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How Does the Digital Economy Affect Sustainable Urban Development? Empirical Evidence from Chinese Cities

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Abstract: The rapid development of modern information technology has promoted the emergence of a new economic form: the digital economy, which has effectively changed economic development patterns and has become an important engine for economic growth in the new era. At the same time, sustainable development is the focus of the world today. Based on the panel data of 280 Chinese cities from 2011 to 2019, this study used the entropy method to measure levels of sustainable urban development while constructing an evaluation system for sustainable urban development levels. In addition, various econometric models were used to empirically analyze the impact, influence mechanisms and spatial effect of the digital economy on sustainable urban development. The results show that (1) the development of the digital economy has effectively promoted the level of sustainable urban development by enhancing the level of green technology innovation and accelerating the upgrading of industrial structures; (2) spatial econometrics regression results indicate that the development of the digital economy is not only an important boost to the sustainable development of local cities, but it also effectively promotes the sustainable development process of surrounding areas; (3) heterogeneity analysis shows that the promoting effect of the digital economy on sustainable urban development is more prominent in the eastern region, in cities larger than medium-size and in non-resource-based cities.

Keywords: digital economy; sustainable urban development; influence mechanism; spatial effect; analysis of heterogeneity

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1. Introduction

Since the reform and opening up, the economy in China has achieved rapid growth, but ecological and environmental problems have also become increasingly prominent at the same time. Resource shortages, environmental pollution and ecological deterioration seriously hindered sustainable development in China [1,2]. In addition, the introduction of the two-carbon goal created new requirements and challenges for Chinese sustainable development. Meanwhile, with the rapid development of the new generation of information technology, such as cloud computing, big data, artificial intelligence and 5G, the digital economy as a new economic form was born, and it developed vigorously [3]. The digital economy refers to a series of economic activities that take digital knowledge and information as critical factors of production and modern information networks as essential carriers, and they aim to effectively use information and communication technology as the important driving forces to improve economic efficiency, optimize economic structure and create new economic value [4]. In fact, the development of the digital economy is injecting new momentum into Chinese economic growth [5]. According to the Digital China Development Report (2021), China ranks second in the world in terms of the size of their digital economy. In addition, the development of the digital economy is generally believed to strongly support COVID-19 prevention and control in China. The continuous integration of the digital economy and the real economy dramatically improves the efficiency of economic development, enables the green and low-carbon transformation of the economy and realizes the coordinated development of the economy and the environment [6]. Moreover, the development of the digital economy coincides with the goal of adjusting and upgrading the Chinese development model and economic structure [7]. Thus, as a new driving force of economic growth, does the digital economy drive sustainable urban development in China? What is the internal influence mechanism by which the digital economy affects the sustainable development of cities? Are there heterogeneity and spatial spillover effects of the digital economy on sustainable urban development? To answer the above questions, based on the panel data of 280 Chinese cities from 2011 to 2019, this study used the entropy method to measure the level of sustainable urban development while constructing an evaluation system to measure sustainable urban development levels. Various econometric models were used to empirically analyze the impact, influence mechanisms and spatial effects of the digital economy on sustainable urban development. The exploration of the above issues not only provide new ideas for the improvement of the level of sustainable urban development in China, but also provide a case reference for the promotion of the process of sustainable development around the world.

The concept of sustainable development was formally put forward in 1987, when sustainable development was first considered as an economic growth model that focuses on long-term development [8]. Specifically, it was regarded as a development that can meet the needs of the present generation without harming the next generations' needs. In addition, it is the result of reflection on the process of industrial civilization and the rational choice made by human beings to overcome a series of environmental, economic and social problems [9]. As the main carriers of human civilization and wealth creation as well as symbols of social progress and civilization development, cities have become the main sites for the promotion of sustainable development, and the body of research about sustainable urban development is constantly being enriched gradually [10]. The existing literature on sustainable development mainly focuses on the construction of index systems and influencing factors. The Sustainable Development Goals (SDGs), consisting of 17 goals and 169 sub-goals set out in the 2030 Agenda for Sustainable Development adopted by the U.N. Sustainable Development Summit in 2015, provide a reference framework for countries to formulate localized sustainable development strategies [11,12]. However, due to great differences in the actual development of countries and regions and the difficulty in unifying data statistics, scholars believe that it is necessary to build a localized sustainable development evaluation index system [13]. For instance, Wang et al. built an evaluation model of sustainable urban development by comprehensively considering expected and non-expected outputs in China [14]. Arkadiusz et al. proposed a comprehensive index including social, economic and environmental indicators to evaluate the comprehensive development level of countries [15]. Based on the United Nations SDGs and tourism competitiveness, Shao et al. constructed an evaluation index system for the sustainable development of Guilin in China and took the coefficient of variation as the main method of measurement [16]. Moreover, scholars believe that rapid economic growth, the continuous expansion of cities, traffic jams, air quality reduction, and the poverty gap will also affect the improvement of the sustainable development levels of cities [17]. Zhang et al. found that economic growth would hurt the sustainable development level of the Yangtze River Delta's urban agglomeration [18]. Lin and Zhu took ecological efficiency as measured with the non-directional distance function method as the proxy variable of sustainable development, and they found that the implementation of energy-saving and emission reduction policies could promote sustainable development prominently [19].

With the rapid rise of the digital economy, the changes in the economic, social and energy fields caused by it also widely concern scholars. The existing research mainly focuses on the following areas. First, in terms of the economic effects brought by the development of the digital economy, Jorgenson et al. showed that information and communication technology (ICT) and computer products play an important role in improving domestic productivity and economic recovery [20]. In the context of the declining rate of return on investment in other industries, the digital economy sector effectively overcame the pressure of the declining rate of labor growth and became the main driver of economic growth beyond the input of production factors [21,22]. Meanwhile, scholars believe that the digital economy gradually became a new driving force for high-quality economic development in China [23,24]. Second, the role of the development of the digital economy in promoting the digital transformation of society is also widely recognized. Existing research found that under the impact of the rapid development of the digital economy, employment structures and employment preferences changed significantly [25–27]. Aghion believes that the employment creation effect brought by the digital economy can significantly improve the employment levels of cities [28]. Based on data related to elderly people in China, He et al. found the digital economy enabled the elderly to enjoy the digital dividend, and the economic structure and wealth of the elderly significantly improved [29]. In addition, the digital economy is also considered to be able to effectively improve social governance and promote social reform. Third, the function of the digital economy as a promoter of economic and environmental governance is also widely discussed by scholars. Hu et al. [30] investigated the relationship between the digital economy and ecological governance performance by analyzing panel data from Chinese cities. They found that due to the rapid development of the digital economy in China, China's urban environmental governance performance also improved. Lv et al. [31] believe that the development of the digital economy has inhibitory effects on carbon emissions in both local and neighboring regions. Li et al. [32] further pointed out that the impact of the digital economy on carbon emissions has a dynamic effect; that is, the role of digital development in inhibiting carbon emissions manifests more in the long term. Wang et al. [33] found that the digital economy can effectively promote the low-carbon sustainable development of cities from the perspective of the innovation factor.

