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Digital Economy, Industrial Structure, and Environmental Quality: Assessing the Roles of Educational Investment, Green Innovation, and Economic Globalization

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Abstract: This study constructs a digital economy (DE) index and explores its impact on environmental quality by utilizing data from China's 287 prefecture-level cities from 2013 to 2019. Unlike past studies, this research examines the indirect effect of DE on environmental pollution through the channels of industrial structure and educational investment. Further, it also analyzes the moderating role of economic globalization and green technology innovation in the nexus between DE and environmental quality. The empirical results indicate that DE significantly and positively enhances environmental quality by mitigating environmental pollution. This outcome remained stable after a series of empirical analyses and stability checks. Secondly, DE positively affects ecological and environmental quality by improving education levels and upgrading industrial structures. Thirdly, green technological innovation and economic globalization positively and significantly moderate the effect of DE development on ecological and environmental quality. Fourthly, associations between the development of DE and environmental quality are heterogeneous in terms of regions and markets, among which the most significant impact exists in the eastern area and the area with higher marketization. Based on the empirical findings, this paper provides comprehensive recommendations for promoting the DE and advancing China's environmental quality. Based on the results, important policy implications are suggested.

Keywords: digital economy; environmental quality; industrial structure upgrading; educational investment; technology innovation

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1. Introduction

In recent years, climate change has brought many destructive results to the Earth, and has become one of the most serious challenges for mankind. With the rise of global temperatures, this situation will continue to deteriorate, and even the vision of keeping the temperature growth below 1.5 °C is extremely difficult to achieve. As the largest developing country, China still lags significantly behind developed countries in terms of economic development and people's income. People need to take urgent actions to deal with climate change in the next decade. However, the improper use of energy in the process of economic development is a major issue that hinders the halting of environmental deterioration. It is important to address this situation in China, which is the leading CO_2-producing nation. As shown in Figure 1, there is a strong synergy between China's GDP growth and carbon dioxide emissions, which to some extent indicates that GDP growth will lead to environmental degradation. To deal with the problem of environmental degradation, we must adopt new technical means.

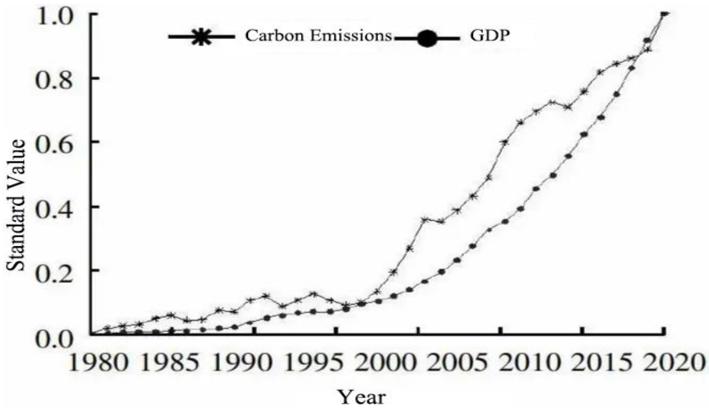


Figure 1. GDP growth and carbon dioxide emissions. Data source: Ministry of Ecology and Environment of the People's Republic of China.

The information technology era has produced the DE, which integrates as well as develops multiple industries in society, and has brought about huge changes in people's lives in the 21st century [1]. As can be seen in Figure 2, China's DE is expanding. Especially in the context of the recent COVID-19 situation, the DE has made outstanding contributions to the stable growth of the economy and epidemic prevention and control. For example, online shopping has replaced offline shopping as the main trading method in epidemic risk management regions. Additonally, governments have used the digital economy to quickly and accurately track the routes of people infected with Coronavirus, as well as those who came into contact with patients. Consequently, the prevention and spread-control of the epidemic increased due to the DE. Another example is the widespread use of online teaching, which not only improves efficiency but also diversifies teaching methods.

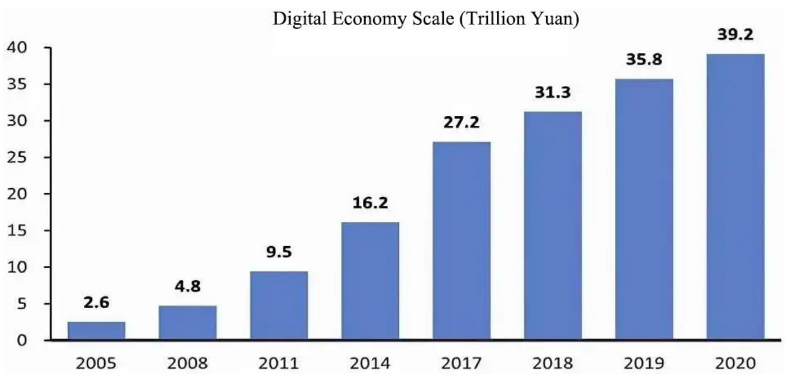


Figure 2. China's digital economy scale. Data source: China Academy of Information and Communications Technology (CAICT).

China's national economy is currently at the stage of high-quality development. We are supposed to devote more attention not only to the high-speed growth of GDP, but also to the sustainable evolutions of national finance. DE can support the fusion of conventional and digital technologies to modernize the industrial structure, and boost the performance of purchasing, production, sales, logistics, after-sales services, and so on, and thus enhances the level of industry collaboration. In terms of reducing carbon emissions, the digital economy promotes green technological innovation, changes traditional patterns of energy consumption, and improves sustainable development [2].

DE has brought many new business opportunities and helped to generate more high-quality talent. New technology has also optimized the industrial structure. The above benefits have a profound and motivating effect on sustainable growth. In today's era, economic globalization is an inevitable trend. Trade between countries is frequent and diverse, which has an impact on DE and ecological advancements. Green innovation is a critical means to realize the national green development strategy. It is necessary to realize the coordinated development of ecological environmental protection, promote the urban economy with high quality, and boost urban green development.

DE encourages technical innovation and industrial transformation for achieving environmental improvement and sustainable growth in China, and has grown to be an important driving force for high-quality advancement. The following are the research contributions of this paper. First, this paper examines the impact of DE on the environment of 287 prefecture-level cities in China from the perspective of human capital and innovation. Most of the previous papers in this field have focused on digital financial inclusion [2], low-carbon [3], economic development [4], and other perspectives. Therefore, this study enriches the literature on environmental sustainability in China. Secondly, this paper studies the incentive effect of green technology and economic globalization. Green technology innovation is becoming an important emerging field in the current era of global industrial revolution and technological competition. Moreover, economic globalization is the process of deepening the interconnection and interdependence of countries, and is the only way forward in terms of the development of human society. Thus, exploring this mechanism could help to develop more concrete policy recommendations for environmental protection. Third, China's regional development is uneven; there is a big gap in the level of marketization, and the regional economic level and the level of marketization are closely related to DE. As such, we explore the heterogeneity of DE in improving the environment and explore its relationship with DE, which is rarely mentioned in the existing studies.

2. Literature Review

2.1. Digital Economy and Environmental Quality

DE records what happened in the past, through which we can roughly predict what will happen in the future. Since human society entered the information age, the rapid development and wide application of digital technology have led to DE. Very different from the agricultural industrial economy, DE is a new economy, a new driving force, and a new form of business, which has triggered profound changes in overall society and the economy. Data have become a new and important factor of production. The data-based digital economy has become a new form of economic and social development, forming new driving forces, reshaping the economic developmental structure, and changing the way of production. Evidently, human beings play the role of facilitators in adopting and promoting DE. The digital economy has externality, independence, and irresistible characteristics, and this complex and emerging product is the product of human thought and behavior [5]. With the close combination of universal technologies, namely, information digitization and the internet, the level of connection between behavior and thought has been dramatically improved, and DE has been rapidly integrated into the economic development of society [6]. DE's rapid development has become the backbone of technological advancement and high-quality economic growth in many countries. DE has also turned into a key driver of China's national income improvement [3]. Zihan et al. studied the correlation between DE and the natural system. The results show that the coupling coordination degree between the two has been on the rise [7].

