER</td>
<td>$-0.063$</td>
<td>$-0.052$</td>
<td>$-0.003$</td>
<td>$0.036$</td>
<td>$0.074^{***}$</td>
</tr>
<tr>
<td></td>
<td>$(0.050)$</td>
<td>$(0.065)$</td>
<td>$(0.075)$</td>
<td>$(0.037)$</td>
<td>$(0.026)$</td>
</tr>
<tr>
<td>TECH</td>
<td>$0.336^{***}$</td>
<td>$0.245^{*}$</td>
<td>$0.321$</td>
<td>$0.131$</td>
<td>$-0.006$</td>
</tr>
<tr>
<td></td>
<td>$(0.111)$</td>
<td>$(0.131)$</td>
<td>$(0.203)$</td>
<td>$(0.183)$</td>
<td>$(0.158)$</td>
</tr>
<tr>
<td>OPEN</td>
<td>$-0.192^{***}$</td>
<td>$-0.194^{***}$</td>
<td>$0.136^{*}$</td>
<td>$-0.095^{**}$</td>
<td>$-0.091^{***}$</td>
</tr>
<tr>
<td></td>
<td>$(0.037)$</td>
<td>$(0.026)$</td>
<td>$(0.071)$</td>
<td>$(0.044)$</td>
<td>$(0.032)$</td>
</tr>
<tr>
<td>_cons</td>
<td>$0.982^{***}$</td>
<td>$0.978^{***}$</td>
<td>$0.987^{***}$</td>
<td>$0.970^{***}$</td>
<td>$1.008^{***}$</td>
</tr>
<tr>
<td></td>
<td>$(0.025)$</td>
<td>$(0.018)$</td>
<td>$(0.026)$</td>
<td>$(0.018)$</td>
<td>$(0.014)$</td>
</tr>
</tbody>
</table>

Note: Standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

5. Conclusions

This paper focuses on the impact of the digital economy on the carbon emissions of the logistics industry. Based on provincial panel data of China from 2005 to 2019, it analyzes the impact mechanism of the digital economy on the carbon emissions of the logistics industry, and uses the nonlinear regression model and quantile regression model to empirically test the digital economy’s impact on the carbon emissions of China’s logistics industry. The main conclusions are as follows: (1) The digital economy has a nonlinear impact on the carbon emissions of China’s logistics industry. There is a U-shaped correlation between the digital economy and the carbon emissions of China’s logistics industry, and this is in the first half of the U-shaped correlation. The development of the digital economy has a significant inhibitory effect on the carbon emissions of China’s logistics industry. (2) The digital economy has an evolutionary effect on the carbon emissions reduction of China’s logistics industry. With the increase in quantiles, the marginal impact of the digital economy on the carbon emissions reduction of the logistics industry decreases. (3) There is a U-shaped correlation between economic development and the carbon emissions of China’s logistics industry, and it is in the first half of the U shape. Economic development drives the carbon emissions reduction of the logistics industry. Technological innovation has a significant impact on carbon emissions reduction in the logistics industry, and its marginal impact demonstrates an increasing trend.

Based on the above conclusions, this study gives the following policy implications. (1) Promote the high-quality development of the digital economy. First, the development foundation of the digital economy should be strengthened. The government should promote the standardization, intensification, greening, and low carbonization of digital infrastructure; improve the efficiency of digital infrastructure utilization; and promote the cooperation, co-construction, and sharing of digital infrastructure between different regions. Second, the development efficiency of the digital economy should be improved. The government should promote the efficient and coordinated development of digital industrialization and industrial digitization, cultivate digital industries and high-tech industrial clusters, and strengthen the construction of digital platforms. Third, the development momentum of the digital economy should be transformed. The government should strengthen financial support, talent support, tax support, and policy support for key core technologies; improve digital technology innovation capabilities; combine academic education, voca-
tional education, and practical education guided by market demand; establish a digital talent training mechanism with big data analysis capabilities, key technology research, and development capabilities, digital technology operation capabilities, and digital integration application capabilities; strengthen digital supervision; create a good, green, safe, and healthy network ecology; and create a good institutional environment for the development of the digital economy. (2) Enhance the driving effect of the digital economy on carbon emission reduction in the logistics industry. First, the network effect of the digital economy should be actively utilized. Combining an effective market and a promising government, we should vigorously develop digital logistics, smart logistics and green logistics; encourage the digital transformation of logistics enterprises; strengthen the demonstration and leading role of leading enterprises, benchmarking enterprises, and key enterprises in digital transformation; and improve the matching ability of logistics supply and demand. Second, the innovation effect of the digital economy should be actively utilized. Encourage the research and development and application of green logistics technology and promote the data-driven, information-driven, innovation-driven, knowledge-driven, and management-driven development of the logistics industry. Third, the efficiency effect of the digital economy should be actively utilized. Strengthen digital empowerment to strengthen the constraints of energy conservation and emission reduction in the development of the logistics industry; promote the application of 5G, the internet, the internet of things, the internet of vehicles, big data, the blockchain, and artificial intelligence in the logistics industry; and encourage the transformation of traditional logistics to smart logistics, modern logistics, digital logistics and green logistics.

This study has the following limitations. Due to data limitations, this paper discards some excellent indicators when building the digital economy evaluation index system and only studies the impact of China’s provincial digital economy on the carbon emissions of the logistics industry from 2005 to 2019. In fact, research on the impact of the digital economy on the carbon emissions of the logistics industry needs to be expanded in both time and region to draw applicable conclusions; this is where future research needs to be further expanded and deepened.

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