Throughout the literature, most studies mainly focus on one aspect of the digital economy promoting sustainable development, such as the economic, social or environmental governance dimensions. There are few studies that include sustainable development as a global concept to explore the impact of the digital economy on sustainable development. Compared to previous studies, the marginal contribution of this study is mainly in the following aspects. First, in terms of measurement of sustainable urban development indicators, this study constructed an evaluation index system of sustainable urban development level with nine second-level indicators and twenty-five third-level indicators from the three latitudes of health and well-being, resources and environment, and economic development. Second, from the content of the research, we integrated the digital economy and sustainable urban development into a single research framework, analyzed the impact of the digital economy on sustainable urban development and its impact path in-depth as well as the heterogeneous impact of the digital economy on sustainable urban development on different geographical locations, city sizes, and resource endowments. Third, this study included use of the spatial econometric model to explore further the spatial spillover effect of the digital economy on sustainable urban development; thus, it supplements the research on the impact of the digital economy on sustainable urban development from the perspective of spatial analysis.

2. Theoretical Analysis and Research Hypothesis

2.1. Digital Economy and Sustainable Urban Development

As a new economic form, the digital economy not only created various emerging industries relying on ICT technology, but it also added a new impetus to economic growth and promoted increased employment opportunities. The digital economy, with data resources as the key elements and modern information networks as the carriers, provides convenient information services and technical support for all walks of life and effectively improved the inefficient allocation of resources; thus, it greatly improved the operating efficiency of the economy and reduced the excessive consumption of resources and energy. Finally, the development of the digital economy gives new vitality to the sustainable development of the urban economy [34,35]. In terms of resources and the environment, the development of the digital economy brought intelligence and information technology to enterprises. The introduction of digital technology in the production of goods or services can help improve productivity and reduce unnecessary energy consumption and pollution emissions [36]. In addition, the digital economy provides consumers with more rapid, convenient, green consumption channels, such as online shopping and intelligent multi-channel distribution. Coupled with the impact of the COVID-19 pandemic, many new forms of work and lifestyles such as online education, home offices and telemedicine populated under the development of the digital economy, greatly reducing the energy consumption and vehicle emissions generated by commuting and working equipment. Moreover, the real-time and fast characteristics of the digital economy relieve the problem of information asymmetry for the government to conduct environmental management. Using big data and other information technologies, environmental pollution information can be fed back in a timely manner to the government, enterprises and the public [37,38], which is more conducive to the dynamic monitoring of pollution emissions in the production process [39]; thus, it improves the efficiency of environmental protection supervision. Finally, the digital economy, as an emerging industry, is inherently highly innovative. In particular, the series of technologies on which the development of the digital economy depends requires a large amount of capital and human resources to serve technological innovation. Therefore, the digital economy is rooted in the land of innovation and in developed regions. In turn, the digital economy promotes local innovation factors to serve local economic growth, forming an upward spiral. In general, the development of the digital economy will effectively promote the three important dimensions of sustainable urban development and comprehensively promote the level of sustainable development. Based on this, the first hypothesis is proposed:

Hypothesis 1 (H1). *The development of the digital economy can help improve the level of sustainable urban development.*

2.2. Influence Mechanism

Green technology innovation and industrial structure upgrading are widely considered to be important changes brought by the development of the digital economy [40,41]; therefore, this paper mainly discusses the influence mechanisms of the digital economy promoting sustainable urban development from these two perspectives. Innovation is the cornerstone of the emergence and development of the digital economy. The technological innovation brought by the digital economy will be more inclined to be green and clean, which is conducive to green technology innovation and to promoting sustainable urban development. Meanwhile, the continuous integration and development of digital technologies, such as big data and cloud computing, with energy development technologies, energy-saving technologies and low-carbon technologies will not only promote the improvement of green technology innovation and eliminate backward production capacity, but it will also usher in a new generation of digital green technologies, promoting the transformation of manufacturing to green, low-carbon and intelligent manufacturing [42]. The innovative factors generated by the digital economy also effectively promote the efficient use of production factors, reduce energy consumption, improve labor productivity, and promote the sustainable development of the local economy. In addition, technological innovation driven by the digital economy also has obvious spillover effects, which is particularly evident among enterprises. The digital economy promotes the digital and green transformation of traditional enterprises, forces enterprises to develop and apply green and clean technologies, transform product production processes, and establish intelligent logistics [43]. The digital economy will also accelerate the diffusion effect of clean digital technology and increase the overflow speed of green technology to achieve the sustainable development of enterprises.

In the process of industrial upgrading, it will guide the flow of production factors such as labor, capital, technology and other factors of production to the industries that create high value. The development of the digital economy objectively promoted the efficiency of resource allocation, reduced resource waste and raised the development potential and upper limit of local economies [44]. The deep integration of the digital economy and traditional industries further stimulated the vitality of local economies. With the help of artificial intelligence, big data and other digital technologies, traditional industries can realize intelligent and low-carbon production in the whole process of products or services, reduce production and management costs, optimize business processes, promote industrial upgrading and transformation and reduce production losses in energy-intensive enterprises [45]. Second, emerging industries derived from the development of the digital economy, such as the software service industry and the electronic information manufacturing industry, provide technical, human and capital support for the development of tangible industries; thus, they promote the value-add of traditional industries. Moreover, these emerging information technology industries are more favored by the market, attracting much talent and investment and increasing the proportion of knowledge-intensive industries [46]. Due to the high permeability of information technology and network technology [47], the synergy of factors between industries is enhanced. The division of labor boundaries in industrial chains is gradually blurred, which can accelerate the transformation of traditional industries and promote the upgrading of industrial structures. Based on this, the second hypothesis is proposed:

Hypothesis 2 (H2). *The digital economy takes improving the level of green technology innovation and promoting the upgrading of industrial structures as influence mechanisms to promote sustainable urban development*.

2.3. Spatial Spillover Effect

Relying on information network technology, the digital economy breaks the limitation of geographic space, enhancing the spatial mobility and correlation of elements [48]. Therefore, the digital economy not only promotes the sustainable development of local cities, but also produces spillover effects for the sustainable development of neighboring cities. The spatial spillover effect of the digital economy that enables sustainable urban development is mainly reflected in the following aspects. In the context of the development of the digital economy, the transmission speed and transparency of information improved unprecedentedly, broke regional barriers in market transactions, reduced information asymmetry and obstruction, and facilitated cross-regional development. With the construction of the data platform, digital information as a key factor of production can penetrate and spread more quickly in various regions, cities and enterprises [49]. The public goods attribute of digital information also reduces the cost of information sharing between different enterprises and regions. Moreover, the digital economy weakens the boundary restrictions between areas and speeds up the flow of the means of production and factors of production between different areas. Unlike production factors such as land and labor, data factors are shared. They can be copied and learned at low cost, which reduces the waste of resources in the flow process and not only promotes the sustainable development of local cities, but also brings some benefits to the sustainable development of nearby cities. Based on this, the third hypothesis is proposed:

Hypothesis 3 (H3). *The improvement of sustainable development in neighboring regions benefits from the spatial spillover effect of the digital economy*.

3. Methods and Data

3.1. Empirical Model Design

3.1.1. Benchmark Regression Model

Based on theoretical analysis, in order to verify the impact of the digital economy on sustainable urban development, the following empirical benchmark model was established:

$$sus_{it} = \alpha_0 + \alpha_1 de_{it} + \alpha_2 Control_{it} + \nu_i + \tau_t + \varepsilon_{it} \quad (1)$$

where i and t denote city and year, respectively; *sus* represents the level of sustainable urban development calculated by using the entropy method; *de* describes the development level of the digital economy. In addition, the estimated coefficient α_1 is the core of our benchmark regression model, which reflects the impact of the digital economy on sustainable urban development. *Control* represents a series of control variables, including economic development level (ed), science and technology support (st), infrastructure construction level (ic), population density (pd) and urbanization level (ur). ν_i represents the region fixed effect; τ_t represents the time fixed effect; ε_{it} represents the random error term.