The transformation and implementation of an economic advancement strategy cannot be achieved without the support of DE. To inspect the link between DE and high-quality growth in China's provinces, Ding et al. [8] employed the mesomeric effect model and the spatial Dubin model. They discovered that DE, to a certain extent, fostered high-quality economic development with spatial spillover effects. While maintaining a high-quality growth model, the Chinese economy is increasingly focusing on green development. Green economic improvement greatly restricts the CO_2 emissions of enterprises. In the shift away from the conventional economic improvement paradigm to the sustainable economic advancement model, the digital economy has acted as a catalyst to constantly change the course of economic expansion. Through testing the nonlinear link between environmental governance and environmental output, Wang et al. [9] concluded that environmental production and environmental governance are positively correlated, and the reasonable implementation of environmental regulation rules can aid industrial structural upgrades, which is beneficial to developing an innovation-driven economy [10]. In response to the advent of the digital technology era, enterprises have made their communication lines open among groups, and the efficiency of communication has greatly increased through digital transmutation, which favors the improvement of enterprises' innovation capacity, and thus contributes positively to the preservation of the natural ecological environment and the saving of natural resources [11].

El-Kassar and Singh took 215 companies as their research samples and found that enterprises could improve their green innovation capability to a large extent by using big data as a digital means [12]. Taking Industry 4.0 as the research background, Mubarak et al. [13] verified that the capacity of businesses to innovate more greenly is improved thanks to the digital economy. According to Feng et al.'s research, DE clearly favors green technology development, significantly affects small enterprises with innovation in green technology, and alleviates the supply–demand imbalance of green innovation investment to a great extent [14]. Lyu et al. found that there is an obvious U-shaped relationship between DE and green total factor productivity, with obvious direct as well as spillover effects [15]. Jun and Guixiang studied the connection between environmental regulation and high-quality financial development with China's 236 cities as study objects, and the study showed that DE enhanced environmental regulation's rising contribution towards superior GDP progress. DE and environmental regulation jointly contributed to superior economic progress [16]. That is to say, the pathway to high-class economic development in China cannot be achieved without green innovation powered by DE, which will be a general trend in China's future development. It can be observed that DE improves the environmental supervision ability.

2.2. Educational Investment and Environmental Quality

So what is the transmission mechanism between DE and the environment? According to the generalized Nelson–Phelps technological innovation and imitation model constructed by Benhabib and Spiegel (2005), increasing human capital can improve the speed of technological innovation and imitation, thus improving total factor productivity [17]. The increase in public education investment can effectively lower the income threshold for receiving education, and more families will invest in their children's education. In this way, the number of people with higher education will increase, and the accumulation of human capital will rise. The more educated the population, the higher the technical level of production, which will adopt a steady state. Moreover, most of the existing studies imply that human capital is conducive to reducing environmental pollution [18]. For example, Mahmood et al. (2019), based on the time series data of Pakistan from 1980 to 2014, empirically found that human capital helps to control pollution [19]. A series of studies on China also mostly support this finding. For example, Lan et al. (2012), based on the provincial panel data of China from 1996 to 2006, empirically found that human capital was significantly negatively correlated with environmental pollution [20]. In addition, increases in higher education and the level of human capital accumulation have enhanced the adaptability of enterprises to new technologies and products, and accelerated the industrialization process of new technologies [21]. A higher level of human capital accumulation can also create a better innovation environment to enhance regional innovation ability and realize environmentally sustainable development.

2.3. Industrial Structure and Environmental Quality

The traditional model of economic development has helped China to achieve remarkable economic achievements, but also led to the depletion of natural resources and the deterioration of the ecological environment in some areas. In order to change this situation, we must coordinate the relationship between economic development and environmental protection. Industrial structure upgrading will not only increase the proportion of knowledge-intensive and technology-intensive industries, but also promote the development of clean industries. Curbing environmental pollution at the source is a key path to coordinating economic development and the environment [22]. Thus, against the background of the weakening of the traditional development impetus, we must change the economic development model dominated by resource dependence [23]. It is important to stimulate innovation regarding pollution treatment technology, advance the production efficiency of enterprises based on energy saving and emission reduction, and promote the industrial structure in order to reduce environmental pollution.

2.4. Green Innovation and Environmental Quality

Data factors have become one of the important production factors. DE is closely related to big data, artificial intelligence, and other advanced technologies. In the process of continuous integration with the traditional economy, DE effectively promotes the development of green and innovative technologies [24]. Green innovation can enhance resource utilization efficiency and reduce ecological pollution. With the continuous improvement of environmental regulation and production environmental protection standards, the proportion of environmental protection costs assigned to the production and operation of enterprises is also expanding. Green technology innovation can reduce emissions from the source, and the resulting green and efficient production mode can effectively reduce the cost of emissions reduction for enterprises [25].

2.5. Economic Globalization and Environmental Quality

Economic globalization is an important source of senior management experience and advanced technology. The Chinese government has been working to increase its technological base by introducing advanced foreign technologies, especially through the foreign direct investment (FDI) channels of multinational corporations. Economic globalization brings positive incentives to enterprises by breaking monopolies, encouraging enterprises to compete with each other, introducing new scientific management techniques to play an exemplary role, and promoting the flow of human capital [26]. Feng et al. [27] argue that foreign enterprises bring more environmentally friendly production standards and technologies into the host country and have a positive impact on the environment. Huang et al. [28] analyzed the impact of FDI on China's environment and economic growth using the spatial Dubin model, and found that FDI had a positive impact on the environment and economic growth in China's inland areas.

2.6. Literature Gap

In summary, there have been many studies on DE and environmental quality, but the following aspects remain yet to be covered. First of all, most of the previous literature did not consider the intermediary role of education investment and industrial structure upgrading between DE and environmental quality. Secondly, the previous literature has hardly studied the incentive effect of economic globalization and green technology innovation. Finally, most of the literature only studies the regional heterogeneity of DE, and limited research works have studied the heterogeneity of marketization.

3. Theoretical Analysis and Research Hypothesis

DE is a contemporary social form in the internet-information age. It evades the shortcomings of information asymmetry, poor production performance, and single production modes in the agricultural and industrial sectors. Because the digital economy is highly penetrable, it can have a lasting and far-reaching impact on every area of society. DE is characterized by diminishing marginal costs. DE reduces the speed and cost of information spreading and expands communication channels, which enables all sectors of society to participate in the development of DE and to use DE to improve the sustainable development level [15] and improve environmental conditions. Considering the previous works, this study suggests the following hypothesis:

Hypothesis 1. *Digital economy development can improve environmental quality.*

All societal sectors must work together in playing their roles in DE development. This paper discusses two indirect mechanisms through which the digital economy improves environmental quality. First, DE can enhance environmental quality by increasing educational investment. Second, DE can enhance environmental quality by promoting industrial structure upgrading. In addition, the moderating effects of green technology innovation and economic globalization regarding the effects of DE on the environment are also discussed. The 2018 edition of the global environmental performance index (EPI, Environmental Performance Index), which covers 180 countries, shows that China ranks 118th in air quality, indicating that environmental quality needs a lot of improvement in China. China's economic growth has resulted in significant environmental damage, and one of the important reasons for this phenomenon is the backward technological level. The growth of DE has resulted in the appearance of numerous burgeoning sectors [29], and it also puts forward higher requirements for human capital. The development of human resources is closely related to education, which is both an opportunity and a challenge for China. The technology of DE will gradually eliminate jobs with high repeatability and low technical skill requirements, and gradually increase the number of jobs related to high technical skill and creativity [30]. In the internet era, workers in emerging industries must possess a higher level of education and should keep learning if they want to be competent [31]. The increase in education can ameliorate the human resources level, and the aggregation of high-quality talents can enhance technical innovation to raise the bar for the environment. In this context, the second hypothesis of the study is as follows:

Hypothesis 2. *The digital economy can play a positive role in improving environmental quality by increasing investment in education.*

The growth of DE simultaneously has a profound effect on the primary, secondary, and tertiary industries' development trends. Above all, against the background of DE, the development of agriculture has broken the conventional acquisition system. The application of e-commerce platforms and 5G technology has greatly changed the mode of agricultural production, cultivation and sales, reduced the production cost, increased the circulation effectiveness of agricultural products, and achieved primary industry upgrades. Secondly, the industrialized departments use digital technology to systematically manage procurement, production, sales, etc., and use innovative technology to carry out green production. This reduces the environmental pollution caused by industrial production, promotes enterprise creation, and realizes secondary industry upgrades. Lastly, for the service industry, the service platform fully utilizes big data technology to entirely and accurately understand user needs and market changes, and the technological development also makes the service process more simple and convenient, thus realizing the upgrading of the tertiary industry. Generally speaking, upgrading industrial infrastructure improves development efficiency and lowers energy consumption costs, which is beneficial for improving environmental quality [32]. Based on these arguments, the third hypothesis is as follows:

Hypothesis 3. *The digital economy can play a positive role in improving environmental quality by promoting industrial structure upgrading.*

China's economic advancement mode has entered a new stage, gradually changing from the conventional high-speed development model to a high-quality development model that is more sustainable. At the same time, the carbon emissions reduction target puts forward higher requirements for economic development. Thus, green development is the only way to improve environmental quality [33]. In line with the research model, the green technology innovation level may affect the environmental quality improvement results of digital economy development. Those areas with sophisticated green technology innovation give more focus to green sustainable development, and thus, the environmental quality of such areas may be better [24]. Relatively speaking, those regions with poor green technological innovation ability are still in the traditional economic development mode, and the awareness of green development is relatively weak, so the environmental quality of such areas may be even worse. These arguments motivated us to design the fourth hypothesis, as follows:

Hypothesis 4. *Green technology innovation positively adjusts the relationship between digital economy development and environmental quality.*

The 21st century is the era of economic globalization, with more and more frequent trade between countries. In the tide of economic globalization, China has launched trade cooperation with other countries, introduced many advanced green technologies, and adopted scientific economic development models, which contribute to the enhancement of environmental quality. Economic globalization has promoted China's technological development, which is conducive to China's DE promotion. Based on these settings, the following fifth hypothesis is designed:

Hypothesis 5. *Economic globalization positively adjusts the relationship between digital economy development and environmental quality.*

To sum up, this paper establishes the following theoretical model, as shown in Figure 3.

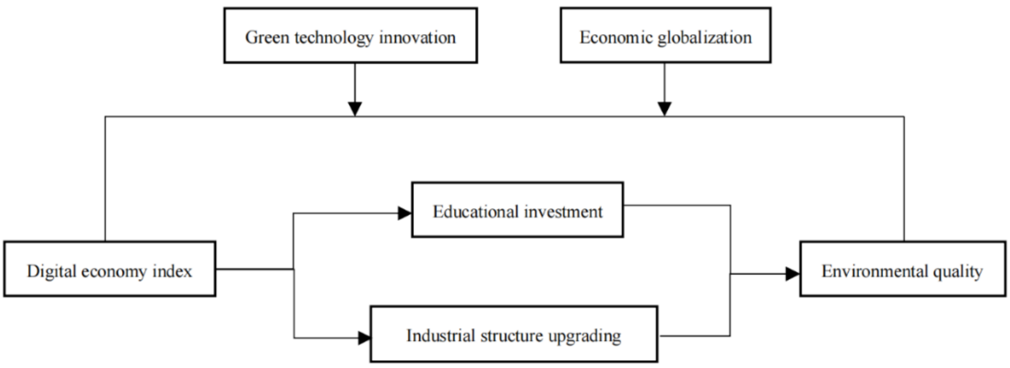


Figure 3. Theoretical model.

4. Model Construction and Data

4.1. Model Construction

In 1991, American economists Grossman and Krueger put forward the Environmental Kuznets Curve (EKC) [34,35]. It pointed out an inverted U-shaped connection between GDP growth and ecological pollution. Ecological damage becomes more and more serious as the economy develops in the early stages of GDP growth. However, the environment will benefit from economic progress when GDP growth achieves a certain level. The causes of the inverted U-shaped curve are as follows: (1) environmental damage results from energy consumption during economic development; (2) economic development encourages technological progress and the modernization of the industrial structure, which supports green development.

Using the aforementioned theoretical foundation, we looked at the fundamental connections between DE and ecological quality. Following the basic model of EKC, this research constructs the basic regression model as follows:

$$lnEQ_{it} = \alpha + \beta_1 DE_{it} + \beta_2 pGDP_{it} + \beta_3 pGDP2_{it} + \beta_4 lnRS_{it} + \beta_5 lnUrban_{it} + u_i + v_t + \varepsilon_{it} \quad (1)$$

where i symbolizes the city, t symbolizes time, EQ_{it} is the explained variable (environmental quality), and DE_{it} symbolizes the core independent variable (the development degree of

DE). The $pGDP_{it}$ is the increasing rate of per capita Gross Domestic Product and $pGDP2_{it}$ means the square of the growth rate of per capita GDP. In addition, RS_{it} represents the total energy consumption, while Urban is the level of urbanization, u_i represents the city-fixed effect, v_t represents the time-fixed effect, and ε_{it} denotes the stochastic component. Besides this, β_1 represents the coefficient of the core independent variable, which reflects the extent of the influence of DE on environmental quality. β_2, β_3, β_4, and β_5 separately refer to the coefficients of the control variables, and α is the intercept term. To prevent the heteroscedasticity issue among variables, this study conducts logarithmic processing on some data.

In accordance with the foregoing study, DE not only directly affects environmental quality, but also indirectly affects it through educational investment, as shown in Figure 4.

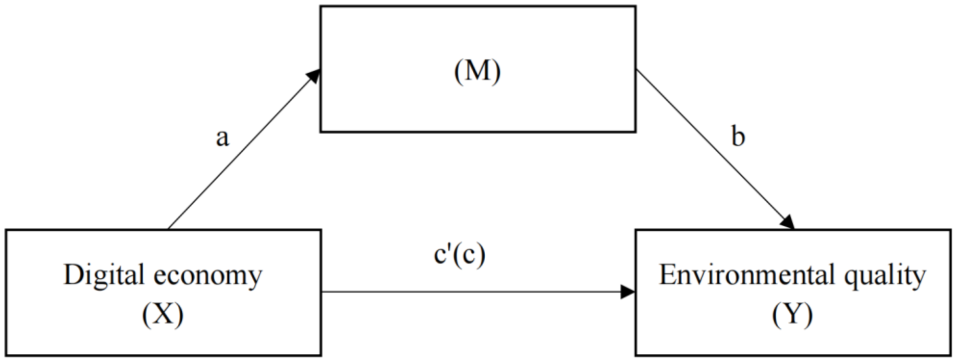


Figure 4. Mediating effect model.

The direct effect is shown in Equation (2a).

$$Y = cX + e_1 \tag{2a}$$

The mediating effect is shown in Equations (2b) and (2c).

$$M = aX + e_2 \tag{2b}$$

$$Y = cX + bM + e_3 \tag{2c}$$

Additoinally, in this study, educational investment and industrial structure upgrading are mediating variables. Drawing on the practice of Baron and Kenny (1986) [36], the following testing approaches were adopted: based on the significance of coefficient β_1 of the linear regression model (1) passing the test, DE's linear regression equation for mediating variables was constructed, and the existence of mediating effects was determined by the significance of regression coefficients, such as β_1, ω_2 and φ_2. The form of the above regression model is defined as follows:

$$lnMed_{it} = \omega_1 + \omega_2 DE_{it} + \omega_3 pGDP_{it} + \omega_4 pGDP2_{it} + \omega_5 lnRS_{it} + \omega_6 lnUrban_{it} + u_i + v_t + \varepsilon_{it} \tag{3}$$

$$lnEQ_{it} = \omega_1 + \varphi_1 DE_{it} + \varphi_2 lnMed_{it} + \varphi_3 pGDP_{it} + \varphi_4 pGDP2_{it} + \varphi_5 lnRS_{it} + \varphi_6 lnUrban_{it} + u_i + v_t + \varepsilon_{it} \tag{4}$$

where *Med* refers to the two mediating variables of educational investment and industrial structure upgrading, ω_1 means the intercept term, and ω_2 , φ_1 *and* φ_2 are the coefficients to be estimated. On the premise that β_1 in Formula (1) is significant, ω_2 and φ_2 obviously indicate that there is a mediating effect between DE and environmental quality. If the regression coefficients ω_2, φ_1 and φ_2 of the two equations are significant, a partial intermediary exists. If regression coefficients ω_2 and φ_2 of the two regression equations are significant, while φ_1 is opposite, there is a complete intermediary.

To check the moderating effect of green technological innovation on DE and ecological conditions, employing the method of Aiken et al. (1991) as a reference [37], this paper incorporates the interactive terms of DE and green technological innovation ability into Equation (1) to construct the following model:

$$lnEQ_{it} = \gamma + \gamma_1 DE_{it} + \gamma_2 GI_{it} + \gamma_3 DE_{it} * GI_{it} + \gamma_4 pGDP_{it} + \gamma_5 pGDP2_{it} + \gamma_6 lnRS_{it} + \gamma_7 lnUrban_{it} + u_i + v_t + \varepsilon_{it} \quad (5)$$

where *GI* stands for the green technology innovation level.

Finally, to examine the moderating effect of economic globalization on *DE* and environmental quality, this research refers to the procedure of Cohen P et al. (2014) [38] and tests the moderating effect of economic globalization on the improvement of *DE* and environmental quality through grouping regression.

4.2. Data

4.2.1. Explained Variable

The explanatory variable is environmental quality (EQ). According to existing research, this research employs carbon emissions to depict ecological quality due to the data's availability [39,40]. This paper collected carbon emission data from 287 prefecture-level cities in China. China's Carbon Accounting Database (CEADs) provides carbon emissions data and its unit is one million tons.

4.2.2. Explanatory Variable

DE is the independent variable. In accordance with the description given in the White Paper on China's Digital Economy Development's (2017), this article summarizes the state of DE development from two dimensions, namely, "digital industrialization" and "industrial digitalization". With reference to Li, Z.H.X. (2021) [7], we measure DE in terms of internet development and digital inclusive finance. In this paper, four variables are used to determine the extent of internet development, including internet penetration rate, employee information, output information, and mobile phone information. The evaluation indicators include the proportion of urban units with workers employed in the computer and software industries, the quantity of telecommunications services consumed per capita, and the number of mobile phone users per 100 persons. The statistics presented above are taken from the China Urban Statistical Yearbook. This study measures digital inclusive finance using the China Digital Inclusive Finance Index, which was created in collaboration with the Ant Financial Group and the Digital Finance Research Center of Peking University. The indicator system of DE is shown in Table 1. The above-mentioned five metrics are combined using the entropy approach to produce the DE development indicator [41]. The calculation process is as follows:

(1) Since the selected indicators have different units and dimensions, the data are first standardized. In Equation (6a), X_{ij} refers to the original data of each indicator, $maxX_{ij}$ and $minX_{ij}$ represent the maximum and minimum values of each indicator, respectively, and $X_{ij}{}'$ refers to the standardized data.

$$X_{ij}{}' = \frac{X_{ij} - minX_{ij}}{maxX_{ij} - minX_{ij}} \quad (6a)$$

(2) Calculate the proportion of each indicator P_{ij}

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \quad (6b)$$

(3) Compute the information entropy e_j

$$e_j = -k \sum_{j=1}^{m} p_{ij} Ln\ p_{ij} \quad (6c)$$

where $k = 1/\text{lnm}$, and j symbolizes the number of indicators;

(4) Compute the difference coefficient g_i and normalize it

$$w_j = \frac{g_j}{\sum_{j=1}^{m} g_j} \tag{6d}$$

$$g_j = 1 - e_j \tag{6e}$$

where w_j represents the entropy weight of the jth index;

(5) Calculate the digital economic development index

$$s_i = \sum_{j=1}^{m} w_j \cdot p_{ij} \tag{6f}$$

Table 1. Digital economic index system.

	Primary Index	Secondary Index	Evaluation Index
Digital economy	Internet development level	Internet penetration rate	The number of internet broadband access users among 100 people
		Information of relevant employees	The proportion of computer service and software industry employees in urban units
		Information on relevant output	The total amount of telecommunications services per capita
		Mobile phone penetration rate	The number of mobile phone users among 100 people
	Digital inclusive finance	Digital inclusive finance	China Digital Inclusive Finance Index

4.2.3. Mediating Variables

Educational investment (Edu) and industrial upgrading (Stru) are mediating variables. Referring to the practice of C Yuan and L Zhang (2015) [42], this study uses the amount of education expenditure (CNY 10,000) in each region to measure the educational investment, and the upgrading of the industrial structure is measured by employing the ratio of tertiary industry added value to the secondary industry added value. The statistics are derived from the China Urban Statistical Yearbook and China Statistical Yearbook.

4.2.4. Moderating Variables

Green technology innovation level (GI) is evaluated using two indicators, including green invention patent grant amount (GI-i) and green utility model patent grant amount (GI-u) [43]. The data on these indicators came from the Chinese Research Data Service Platform (CNRDS).

With the deepening of economic globalization, scholars began to focus on the impact of economic globalization (OP) on the environment during the promotion of national economic growth. They mainly focused on using transnational panel data to study the impact of trade openness and FDI on CO_2 emissions, and reached different conclusions [44]. This paper measures the level of economic globalization using the proportion of the actual utilized foreign capital out of the regional GDP. The data on OP came from the China Urban Statistical Yearbook.

4.2.5. Control Variables

There are many variables related to environmental quality. This paper selects the control variables by referring to the existing research results. The first control variable is energy consumption (RS). Waste from energy consumption can have a serious impact on the environment [45]. Generally speaking, the scale of energy consumption is inversely proportional to environmental quality [46]. Studies have shown that population density is related to environmental quality [47]. In order to eliminate the difference in energy use caused by the difference in urban population size, this study adopts the ratio of the sum of fuel consumption, natural gas consumption, and electricity consumption in each region to the total population at the end of the year to compute this index. Among these, fuel consumption specifically includes crude oil consumption, diesel oil consumption, coke consumption, kerosene consumption, coal consumption, and fuel oil consumption. Notably, natural gas and electric power differ in measurement units; for instance, fuel consumption is calculated in tons, natural gas consumption in cubic meters, and electric power consumption in kilowatt-hours. So, this paper standardizes these three types of energy consumption and then obtains the total regional energy consumption. The data on these indicators came from the China Energy Statistical Yearbook and China Electric Power Statistical Yearbook. The second control variable is economic growth (pGDP). To prevent the difference in regional GDP generated by different urban populations, considering the availability of data and taking guidance from Acheampong (2019) [48], this study uses the per capita GDP growth rate to assess the financial growth standards. The China Urban Statistical Yearbook is used to acquire the data on this indicator. Urbanization level (Urban) is the third control variable. Another important element affecting environmental quality is urbanization, which increases the use of natural resources. The population density of each city is utilized in this study to determine the degree of urbanization, and the statistics are taken from the China Urban Statistical Yearbook. Additionally, to eliminate the influence caused by year and city differences, this study used year-fixed effects (Year) and city-fixed effects (City).