In addition, in order to verify the specific path of the development of the digital economy to promote the sustainable development of cities, referring to Baron and Kenny's [50] improved step-by-step regression method of mediating effect, this study took green technology innovation and industrial structure upgrading as mediating variables and constructed the following model based on Equation (1):

$$med_{it} = \beta_0 + \beta_1 de_{it} + \beta_2 Control_{it} + \nu_i + \tau_t + \varepsilon_{it} \tag{2}$$

$$sus_{it} = \gamma_0 + \gamma_1 de_{it} + \gamma_2 med_{it} + \gamma_3 Control_{it} + \nu_i + \tau_t + \varepsilon_{it} \tag{3}$$

where *med* represents the mediating variables, that is, those of green technology innovation (gt) and industrial structure upgrading (is). The meanings of other variables are the same as those in Equation (1). According to Baron and Kenny (1986)'s inspection idea [50], if only coefficient α_1 passes the significance test in Equation (1), then the next step of the mechanism test analysis can be carried out. The second step is to test the role of the core explanatory variable on the mechanism variable (i.e., Equation (2)). When β_1 is significant in Equation (2), it shows that the digital economy and mediating variables change in the same direction, thereby establishing a significant statistical correlation between the mediating variables and core explanatory variables. Finally, if γ_2 also passes the significance test in Equation (3), then it indicates the existence of an intermediary effect, for which $\beta_1 \times \gamma_2$ indicates its size.

3.1.2. Spatial Econometric Model

With the increasingly frequent flow of traffic, personnel and production factors between cities, the economic, social and environmental development of neighboring cities will also affect the development of a given city. Similarly, the development of the digital economy in a specific region will also affect the development of nearby cities, resulting in spatial spillover effects [51]. The development of spatial econometrics, as one of the most important achievements of the development of econometrics in recent years, reveals the interactions between different regions. Thus, through the introduction of spatial econometric model, we adopted a spatial autoregressive model (SAR) to test the spatial impact of the digital economy on sustainable urban development:

$$sus_{it} = \eta_0 + \rho W sus_{it} + \eta_1 de_{it} + \eta_2 Control_{it} + \nu_i + \tau_i + \varepsilon_{it} \tag{4}$$

where W represents the spatial weight matrix. In order to ensure the robustness of the empirical results, this study adopted the inverse distance spatial weight matrix, economic distance spatial weight matrix and geographical proximity spatial weight matrix calculated based on the longitude and latitude of each city and the average per capita GDP for spatial empirical analysis. ρ is the spatial auto-regressive coefficient, and $W \times sus$ represents the spatial lag term of the sustainable urban development level. The other variables have the same meanings as in Equation (1).

3.2. Main Variables

3.2.1. Explained Variable

The level of sustainable urban development (*sus*) is based on the United Nations System of Sustainable Development Goals (SDGs). By systematically absorbing existing research on sustainable development indicators [13,52,53], we followed the principles that were scientific, systematic, adaptive, had reliable data availability, had a localized index and were extensible. We constructed the evaluation index system of sustainable urban development levels, which consists of 3 first-level indicators (health and well-being index, resources and environment index and economic development index), 9 second-level indicators and 25 third-level indicators. Referring to the United Nations Human Development Index, we constructed the health and well-being index from four dimensions: health, education, income and equity. In terms of the resource and environment index, it reflects three subsystems. Among them, the level of environmental quality improvement comes from the report "China's Ecological Footprint" jointly issued by the China International Cooperation Commission on Environment and Development and the World Foundation, and its third-level indicators briefly reflect the urban environmental status. The level of ecological protection is based on the "Earth Vitality Report" issued by the World Wide Fund for Nature, which mainly measures the level of ecological environment protection in a region. The level of resource utilization represents the pollution emission per unit of GDP of cities under the premise of limited resources. For the economic development index, we fully considered the relationship between the current situation and the potential of economic development. The local economic development level is reflected through the calculation of GDP and its growth rate, and the potential of cities to achieve sustainable development was measured by introducing relevant indicators of innovative development. The specific indicators are shown in Table 1.

Table 1. The evaluation index system of sustainable urban development levels.

Objectives	Primary Index	Secondary Index	Index Interpretation	Attributes
Sustainable urban development level (*sus*)	Health and well-being index (hw)	Health level	The participation rate of basic medical insurance for urban employees (%)	+
			Number of beds per 10,000 persons in medical institutions (bed)	+
			Number of practicing (assistant) physicians per 1000 resident population (person)	+
		Education level	The proportion of educational outliers in the financial expenditures at the corresponding level (%)	+
			The ratio of pupils to teachers	+
			The ratio of students to teachers in middle school	+
			The ratio of students to teachers in colleges and universities	+
		Income level	Per capital gross domestic product (yuan/person)	+
			The average salary of on-the-job staff and workers (yuan/person)	+
		Coefficient of fairness	Income ratio of urban and rural residents	-
			Gini coefficient	-
	Resource and environment index (re)	Level of environmental quality improvement	The proportion of days with good air quality (%)	+
			Annual average concentration of PM2.5 ($\mu g/m^3$)	-
			The ratio of consumption wastes treated (%)	+
		Level of ecological protection	The proportion of green coverage to built-up areas (%)	+
			Per capita area of green park space (ha/person)	+
		Level of resource utilization	Water consumption per 10,000 yuan of GDP (cubic meters/10,000 yuan)	-
			The energy consumption rate of 10,000 yuan GDP (%)	+
			The CO2 emission intensity of 10,000 yuan GDP (ton/10,000 yuan)	-
			Land development intensity (%)	+
	Economic development index (eco)	Innovation-driven level	R&D expenditure as a proportion of regional GDP (%)	+
			Number of patents per 10,000 people (piece)	+
			Internet penetration (%)	+
		Economic performance	Total labor productivity (10,000 yuan per person)	+
			The annual growth rate of the gross domestic product (GDP) of the region (%)	+

Note: "+ " indicates the positive attribute, and"-"indicates the negative attribute.

Due to the different units and attributes between different indicators, in order to eliminate the impact of each dimension on the evaluation index system, we standardized the indicators at all levels to eliminate the dimensions, and then we used the entropy method to calculate.

Figure 1 briefly depicts the evolution of sustainable urban development levels in China. It shows that the level of sustainable development of Chinese cities increased slightly compared to 2011, although this process was mainly realized in fluctuations. The results of the regional heterogeneity analysis show that from 2011 to 2019, the sustainable urban development level of the eastern region was significantly higher than those of the central and western areas, and it was also higher than the national average level. The distribution pattern of sustainable development presents the pattern of "eastern > national > central/western".

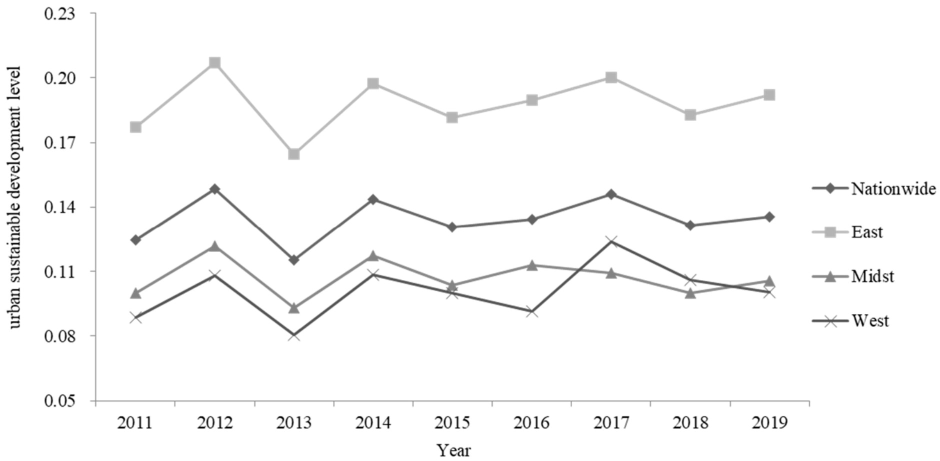


Figure 1. Sustainable urban development level in China.

3.2.2. Explanatory Variable

Concerning the research of Zhao et al. [54], we measured the development level of the digital economy (*de*) from two aspects: Internet development and digital finance. The development of the Internet includes four specific indicators obtained by using the entropy method: the income of telecommunications business, the number of employees of computer services and software for information transmission, the number of Internet broadband users and the number of mobile phone users. The level of digital finance is represented by the Digital Financial Inclusion Index jointly compiled by Peking University and Ant Financial.

3.2.3. Mediating Variables

Due to the time lag from patent application to authorization [55], the number of urban green patent applications was taken to characterize green technology innovation (gt) [56]. The number of green patent applications was based on the IPC classification number of the "Green List of International Patent Classification" issued by the World Intellectual Property Organization and the patent application information provided by China's national Intellectual Property Administration.

The transformation of economic structure to the tertiary industry is one of the main objectives of industrial structure upgrading (is), and serving the tertiary industry is also one of the main characteristics of the digital economy. Therefore, referring to the practices of Yan et al. [57] and Xu et al. [58], the ratio between the output value of the city's tertiary industry to the second product was selected to measure the level of industrial structure upgrading.

3.2.4. Control Variables

At the same time, based on the practice of relevant studies [59,60], the following variables were selected as control variables: economic development level (ed), expressed as urban per capita gross regional product; science and technology support (st), expressed as the percentage of urban expenditure on science and technology in local fiscal cost; infrastructure construction level (ic), expressed as the per capita metropolitan road area of each city; population density (pd), using the natural logarithm of urban population density as its proxy variable; urbanization level (ur), which is represented by the urbanization rate of a city.

3.3. Data Source and Descriptive Statistics

Considering the availability and reliability of data, this study selected 280 prefecture-level cities in China from 2011 to 2019 as research samples. The data comes from the China Urban Statistical Yearbook, Chinese Urban Construction Statistical Yearbook, National Economic and Social Development Statistical Bulletin, Ecological and Environmental Status Bulletin, and WIND database data for each city over the years. The interpolation method and mean value method were used to fill in the missing data. Meanwhile, to reduce the impact of extreme values, continuous variables were Winsorized. The descriptive statistical results of each variable are shown in Table 2.

Table 2. Descriptive statistics of variables.

Variable	Obs	Mean	SD	Min	P50	Max
sus	2520	0.133	0.100	0.025	0.104	0.635
de	2520	0.063	9.700	0.010	0.042	0.454
gt	2520	5.178	1.646	1.792	5.050	9.302
is	2520	0.993	0.536	0.305	0.857	3.458
ed	2520	5.367	3.262	1.248	4.422	17.098
st	2520	1.624	1.483	0.150	1.157	7.940
ic	2520	12.984	6.923	2.404	11.737	40.470
pd	2520	5.766	0.865	3.225	5.903	7.336
ur	2520	8.686	9.136	0.420	5.590	48.120

4. Empirical Results and Discussion

4.1. Benchmark Regression Result

Before the regression analysis, a multicollinearity test was conducted on the variables. The results show that the variance expansion coefficients (VIF) of the variables were all less than 4, far less than 10, indicating that there was no multicollinearity. Second, the stability and co-integration of the data were tested to avoid the appearance of pseudo-regression. The specific results are shown in Table 3, which depicts how the LLC and Fisher-ADF methods passed the unit root test [61,62], and both *p* values were 0.000, indicating that the data was stable. At the same time, the *p*-values of the co-integration test results were all less than 0.05, indicating the existence of a co-integration relationship. This analysis shows that the sample data is applicable to regression analysis.

Table 3. The test results of stationarity and co-integration.

Variable	LLC		Fisher-ADF		Kao Test		
	t	*p*	t	*p*	Item	t	*p*
sus	−21.193	0.000	1437.872	0.000	Modified Dickey–Fuller t	−1.881	0.030
de	−29.941	0.000	1527.969	0.000	Dickey–Fuller t	−16.138	0.000
ed	−3.413	0.000	1010.652	0.000	Augmented Dickey–Fuller t	−1.777	0.038
st	−10.291	0.000	1152.349	0.000			
ic	−11.187	0.000	1107.687	0.000	Unadjusted Modified Dickey–Fuller t	−25.004	0.000
pd	−16.397	0.000	1072.909	0.000			
ur	−16.000	0.000	1469.356	0.000	Unadjusted Dickey–Fuller t	−29.460	0.000

Table 4 lists the benchmark regression results of the digital economy on sustainable urban development. Among them, after fixed effect and control variables were gradually added into Models (1)–(4), the regression coefficients of the digital economy (*de*) on sustainable urban development (*sus*) were both positive and passed the significance test at the 1%

level, indicating that the development of the digital economy will significantly promote the progress of local sustainable development. The benchmark regression results verified the rationality of Hypothesis 1.

Table 4. The results of benchmark regression.

Variable	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)	Model (7)
	sus	*sus*	*sus*	*sus*	**hw**	**re**	**eco**
de	1.162 *** (69.84)	1.106 *** (54.49)	0.737 *** (48.13)	0.563 *** (32.99)	0.288 *** (11.26)	0.699 *** (38.92)	0.423 *** (18.31)
ed			0.008 *** (23.51)	0.009 *** (25.43)	0.021 *** (38.31)	0.002 *** (4.61)	0.007 *** (14.62)
st			0.009 *** (11.63)	0.011 *** (12.80)	0.011 *** (9.29)	0.002 ** (1.98)	0.014 *** (12.76)
ic			0.001 *** (6.15)	0.001 *** (9.11)	0.002 *** (8.46)	0.001 *** (3.57)	0.002 *** (8.55)
pd			−0.004 *** (−3.60)	0.005 *** (3.16)	0.014 *** (6.11)	−0.003 ** (−1.98)	0.001 (0.52)
ur			0.003 *** (23.56)	0.003 *** (24.55)	0.003 * (1.81)	0.004 *** (35.43)	0.001 *** (3.70)
Constant	0.060 *** (37.92)	0.042 ** (2.04)	0.017 ** (2.57)	−0.005 (−0.33)	0.014 (0.58)	0.030 * (1.78)	−0.087 *** (−4.10)
Year fe	No	Yes	No	Yes	Yes	Yes	Yes
Area fe	No	Yes	No	Yes	Yes	Yes	Yes
R^2	0.660	0.713	0.835	0.876	0.815	0.840	0.698
obs	2520	2520	2520	2520	2520	2520	2520

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$; the values in parentheses are t values.