4.2.6. Data Source

This study makes use of panel data collected from 287 Chinese cities between 2013 and 2019. The description of the variables is shown in Table 2.

Table 2. Variable definition.

Variable Type	Variable Name	Measurement Method
Explained variable	Environmental quality (EQ)	Carbon emissions (million tons)
Explanatory variable	Digital economy development (DE)	Weighting the relevant indicators with the entropy method
Mediating variable	Educational investment (Edu)	Educational expenditure
	Industrial structure upgrading (Stru)	The proportion of the added value of the tertiary industry and the added value of the secondary industry
Moderating variable	Green technology innovation (GI)	Number of green invention patents (GI-i) and green utility model patents (GI-u)
	Economic globalization (OP)	Amount of foreign capital actually used/GDP
Control variable	Energy consumption (RS)	Sum of fuel consumption, natural gas consumption, and power consumption/total population at the end of the year
	Economic growth (PGDP)	Per capita GDP growth rate
	Urbanization (Urban)	Total population/land area of administrative region at the end of the year
	Year control variable (Year)	Year dummy variable
	City control variables (City)	City dummy variable

5. Results and Discussion

5.1. Descriptive Statistics

Statistical findings for key research proxies are introduced in Table 3. The carbon emissions of different cities in China are quite different, as displayed in Table 3, where the average value of the explained variable EQ is 3.410, the maximum value is 6.126, the minimum size is 0.566, and the SD is 0.901. The explanatory variable DE has an average value of 0.111, which also shows the characteristics of "small mean value and big standard error", indicating that the DE of each city needs to be improved. Compared to the control variables, there are obvious differences in regional income (pGDP), energy use scale (RS), and urbanization level (urban) among different prefecture-level cities.

Table 3. Descriptive statistics.

Variables	(1) N	(2) Mean	(3) Sd	(4) Min	(5) Max	(6) p50
lnEQ	1399	3.410	0.901	0.566	6.126	3.421
DE	1399	0.111	0.0619	0.0379	0.820	0.0961
lnUrban	1399	1.758	0.169	0.825	2.065	1.797
lnRS	1399	−1.241	0.974	−4.983	2.414	−1.267
pGDP	1399	0.0279	0.0388	−0.661	0.696	0.0210
pGDP2	1399	0.00228	0.0187	0	0.485	0.000446
Edu	1399	745,163.009	941,373.886	30,069.000	11,360,185.000	534,660.000
Stru	1399	1.045	0.571	0.207	5.168	0.907
GI-i	1399	477.442	1538.567	0	26,435.000	72.000
GI-u	1399	430.333	1055.463	0	12,488.000	106.500
OP	1399	0.310	0.444	0	11.476	0.197

5.2. Variable Multicollinearity Test Results

Table 4 shows the correlation among variables. The correlation between DE and environmental quality (EQ) is significant at the level of 1%. Most controlled variables are highly correlated with the explained variables at the level of 1%, judging from the correlation coefficient between the controlled variables and the explained variables, which indicates that the choice of the controlled variables is reasonable. The correlation coefficients of variables depict that in addition to the correlation coefficients between GI-u and DE of 0.69, GI-i and Edu of 0.85, GI-u and DE of 0.85, and GI-i and GI-u of 0.91, the correlation coefficient between other variables is less than 0.6, indicating that there is no significant multicollinearity among variables. The regression results in this paper basically eliminate the adverse effects caused by multicollinearity.

Table 4. Variable multicollinearity test.

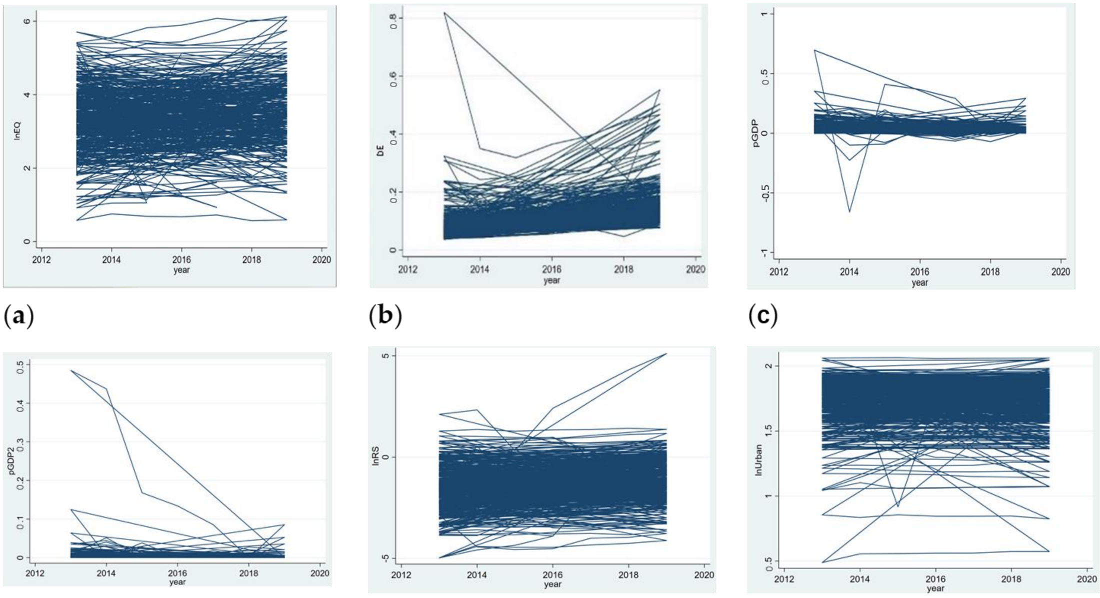
	lnEQ	DE	lnUrban	lnRS	pGDP	pGDP2	Edu	Stru	GI-i	GI-u	OP
lnEQ	1										
DE	0.23 ***	1									
lnUrban	0.14 ***	0.29 ***	1								
lnRS	0.46 ***	0.47 ***	0.20 ***	1							
pGDP	−0.18 ***	−0.14 ***	−0.21 ***	0.077 **	1						
pGDP2	−0.024	−0.015	−0.13 ***	0.18 ***	0.24 ***	1					
Edu	0.40 ***	0.51 ***	0.36 ***	0.56 ***	0.42 ***	0.41 ***	1				
Stru	0.034	0.37 ***	−0.083 ***	0.10 ***	0.038	0.049 *	0.32 ***	1			
GI-i	0.30 ***	0.60 ***	0.29 ***	0.51 ***	0.50 ***	0.50 ***	0.85 ***	0.37 ***	1		
GI-u	0.36 ***	0.69 ***	0.35 ***	0.59 ***	0.59 ***	0.59 ***	0.85 ***	0.31 ***	0.91 ***	1	
OP	0.12 ***	0.13 ***	0.19 ***	0.17 ***	0.16 ***	0.12 ***	0.16 ***	−0.0026	0.14 ***	0.15 ***	1

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Because the correlation test does not control the influence of other factors, it has been found that urbanization level, energy consumption scale, and economic growth have a significant influence on environmental quality, and these variables are often highly correlated with DE. Consequently, it is essential to further control the effects of other influencing factors on environmental quality through multiple regression analysis in order to obtain more reliable conclusions.

5.3. Unit Root Test

To check if there is a unit root in the sequence and guarantee the reliability of the index data, this study expands the panel unit root test using the IPS approach. Firstly, the time trend analysis of each variable shows that there is no time trend in each variable, as shown in Figure 5. Therefore, there is no need to add the time trend option in the unit root tests. The unit root test of panel data is carried out, and the environmental quality, digital economy, economic growth, energy consumption scale, and urbanization level are processed in the logarithm. The results are displayed in Table 5. The statistic of the energy consumption scale under the zero-order condition is not significant. After the first-order differential treatment of energy consumption scale, all variables are stable.