To further verify the impact of the digital economy on the three dimensions of sustainable urban development, this study took the health and well-being index, resource and environment index, and economic development index as the explanatory variables into Model (1). According to the regression results of Models (5)–(7), the marginal effect of the digital economy on the three indexes of the sustainable urban development was significantly positive at the level of 1%, indicating that the development of the digital economy effectively promoted all aspects of sustainable urban development. The regression results of the control variables show that the levels of economic development, scientific and technological support, infrastructure construction, and urbanization were significantly positive to the level of sustainable urban development and its three indexes at the 1% level. However, population density only had a significant negative impact on the resource and environment index, and the potential cause may be that with the increase in population density, the supply of various resources in the city appears to be a bottleneck, and the environment's carrying capacity of the population, tolerance capacity for behavior and self-repair capacity also become weak.

4.2. Robustness Test

To ensure the robustness of the above conclusions, this study adopted the following methods to carry out the robustness test. First, the measurement method of core explanatory variables was changed. We selected the coefficient of variation method to re-calculate the development level of the digital economy. The regression results after replacing the core explanatory variable are shown in Model (1) in Table 5. Second, considering the result deviation possibly caused by the hysteresis and dynamics of the digital economy, the first-order lag term of the digital economy was adopted for regression. The regression results are shown in Model (2) in Table 5. Third, to reduce the impact of urban particularity on the conclusion, we deleted data for municipalities directly managed under the central government (i.e., Beijing, Shanghai, Tianjin, and Chongqing) and rebuilt the sample for regression. For specific results, see Model (3) in Table 5. Fourth, we changed the empirical test method; the panel correction standard error (pcse) and generalized least square method (GLS) were used for re-regression, and the regression results are shown in Model (4) and Model (5) in Table 5. All of the above robustness test results indicate that the digital economy plays a significant role in promoting sustainable urban development at the 1% level, which is consistent with the baseline regression results, indicating that the conclusions of this study are robust.

Table 5. Results of the robustness test.

Variable	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)
	sus	*sus*	*sus*	*sus*	*sus*
de	0.557 *** (32.71)	0.572 *** (30.46)	0.568 *** (33.27)	0.553 *** (13.83)	0.551 *** (30.12)
ed	0.009 *** (24.20)	0.009 *** (23.33)	0.009 *** (25.64)	0.008 *** (6.54)	0.009 *** (31.64)
st	0.010 *** (12.46)	0.011 *** (12.16)	0.010 *** (12.62)	0.0106 *** (6.58)	0.008 *** (11.76)
ic	0.001 *** (9.18)	0.001 *** (8.37)	0.001 *** (8.75)	0.001 *** (7.8556)	0.001 *** (3.95)
pd	0.005 *** (3.164)	0.003 * (1.94)	0.004 *** (2.80)	0.007 *** (2.80)	0.003 ** (2.54)
ur	0.003 *** (24.37)	0.003 *** (22.87)	0.003 *** (25.18)	0.003 *** (6.38)	0.003 *** (26.97)
Constant	−0.006 (−0.39)	0.018 (1.08)	−0.029 *** (−3.22)	0.003 (0.02)	0.031 (1.38)
Year fe	Yes	Yes	Yes	Yes	Yes
Area fe	Yes	Yes	Yes	Yes	Yes
R^2	0.876	0.878	0.851	0.820	
obs	2520	2240	2484	2520	2520

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$; the values in parentheses are t values.

4.3. Analysis of Influence Mechanism

Table 6 reports the empirical results of the influence mechanism of the digital economy on sustainable urban development. Model (1) is the benchmark regression result, which shows that the digital economy can significantly promote sustainable urban development ($\alpha = 0.563$, $p < 0.01$). The results of Models (2) and (3) show that there is a positive relationship between the digital economy and the two mechanism variables, green technology innovation and industrial structure upgrading, at the significance level of 1% ($\beta_1 = 10.513$, $p_1 < 0.01$; $\beta_2 = 3.545$, $p_2 < 0.01$), indicating that the digital economy can promote the level of green technology innovation and industrial structure upgrading. Models (4) and (5) are the regression results after adding two mechanism variables of green technology innovation and industrial structure upgrading into the benchmark regression model, Model (1). It can be found that the impact of the digital economy, green technology innovation and industrial structure upgrading on sustainable urban development is significantly positive at the 1% level, and both show promoting effects. Moreover, the regression coefficients of the digital economy to sustainable urban development decreased ($\chi_1 = 0.527$, $p_1 < 0.01$; $\chi_2 = 0.524$, $p_2 < 0.01$), indicating that both green technology innovation and industrial structure upgrading are critical transmission paths for the digital economy to promote sustainable urban development. Green technology innovation and industrial structure upgrading showed partial mediating roles, with mediating sizes of 0.036 and 0.038, respectively, which verifies the hypothesis of the previous research.

Table 6. Empirical results of the analysis of the influence mechanism.

Variable	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)
	sus	gp	is	*sus*	*sus*
de	0.563 *** (32.99)	10.513 *** (31.79)	3.545 *** (21.54)	0.527 *** (26.10)	0.524 *** (28.36)
gt				0.003 *** (3.27)	
is					0.011 *** (5.23)
ed	0.009 *** (25.43)	0.063 *** (8.84)	−0.044 *** (−12.52)	0.009 *** (24.51)	0.010 *** (26.07)
st	0.011 *** (12.80)	0.169 *** (10.60)	0.002 (0.22)	0.010 *** (11.86)	0.011 *** (12.8417)
inf	0.001 *** (9.11)	0.018 *** (6.56)	−0.008 *** (-5.48)	0.001 *** (8.62)	0.001 *** (9.68)
ps	0.005 *** (3.16)	0.340 *** (11.58)	−0.062 *** (−4.26)	0.004 ** (2.34)	0.005 *** (3.61)
ur	0.003 *** (24.55)	0.008 *** (3.71)	0.001 (0.13)	0.003 *** (24.28)	0.003 *** (24.66)
Constant	−0.005 (−0.33)	−1.125 *** (−3.69)	1.066 *** (7.03)	−0.001 (−0.09)	−0.017 (−1.06)
Year fe	YES	YES	YES	YES	YES
Area fe	YES	YES	YES	YES	YES
R^2	0.876	0.828	0.597	0.877	0.878
obs	2520	2520	2520	2520	2520

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$; the values in parentheses are t values.

In this study, the Sobel test and the Bootstrap test were adopted to further verify the effectiveness of the influence mechanism. The results are shown in Tables 7 and 8. As seen in Table 7, the Sobel values of green technology innovation and industrial structure upgrading were both significantly positive at the 1% level, which shows the rationality of the discussion of the impact mechanism in this study.

Table 7. Results of the Sobel test.

Mediation Variable	Sobel Value	Indirect Effect	Direct Effect	Total Effect	Proportion of Mediating Effects
gt	0.036 *** (3.26)	0.036 *** (3.26)	0.527 *** (26.10)	0.563 *** (32.99)	6.33%
is	0.038 *** (5.09)	0.038 *** (5.09)	0.524 *** (28.36)	0.563 *** (32.99)	6.83%

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$; the values in brackets are z values.