(**a**) (**b**) (**c**)

(d) (e) (f)

Figure 5. Time trend chart of variables. (**a**) Time trend of variable lnEQ. (**b**) Time trend of variable DE. (**c**) Time trend of variable pGDP. (**d**) Time trend of variable pGDP2. (**e**) Time trend of variable lnRS. (**f**) Time trend of variable lnUrban.

Table 5. Unit root test.

Variable	Statistical Value	HT *p*	Result
lnEQ	0.3617	0.0004	Stable
DE	0.3752	0.000	Stable
pGDP	−0.3773	0.000	Stable
pGDP2	0.5481	0.003	Stable
lnRS	0.6407	0.7610	Unstable
D(lnRS)	−0.2627	0.000	Stable
lnUrban	−0.1454	0.000	Stable

5.4. Baseline Regression Results

In this paper, DE is used as the explanatory variable to empirically study its impact on environmental quality. Table 6 reveals the OLS regression outcomes of the main effect test. Based on controlling the year- and industry-fixed effects, column (3) reports that DE's regression coefficient is significant. The regression findings in column (4) demonstrate that DE's regression coefficient is still significant even after the addition of additional control indexes, and the coefficient is −0.588. This indicates that DE's growth is advantageous for the advancement of environmental quality, since the digital economy is inversely correlated with carbon emissions. In combination with the above-mentioned reasons, the growth of DE helps to change the industrial structure, and the coordinated growth of DE and traditional industries advances energy technology, which lowers carbon emission intensity and ultimately improves environmental quality, which verifies hypothesis 1.

Table 6. Baseline regression results.

	(1) lnEQ	(2) lnEQ	(3) lnEQ	(4) lnEQ
DE	3.365 ***	−0.591	−0.588 ***	−0.590 ***
	(8.919)	(−1.428)	(−3.560)	(−3.616)
pGDP		−4.878 **		−0.016
		(−2.562)		(−0.141)
pGDP2		−3.112		−0.751 *
		(−0.637)		(−1.686)
lnRS		0.465 ***		0.054 **
		(18.023)		(1.989)
lnUrban		0.008		−0.292 **
		(0.041)		(−2.090)
_cons	3.034 ***	4.182 ***	1.964 ***	2.642 ***
	(63.734)	(10.885)	(63.606)	(9.816)
Year	NO	NO	YES	YES
City	NO	NO	YES	YES
N	1399	1399	1399	1399
r2	0.053	0.260	0.969	0.969

t statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

When controlling for other factors, the regression result of the per capita GDP is not significant, while its square term variable is negatively significant. This shows that the link between the economic boom and the ecological condition is just linear, not a U-shaped curve. This shows that economic growth and improvement in environmental quality complement each other in China. This result argues against the EKC hypothesis [49]. The coefficient of the per capita energy use is significantly positive, that is, the higher the energy use, the greater the carbon emission intensity, and thus the more detrimental the impact on environmental quality, which is consistent with the results of Sofien Tiba et al. (2017) [50]. The regression coefficient of urbanization at the 5% significance level is negative, showing that urbanization is good for environmental quality, which is consistent with the results of Zhao P et al. (2021) [51]. This is because urbanization concentrates on production factors and innovative technologies, and improves energy consumption patterns, thus reducing environmental problems.

5.5. Mediation Effect Test

5.5.1. Mediation Effect Test of Educational Investment

Columns (1) and (2) of Table 7 display the consequences of the mediating effect of educational investment (Edu). The estimated result of DE, which is positive and substantial at the level of 5% in column (1), suggests that DE will increase regional education input. Column (2) reports that when the mediating variable education investment (Edu) is added to the basic model, investment in education has a significant regression coefficient, and DE has a significant regression coefficient. Additionally, the Z measure of the Sobel test is significant, denoting that education investment plays a partial intermediary role between DE and environmental quality. Thus, the mediating effect of DE on the improvement of ecological quality does exist, and the improvement of ecological quality can be further promoted by increasing educational investment. In economies that are more at the cutting edge of technology, skilled human capital has a greater growth-enhancing impact [52]. Economic development is a necessary condition for upgrading the industrial structure and thus promoting environmental improvement. Thus, hypothesis 2 has been verified.

Table 7. Mediation effect test.

	(1) lnEdu	(2) lnEQ	(3) Stru	(4) lnEQ
DE	0.476 **	−0.556 ***	4.611 ***	−0.928 ***
	(2.278)	(−2.696)	(19.046)	(−3.026)
pGDP	0.122	−0.002	−4.876 ***	1.222 *
	(1.494)	(−0.012)	(−7.771)	(1.820)
pGDP2	−0.070	−0.735	7.548 *	−8.817 *
	(−0.322)	(−1.325)	(1.879)	(−1.876)
lnRS	−0.009	0.053 **	0.150 ***	0.082 ***
	(−0.718)	(2.472)	(6.547)	(3.621)
lnUrban	0.341	−0.282	−0.219	−0.275
	(9.247)	(−2.068)	(−0.614)	(−1.007)
lnEdu		−0.086 *		
		(−1.707)		
Stru				−0.071 **
				(−2.007)
_cons	13.284 ***	6.633 ***	0.269	2.692 ***
	(21.309)	(7.292)	(0.376)	(4.952)
Year	YES	YES	YES	YES
City	YES	YES	YES	YES
N	1399	1399	1399	1399
r2	0.983	0.969	0.852	0.969

t statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

5.5.2. Mediation Effect Test of Industrial Structure Upgrading

Columns (3) and (4) of Table 7 state the outcomes of the mediating action of industrial structure upgrading (Stru). The estimation result for DE, which is significantly positive in column (3), suggests that DE will support the modernization of the industrial structure. Column (4) states that when the mediating variable industrial structure upgrading (Stru) is added to the basic model, the coefficient of DE becomes significant and the coefficient of industrial structure upgrading becomes significant. In addition, the Z value of the Sobel test is significant, indicating that industrial structure upgrading plays a partial mediating role between DE and environmental quality improvement. The growth of DE gives the industrial structure new life [53]. Industrial structure upgrading can stimulate regions to improve technical services, increase innovation input, improve green innovation, and further encourage the advancement of environmental quality. In addition, industrial structure upgrading will promote regional innovation competition and cooperation, and promote the diffusion and spillover of technology levels among regions. DE has played a favorable role in improving resource allocation efficiency and the change of industrial structure. DE promotes the development of new industries, which in turn leads to the digital transformation of traditional industries [54], thus improving the overall ecological condition. Therefore, the mediating effect of DE on the advancement of ecological quality does exist, which further supports ecological quality improvements by encouraging industrial structure modernization. Thus, hypothesis 3 has been verified.

5.6. Moderating Effect Test

5.6.1. Moderating Effect Test of Green Technology Innovation

Columns (1) and (2) of Table 8 display the outcomes of the moderating effect on green technological innovation. The results of green invention patents that have been used as a regression measure of green technological innovation are shown in column (1). The results indicate the coefficient of interactive terms is significantly unfavorable, and the coefficient of DE is still significantly unfavorable. Column (2) shows the interactive effect result of green technology innovation measured by the green utility model patents amount, which is consistent with the conclusion of column (1). The findings of Saunila et al. demonstrate that institutional and economic pressures drive green innovation, and that this type of innovation can be beneficial for social sustainability [55]. The above empirical findings demonstrate that improving green technology innovation can increase the promotion effect of DE on environmental quality. Hence, hypothesis 4 has been verified.

Table 8. Moderating effect test.

	(1) lnEQ	(2) lnEQ	(3) (high OP) lnEQ	(4) (low OP) lnEQ
DE	−1.969 *** (−4.161)	−3.297 *** (−6.440)	−0.570 ** (−2.555)	−0.118 (−0.232)
GI-i	0.001 ** (7.211)			
DE*GI-i	−0.001 *** (−3.752)			
GI-u		0.001 ** (10.160)		
DE*GI-u		−0.001 *** (−4.024)		
pGDP	−4.395 *** (−7.835)	−4.101 *** (−7.425)	−1.408 (−1.311)	0.011 (0.066)
pGDP2	−2.793 ** (−2.432)	−2.608 ** (−2.314)	0.988 (0.122)	−0.610 (−1.014)
lnRS	0.432 *** (17.035)	0.420 *** (16.785)	0.097 *** (2.864)	0.028 (0.899)
lnUrban	−0.150 (−1.149)	−0.260 ** (−2.012)	−0.313 (−1.410)	0.721 (0.411)
_cons	4.470 *** (18.679)	4.710 *** (19.847)	4.019 *** (9.336)	2.784 (0.824)
Year	YES	YES	YES	YES
City	YES	YES	YES	YES
N	1399	1399	814	585
r2	0.293	0.320	0.972	0.970

t statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

5.6.2. Moderating Effect Test of Economic Globalization

Columns (3) and (4) and Columns (1) and (2) of Table 8 display the outcomes of the moderating effect on green technological innovation. The results of green invention patents that have been used as a regression measure of green technological innovation are shown in column (1). The results indicate that the coefficient of interactive terms is significantly unfavorable, and the coefficient of DE is still significantly unfavorable. Column (2) shows the interactive effect result of green technology innovation measured by the green utility model patents amount, which is consistent with the conclusion of column (1). The findings of Saunila et al. demonstrate that institutional and economic pressures drive green innovation and that this type of innovation can be beneficial for social sustainability [55]. The above empirical findings demonstrate that improving green technology innovation can increase the promotion effect of DE on environmental quality. Hence, hypothesis 4 has been verified.

Table 8 displays grouping regression results. Columns (3) and (4), respectively, show test outcomes of samples with higher economic globalization levels and samples with lower economic globalization levels. In the samples with high levels of economic globalization, the coefficient of DE is negatively significant, while in the group with low levels of economic globalization, the coefficient of DE is insignificant, which shows that the improvement of economic globalization can strengthen the role of DE in enhancing environmental quality. Cross-border information flows promote growth, and hence globalization is good for growth, including DE [44]. Thus, hypothesis 5 has been certified.

5.7. Heterogeneity Test

5.7.1. Regional Heterogeneity

Due to the differences in policy background, market environment, geographical location, industrial structure, and other aspects among Chinese cities, there can be local heterogeneity in the level of DE and environmental quality, which is further discussed in this paper. In this paper, following the Division Method suggested by the National Bureau of Statistics, cities are partitioned into three districts: east, central, and west. First, descriptive statistics of DE and environmental quality in various districts are presented, and the study outcomes are indicated in Table 9. (1) In terms of environmental quality, the eastern area emits the most carbon. Overall, the environmental quality in the western area is the best, followed by the central area, and the environmental quality in the eastern area is relatively poor [56]. The main reason for this is that the industrialization level of the eastern area is higher than that of the central and western areas, but the difficulties that follow include high energy use and serious environmental degradation [57]. (2) In terms of DE, from the perspective of the mean, median, minimum as well as maximum values, the eastern region shows the best development, followed by the middle region, while the western area is relatively regressive. The eastern region shows a relatively comprehensive infrastructure, high levels of technological innovation, and concentrated information resources, which are conducive to digital economic growth. These results provide a foundation for a deeper examination of regional variations in the impact of DE on environmental quality.

Table 9. Regional heterogeneity descriptive statistics.

Environmental Quality (lnEQ)					
Region	**Mean**	**Median**	**sd**	**Min**	**Max**
East	3.607	3.636	0.862	0.918	6.031
Center	3.266	3.278	0.845	0.566	5.748
West	3.230	3.364	1.029	1.193	6.126
Digital Economy (DE)					
Region	**Mean**	**Median**	**sd**	**Min**	**Max**
East	0.127	0.107	0.073	0.043	0.820
Center	0.093	0.089	0.033	0.038	0.428
West	0.092	0.085	0.036	0.037	0.248

The results for the eastern, middle, and western regions are separately displayed in Columns (1) to (3) of Table 10. DE has significantly improved the environmental quality in the eastern and central regions, while the regression results in western areas are insignificant. The possible reason for this is that, in comparison to western areas, DE in the eastern and central regions started earlier, and the technology is more mature, so these regions have the "first-mover advantage". Additionally, the eastern and central areas have more concentrated information resources, a greater level of internet development, a favorable market environment, strong funds, and high-level talents to fully utilize the favorable environmental effects of DE [58]. The main economic progress mode in the western areas is still the traditional one, which is dominated by high energy use and pollution, and a lack of digital talents and moinimal information, which is detrimental to the positive effect of DE.

Table 10. Regional heterogeneity.

	(1) East lnEQ	(2) Center lnEQ	(3)West lnEQ
DE	−0.428 **	−1.930 ***	2.181
	(−1.976)	(−3.662)	(1.512)
pGDP	−0.165	0.616	−0.030
	(−0.148)	(0.981)	(−0.142)
pGDP2	0.444	−5.341	−0.958
	(0.070)	(−1.442)	(−1.296)
lnRS	0.120 ***	0.031	0.024
	(3.240)	(0.972)	(0.471)
lnUrban	0.835	−0.354	2.151
	(0.519)	(−1.578)	(0.764)
_cons	2.041	4.267 ***	−1.456
	(0.759)	(9.374)	(−0.303)
Year	YES	YES	YES
City	YES	YES	YES
N	596	595	208
r2	0.971	0.966	0.970

t statistics in parentheses. ** $p < 0.05$, *** $p < 0.01$.

5.7.2. Marketization Heterogeneity

Since the reform and opening up, the level of market-oriented development in China has continuously improved. However, market-oriented development is typically heterogeneous due to the different policy contexts, geographical locations, and market environments of each city. In this research, the degree of marketization is measured according to the Index Report of China by Provinces, edited by Wang Xiaolu and Fan Gang. In addition, full study samples are separated into high-marketization samples and low-marketization samples based on the median of the marketization index, and group regression is conducted to investigate market heterogeneity.

Table 11 displays the results. In column (1), the regression coefficient of DE is significant, and the absolute value of the regression coefficient is larger than that of the full sample, which indicates that in areas with high marketization, DE has a favorable effect on environmental quality, and the positive effect is higher than in full samples. This is because market-oriented development can promote regional income and the advancement of innovation level, a higher degree of marketization is conducive to the continued growth of DE, and a flexible market atmosphere makes it easy for DE to play its part in improving the environment [59].

Table 11. Marketization heterogeneity.

	(1) High Marketization lnEQ	(2) Low Marketization lnEQ	(3) Full Sample lnEQ
DE	−1.372 ***	−0.981	−0.590 ***
	(−2.615)	(−1.515)	(−3.616)
pGDP	−17.300 ***	−3.479 ***	−0.016
	(−7.575)	(−5.514)	(−0.141)
pGDP2	41.273 **	−3.019 **	−0.751 *
	(2.496)	(−2.488)	(−1.686)
lnRS	0.532 ***	0.439 ***	0.054 **
	(13.988)	(13.133)	(1.989)
lnUrban	−0.037	0.013	−0.292 **
	(−0.182)	(0.075)	(−2.090)
_cons	4.702 ***	4.110 ***	2.642 ***
	(12.624)	(12.992)	(9.816)

Table 11. *Cont.*

	(1) High Marketization lnEQ	(2) Low Marketization lnEQ	(3) Full Sample lnEQ
Year	YES	YES	YES
City	YES	YES	YES
N	689	710	1399
r2	0.319	0.240	0.969

t statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Based on the above empirical results, we can conclude that DE can indeed improve environmental quality, and this effect can be achieved by increasing educational input and promoting industrial upgrading. In addition, this paper found that green technology innovation has a positive incentive effect on the improvement of the environment for DE growth, and economic globalization also plays a similar role. The role of DE has regional heterogeneity, that is, the eastern region can more easily facilitate DE in playing the role of improving the environment. In regions with a higher degree of marketization, it is easier for DE to play a positive role. To sum up, we accept all the hypotheses discussed earlier.