Table 8. Results of bootstrap test.

Effect Type	gt		is	
	Coefficient	**95% Confidence Interval**	**Coefficient**	**95% Confidence Interval**
Indirect effect	0.036 ***(2.69)	[0.0063, 0.0587]	0.038 ***(4.77)	[0.0231, 0.0545]
Direct effect	0.527 ***(12.18)	[0.0.4462, 0.6207]	0.524 ***(13.08)	[0.4493, 0.6090]

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$; the sampling time of the bootstrap test was 500, the values in square brackets are Z-values, and the 95% confidence interval is bias-corrected.

The results of bootstrap test are shown in Table 8. The coefficients of the indirect and direct effects of green technology innovation and industrial structure upgrading were both significantly positive at the 1% level; the confidence intervals of the indirect effects do not include 0, which indicates that the intermediary conduction effect of green technology innovation and industrial structure upgrading was verified again.

4.4. Endogeneity Test

It was shown previously that the digital economy can promote sustainable urban development, and the existence of its influence mechanism was also shown. Still, there may be the endogeneity problems caused by measurement errors and missing variables, which will affect the robustness of the conclusion. Therefore, the instrumental variable method was adopted to solve the endogeneity problems. Referring to the research of Zhang et al. [63], the spherical distance between each city and Hangzhou was used as the instrumental variable. However, the data of the instrumental variable does not change with time and cannot be directly used in the panel measurement model. Therefore, panel instrumental variables that change with time needed to be constructed as the instrumental variable of the urban digital economy (IV). The endogeneity test was then performed using the two-stage least square method (2SLS). The results are shown in Table 9. Model (1) shows the regression results of the first stage, and Models (2)–(6) reflect the regression results of the second stage. The results show that, when endogeneity is taken into consideration, the digital economy can still promote sustainable urban development, that its two transmission paths (namely green technology innovation and industrial structure upgrading) are still valid and that the results are both significant at the 1% level. In addition, the correlation test of instrumental variables showed that the *p*-value of the Kleibergen–Paap rk LM statistic was less than 0.01, indicating that the null hypothesis of insufficient instrumental variable identification was rejected. At the same time, the Kleibergen–Paap Wald rk F statistic in the tool weak recognition test is significantly larger than the critical value of 16.38 in the Stock–Yogo test, which indicates the rationality of the selection of instrumental variables.

Table 9. The results of the endogenous test.

Variable	The First Stage	The Second Stage				
	Model (1)	**Model (2)**	**Model (3)**	**Model (4)**	**Model (5)**	**Model (6)**
	de	***sus***	**gt**	**is**	***sus***	***sus***
de		0.575 *** [13.39]	12.527 *** [14.22]	3.788 *** [12.29]	0.535 *** [9.59]	0.536 *** [11.69]
IV	0.001 *** (43.06)					
gt					0.003 ** [2.12]	
is						0.010 *** [3.93]
ed	0.001 *** (3.92)	0.009 *** [17.4]	0.053 *** [7.12]	−0.045 *** [−12.71]	0.009 *** [17.25]	0.010 *** [17.34]

Table 9. *Cont.*

Variable	The First Stage	The Second Stage				
	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
	de	***sus***	**gt**	**is**	***sus***	***sus***
st	0.006 *** (7.18)	0.010 *** [8.63]	0.145 *** [7.82]	−0.001 [−0.16)	0.010 *** [8.65]	0.010 *** [8.81]
ic	0.001 (0.14)	0.001 *** [4.72]	0.018 *** [6.40]	−0.008 *** [−5.16]	0.001 *** [4.51]	0.001 *** [5.01]
pd	0.004 *** (5.30)	0.005 *** [2.61]	0.295 *** [7.95]	−0.068 *** [−3.85]	0.004 ** [2.21]	0.005 *** [2.99]
ur	0.001 *** (6.41)	0.003 *** [12.18]	0.006 ** [2.54]	−0.001 [−0.13]	0.003 *** (12.23]	0.003 *** [12.22]
Constant	0.300 *** (38.13)	−0.007 [−0.36]	−1.423 *** [−4.27]	1.031 *** [7.43]	−0.003 [−0.13]	−0.018 [−0.90]
Year fe	YES	YES	YES	YES	YES	YES
Area fe	YES	YES	YES	YES	YES	YES
Kleibergen-Paap rk LM	100.25 ***	100.25 ***	100.25 ***	100.25 ***	73.66 ***	92.68 ***
Kleibergen-Paap Wald rk F	1853.97 {16.38}	1853.974 {16.38}	1853.974 {16.38}	1853.974 {16.38}	960.585 {16.38}	1459.635 {16.38}
R^2	0.905	0.876	0.825	0.825	0.877	0.878
obs	2520	2520	2520	2520	2520	2520

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$; the t value is in parentheses, the z value is in square brackets, and the critical value of the Stock–Yogo test is in curly braces.

4.5. Analysis of Spatial Spillover Effect

4.5.1. Spatial Correlation Test

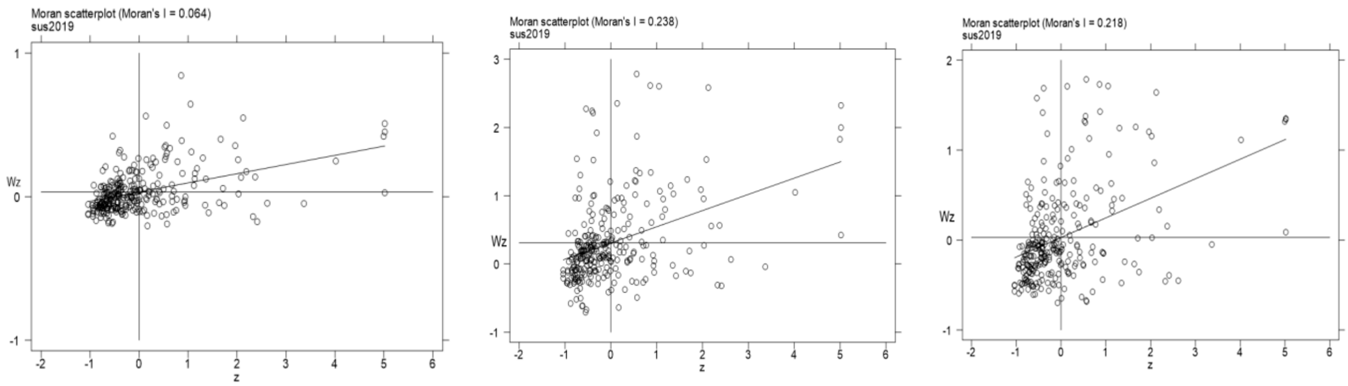
Considering the existence of the spatial spillover effect, we introduced the methods of spatial econometrics to discuss this problem. Before verifying the spatial spillover effect, it was necessary to test the spatial correlation between sustainable urban development and the digital economy. We selected the global Moran's index to explore the spatial correlation between sustainable urban development and the digital economy in China during 2011–2019, and the results are shown in Table 10. It can be found that, under the three spatial weight matrices of inverse distance, economic distance and geographical proximity, Moran's indices of the digital economy and of sustainable urban development level were positive, and both reached the statistical significance level of 1% during 2011–2019, indicating that there is a significant spatial positive correlation between the digital economy and sustainable urban development in China in that period.