5.8. Robustness Check

5.8.1. Replace Explanatory Variables

This paper uses DE recalculated by PCA to replace the original core explanatory variable. The test outcomes are displayed in columns (1) and (2) of Table 12. The regression coefficient for DE remains significantly negative despite including control variables. This again shows that DE can significantly benefit the environmental quality, and this outcome is consistent with the previous conclusions.

Table 12. Replace explanatory variables and explained variables.

	(1) lnEQ	(2) lnEQ	(3) lnpEQ	(4) lnpEQ
DE	−0.038 **	−0.038 **	−0.720 ***	−0.712 ***
	(−2.296)	(−2.215)	(−3.396)	(−3.359)
pGDP		−0.008		0.175
		(−0.073)		(1.087)
pGDP2		−0.798 *		−0.738
		(−1.761)		(−1.288)
lnRS		0.055 **		0.078 ***
		(2.031)		(3.542)
lnUrban		−0.278 **		−0.415 *
		(−1.982)		(−1.789)
_cons	2.335 ***	2.553 ***	0.320 *	1.278 ***
	(139.607)	(9.469)	(1.738)	(2.694)
Year	YES	YES	YES	YES
City	YES	YES	YES	YES
N	1399	1399	1399	1399
r2	0.969	0.969	0.970	0.970

t statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

5.8.2. Replace Explained Variables

Due to the different levels of population in different regions, in this paper, we used per capita carbon emissions to measure environmental quality. The test outcomes are displayed in columns (3) and (4) of Table 12. DE can significantly improve environmental quality, even when control variables are included, suggesting that previous conclusions are robust.

5.8.3. Endogenous Examination

This work uses the instrumental variables (IV) method to conduct an endogeneity test to eliminate the endogeneity issue produced by bidirectional causality and other factors. Usually, environmental quality in the next year will be impacted by DE [60]. Therefore, this study selects the first-order lag term of DE as IV. At the same time, DE last year could affect DE next year. In general, a high degree of DE in the previous year will positively influence the growth of the sector in the following year. The first-order lag term thus satisfies the correlation requirement for an instrumental variable. The first stage of regression findings are displayed in Column (1) of Table 13. Since IV passed the tests for independence, weak instrumental variable, and unidentifiability, the first-order lag term of DE is significant, indicating a high link between the instrumental factors and DE. The instrumental factors chosen for this study are generally reasonable. Column (2) reports the second stage's regression findings. DE still plays a favorable part in improving environmental quality, which indicates that the conclusion is robust even when endogenous concerns are taken into account.

Table 13. Endogenous examination.

Variables	**(1) First DE**	**(2) Second lnEQ**
l.DE	0.928 ***	
	(54.28)	
DE		−0.900 *
		(−1.87)
pGDP	−0.029	−4.944 ***
	(−1.31)	(−8.66)
pGDP2	−0.013	−3.158 ***
	(−0.28)	(−2.69)
lnRS	0.005 ***	0.474 ***
	(4.94)	(18.01)
lnUrban	0.016 ***	0.027
	(3.16)	(0.20)
Constant	−0.002	4.196 ***
	(−0.18)	(17.37)
Year	YES	YES
City	YES	YES
Observations	1399	1399
R-squared	0.770	0.259

t statistics in parentheses. * $p < 0.1$, *** $p < 0.01$.

5.8.4. Exclude the Influence of Outliers

There is a big gap between the policy background and historical development of each city. In order to avoid the huge difference in DE and environmental quality caused by this, this paper winsorizes the data by 1% and 3%, respectively, to wipe out the impact of extreme values. Outcomes are displayed in Table 14. Columns (1) and (2) represent regression outcomes of data processed by 1% winsorizing. Columns (3) and (4) represent regression outcomes of data processed by 3% winsorizing. The regression coefficient of DE is still considerably negative, which denotes that the results are robust.

Table 14. Winsorize treatment.

	(1) lnEQ	(2) lnEQ	(3) lnEQ	(4) lnEQ
DE	−0.869 ***	−0.890 ***	−0.593 *	−0.721 **
	(−3.339)	(−3.018)	(−1.720)	(−1.992)
pGDP		0.757		0.834
		(1.210)		(0.957)
pGDP2		−4.478		−4.620
		(−1.007)		(−0.549)
lnRS		0.068 ***		0.082 ***
		(3.173)		(3.756)
lnUrban		−0.387		−0.511
		(−1.456)		(−1.313)
_cons	3.486 ***	2.860 ***	3.442 ***	3.103 ***
	(79.786)	(5.399)	(69.049)	(4.126)
Year	YES	YES	YES	YES
City	YES	YES	YES	YES
N	1415	1399	1415	1399
r2	0.969	0.969	0.967	0.968

t statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

6. Conclusions and Recommendations

6.1. Conclusions

The following conclusions are made after studying the mechanisms of digital economic development to improve environmental quality, utilizing data from 287 Chinese cities between 2013 and 2019 and employing the fixed effect model, mediating effect model, and moderating effect model. First, DE significantly improves environmental quality, which conclusion has passed the robustness test. Second, DE can improve the environment by improving education investment. Third, DE can optimize the industrial structure, make the industrial structure move towards the middle and high-end, and thus improve the environmental quality. Fourth, green technology innovation positively regulates the relationship between DE and the environment, that is, the impact of the development of DE in enhancing environmental quality increases with the amount of innovation in green technology. Fifth, economic globalization positively regulates the relationship between DE and environmental quality, that is, the higher the level of economic globalization, the more significant the role of DE becomes in improving the environment. Sixth, the effects of the growth of DE on the environment vary by region. In the eastern and central regions with relatively high economic development levels, DE plays a significant role in improving the environment, while in the western regions, with a relatively regressive economy, this role is not significant. Seventh, the impact of DE on the environment is marked by heterogeneous marketization. DE has a significant impact on environmental quality in areas with high marketization, while the effect is less significant in areas with low marketization.

6.2. Recommendations

According to the aforementioned verdicts, the following recommendations are made in this paper: The first is to vigorously develop the digital economy, tap its potential advantages, and make full use of its positive impact on the environment. In this context, it is required to actively adjust the economic development model by using technological innovation, big data technology, and other technologies to achieve sustainable development. Second, it is suggested to actively apply the digital economy to education, boost digital teaching, improve teaching level, increase education investment, improve the level of human capital, and cultivate more high-level knowledge talents. Third, make full use of digital economy technology to upgrade the industrial structure, optimize the energy consumption mode, fully develop green technology, and reduce the environmental pollution caused by economic development. Fourth, all sectors of society should vigorously perform green innovation so that green technology can fully play a part in the development of DE. Fifth, against the background of economic globalization, China should actively engage in trade and technological exchanges with other countries, learn advanced production techniques, and promote sustainable development. Sixth, taking into account the uneven development levels of DE in various economic areas and market environments in China, the government should provide policy support to the relatively regressive western regions and regions with low marketization levels. This will reduce the backwardness of these regions and increase their DE level. Finally, DE and culture should be promoted throughout society to form a situation of national participation, so that the digital economy can permeate every aspect of life and the positive effects of DE can be fully unleashed.

With the deepening of future research, the above suggestions put forward in this paper can also be applied to the construction of other digital fields, and provide references for environmental development and information technology construction in other countries or regions.

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