To further explore the spatial agglomeration trend of sustainable urban development, the Moran's index scatter plots of sustainable urban development under three spatial weight matrices are shown in Figure 2 (limited by space; only the results of 2019 are shown). It can be seen from Figure 2 that the local Moran's indices of sustainable urban development in 2019 under the three weight matrices were 0.064, 0.238 and 0.218, and most cities are in the third and first quadrants, indicating that the level of sustainable urban development has significant spatial agglomeration.

Table 10. Moran's indices of the digital economy and of sustainable urban development.

Year	*de*			*sus*		
	Inverse Distance	**Economic Distance**	**Geographical Proximity**	**Inverse Distance**	**Economic Distance**	**Geographical Proximity**
2011	0.047 *** (8.08)	0.169 (6.80)	0.170 (7.19)	0.056 *** (9.57)	0.202 *** (8.05)	0.205 *** (8.54)
2012	0.046 *** (7.90)	0.168 *** (6.77)	0.171 *** (7.21)	0.072 *** (12.09)	0.260 *** (10.27)	0.260 *** (10.79)
2013	0.037 *** (6.58)	0.139 *** (5.62)	0.141 *** (5.98)	0.073 *** (12.17)	0.259 *** (10.28)	0.254 *** (10.56)
2014	0.037 *** (6.58)	0.150 *** (6.08)	0.144 *** (6.09)	0.072 *** (12.05)	0.266 *** (10.53)	0.258 *** (10.70)
2015	0.036 *** (6.40)	0.150 *** (6.04)	0.141 *** (5.94)	0.087 *** (14.37)	0.304 *** (12.00)	0.302 *** (12.46)
2016	0.032 *** (5.84)	0.135 *** (5.48)	0.136 *** (5.80)	0.077 *** (12.89)	0.270 *** (10.69)	0.263 *** (10.91)
2017	0.037 *** (6.56)	0.148 *** (6.00)	0.152 *** (6.44)	0.065 *** (10.91)	0.224 *** (8.89)	0.230 *** (9.55)
2018	0.036 *** (6.41)	0.145 *** (5.88)	0.140 *** (5.94)	0.072 *** (12.02)	0.254 *** (10.06)	0.245 *** (10.19)
2019	0.025 *** (4.62)	0.118 *** (4.83)	0.123 *** (5.29)	0.064 *** (10.78)	0.238 *** (9.42)	0.218 *** (9.05)

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$; z values are in parentheses.



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

Figure 2. Moran's index scatter plot of sustainable urban development in 2019. (**a**) Inverse distance; (**b**) Economic distance; (**c**) Geographical proximity.

In this study, the sustainable urban development levels of 280 cities in 2019 were clustered and divided into four quadrants. The results are shown in Table 11. Under the three spatial weights, the proportions of cities in the first quadrant (H-H) and the third quadrant (L-L) in 2019 are 60.36% (for weight 0.064), 67.50% (0.238) and 68.57% (0.218), indicating a significant positive correlation between levels of sustainable urban development. In addition, a small number of cities were located in the second quadrant, indicating that a small number of cities with lower development levels are surrounded by cities with higher development levels.

Table 11. Spatial cluster analysis results of sustainable urban development levels in 2019.

Matrix of Weights	Result of Clustering	First Quadrant (H-H)	Second Quadrant (L-H)	Third Quadrant (L-L)	Fourth Quadrant (H-L)
Inverse distance	Number of cities	57	77	112	34
	Proportion (%)	20.36	27.50	40.00	12.14
Economic distance	Number of cities	71	70	118	21
	Proportion (%)	25.36	25.00	42.14	7.50
Geographical proximity	Number of cities	51	47	141	41
	Proportion (%)	18.21	16.79	50.36	14.64

4.5.2. Empirical Analysis of the Spatial Effect

Table 12 lists the test results of the spatial auto-regressive model. It can be found that under the three spatial weight matrices, the ρ of the spatial auto-regressive coefficient was significantly positive at the level of 1% regardless of whether control variables were added, indicating that there is a significant positive spatial spillover effect from sustainable urban development. At the same time, it was found that the regression coefficients of the digital economy on sustainable urban development were significantly positive, which proves that the digital economy can still effectively improve the level of sustainable urban development even if space overflow is considered, which is demonstrated in the results of the benchmark regression.

Table 12. Test results of spatial auto-regressive model.

	Inverse Distance		Economic Distance		Geographical Proximity	
Variable	*sus*	*sus*	*sus*	*sus*	*sus*	*sus*
de	0.309 *** (8.31)	0.382 *** (11.29)	0.293 *** (7.86)	0.351 *** (10.20)	0.292 *** (7.99)	0.339 *** (10.33)
ed		0.003 *** (8.43)		0.003 *** (7.54)		0.003 *** (8.55)
st		0.006 *** (6.95)		0.006 *** (6.42)		0.005 *** (6.01)
ic		0.001 *** (2.82)		0.001 *** (2.84)		0.001 *** (3.23)
pd		0.008 ** (2.37)		0.007 * (1.87)		0.006 * (1.65)
ur		0.003 *** (21.79)		0.003 *** (21.23)		0.0025 *** (21.36)
ρ	0.909 *** (34.89)	0.861 *** (25.92)	0.462 *** (19.76)	0.366 *** (15.72)	0.565 *** (22.16)	0.4837 *** (18.80)
Constant	−0.010 (−1.59)	−0.112 *** (−5.80)	0.038 *** (6.09)	−0.044 ** (−2.21)	0.0385 *** (6.41)	−0.044 ** (−2.24)
R^2	0.433	0.668	0.630	0.713	0.617	0.681
obs	2520	2520	2520	2520	2520	2520

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$; z values in parentheses.

Table 13 shows the total effect decomposition results of the spatial auto-regressive model. From the results of effect decomposition, it can be found that no matter the spatial weight of reverse distance, the spatial weight matrix of economic distance, or the spatial weight matrix of geographical proximity space, the direct spillover effect and total effect of the digital economy on the level of sustainable urban development passed the significance level test, and the influence coefficients were all positive. This shows that the digital economy of the city can not only improve the sustainable development level of the local cities, but also be promoted by developing the digital economy of neighboring cities; that is, there is a positive spillover effect of the digital economy on sustainable urban development. It may be because the development of the digital economy realized the cross-regional integration and synergy effect of resources, promoted the innovation of relevant technical knowledge and the adjustment of industrial layouts, improved the utilization rate of regional resources, accelerated the driving impact of data information flow on labor, capital and other production factors and then brought positive external impact to the sustainable development of different regions.

Table 13. The effect decomposition results of the spatial auto-regressive model.

Variable	Inverse Distance			Economic Distance			Geographical Proximity		
	Direct Effect	Spillover Effect	Total Effect	Direct Effect	Spillover Effect	Total Effect	Direct Effect	Spillover Effect	Total Effect
de	0.393 *** (11.09)	2.514 *** (3.07)	2.908 *** (3.51)	0.358 *** (10.02)	0.198 *** (8.25)	0.556 *** (10.29)	0.350 *** (10.19)	0.308 *** (8.21)	0.658 *** (10.17)
ed	0.004 *** (8.83)	0.022 *** (3.17)	0.026 *** (3.61)	0.003 *** (7.85)	0.002 *** (7.49)	0.005 *** (8.27)	0.004 *** (8.92)	0.003 *** (7.69)	0.007 *** (9.04)
st	0.006 *** (7.39)	0.041 *** (2.96)	0.047 *** (3.33)	0.006 *** (6.83)	0.003 *** (6.07)	0.009 *** (6.86)	0.056 *** (6.40)	0.005 *** (5.77)	0.011 *** (6.37)
ic	0.001 *** (2.91)	0.003 ** (2.09)	0.004 ** (2.23)	0.001 *** (2.94)	0.001 *** (2.85)	0.001 *** (2.95)	0.001 *** (3.35)	0.001 *** (3.19)	0.001 *** (3.32)
pd	0.008 ** (2.51)	0.052 ** (1.99)	0.061 ** (2.10)	0.007 ** (1.97)	0.004 ** (1.97)	0.011 ** (1.98)	0.006 * (1.72)	0.005 * (1.74)	0.011 * (1.75)
ur	0.003 *** (21.43)	0.017 *** (3.04)	0.020 *** (3.48)	0.003 *** (21.35)	0.002 *** (9.06)	0.004 *** (16.74)	0.003 *** (21.45)	0.002 *** (8.96)	0.005 *** (14.73)
R^2	0.668	0.668	0.668	0.713	0.713	0.713	0.681	0.681	0.681
obs	2520	2520	2520	2520	2520	2520	2520	2520	2520

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$; z values in parentheses.

4.6. Analysis of Heterogeneity

The different development conditions, such as location, resource endowment, policy implementation and the development level of the digital economy may lead to differences in the level of the sustainable development of cities. Therefore, to further investigate the impact of the digital economy on sustainable urban development, the following heterogeneity analysis was carried out by referring to existing studies [60]. First, based on the division of the three economic belts by the National Bureau of Statistics, the research samples were divided into two sub-samples, the eastern region and the central and western regions. Second, referring to the Notice on Adjusting the Classification Standards of City Size issued by The State Council of the People's Republic of China, the city was divided into four categories according to the population: super-large, Type I large cities, Type II large cities, and small-medium-sized cities. Third, according to the National Sustainable Development Plan for Resource-Based Cities (2013–2020) issued by The State Council of the People's Republic of China, the cities were divided into resource-based and non-resource-based cities. The results of the heterogeneity regression are shown in Table 14.

Table 14. Results of heterogeneity regression.

Variable	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)	Model (7)	Model (8)
	East	**Midwest**	**Super-Large**	**Type I**	**Type II**	**Small-Medium**	**Resource**	**Non-Resource**
de	0.666 *** (21.31)	0.436 *** (21.99)	0.546 *** (18.23)	0.741 *** (8.69)	0.321 *** (4.28)	0.297 (0.50)	0.215 *** (3.62)	0.527 *** (24.96)
ed	0.008 *** (10.68)	0.010 *** (25.08)	0.010 *** (11.79)	0.007 *** (10.22)	0.008 *** (16.08)	0.004 ** (2.31)	0.007 *** (17.20)	0.011 *** (18.14)
st	0.011 *** (6.98)	0.009 *** (9.90)	0.009 *** (4.91)	0.015 *** (12.56)	0.010 *** (8.01)	0.002 (0.41)	0.006 *** (5.05)	0.009 *** (7.60)
ic	0.003 *** (8.29)	0.001 *** (3.71)	0.003 *** (8.61)	0.001 (0.31)	0.001 *** (4.72)	0.002 (0.27)	0.001 *** (3.28)	0.002 *** (9.28)
pd	0.012 *** (3.40)	0.004 ** (2.48)	0.016 *** (2.85)	−0.003 (−1.27)	0.006 *** (2.78)	0.002 (0.12)	−0.003 * (−1.94)	0.012 *** (4.98)
ur	0.001 *** (8.67)	0.003 *** (26.08)	0.002 *** (11.74)	0.003 *** (17.34)	0.003 *** (13.61)	0.002 (0.58)	0.003 *** (19.74)	0.003 *** (16.49)
Constant	−0.087 *** (−3.301)	−0.012 (−1.42)	−0.075 * (−1.84)	0.021 (1.56)	−0.027 ** (−2.38)	0.053 (0.58)	0.030 *** (2.98)	−0.049 ** (−2.39)
Year fe	YES	YES	YES	YES	YES	YES	YES	YES
Area fe	YES	YES	YES	YES	YES	YES	YES	YES
R^2	0.894	0.818	0.916	0.836	0.744	0.859	0.719	0.897
obs	783	1737	801	720	909	90	1008	1512

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$; t values in parentheses.

The results in Models (1) and (2) of Table 14 show that, from the perspective of regional differences, the development of the digital economy in the eastern region ($\alpha = 0.666$, $p < 0.01$) had a stronger promotional effect on the sustainable development of cities in the central and western regions ($\alpha = 0.436$, $p < 0.01$). It indicates that the size of the digital dividend is closely related to regional development. Obviously, the development of the digital economy in regions with better economic development foundations are also more capable of driving local sustainable development. Models (3) to (6) show that the digital economy can only promote sustainable urban development processes above a certain scale. This may be because it is only when the urban population, economy and digital infrastructure have accumulated to a certain extent that the digital economy is able to prosper. Therefore, when the city is small, the development of the digital economy hardly promotes sustainable development by supporting the development of the primary and secondary industries. It can be seen from the results for Models (7) and (8) that, compared to resource-based cities, the digital economy plays a more vital role in promoting the sustainable development of non-resource-based cities. The possible reason is that resource-based cities have a higher dependence on resources, whereas non-resource-based cities rely on production factors such as talent, capital and technology to meet the needs of the development of the digital economy. For non-resource-based cities, the digital elements in the digital economy can more effectively break the barriers of the integration of the digital economy and the real economy, release the digital dividend, and create good conditions for sustainable development.

5. Conclusions and Suggestions

Based on theoretical analysis, this study used the panel data of 280 prefecture-level cities from 2011 to 2019 to construct a measurement index of sustainable urban development. We combined multiple econometric methods to empirically test the influence of the digital economy on sustainable urban development and its influence mechanisms in multiple dimensions. The conclusions are as follows. First, as a new economic form, the development of the digital economy effectively promoted the level of sustainable urban development. Even after a series of robustness tests, the conclusion is still robust. Second, improving the level of green technology innovation and promoting the upgrading of industrial structures are the two influence mechanisms that the digital economy can use to positively accelerate sustainable urban development. Third, considering the spatial factors, the development of the digital economy is not only an important boost to the sustainable development of local cities, but it also effectively promotes the sustainable development processes of the surrounding areas. In other words, the development of the digital economy has an obvious positive spillover effect. Fourth, the heterogeneity analysis shows that the promotional effect of the digital economy on sustainable urban development is more prominent in the eastern region and in large, non-resource-based cities.

According to the above conclusions, the following suggestions are put forward. First, the government should strengthen the construction of digital infrastructure and comprehensively promote the development of the digital economy to accelerate sustainable urban development. In addition, enterprises should actively introduce digital-related technologies to accelerate the process of digital transformation and give full play to the sustainable development effect of the digital economy in energy conservation, emission reduction and economic growth. Second, the development of the digital economy needs to implement a differentiated and dynamic strategy. Given the development status of different regions and cities, the phenomenon of blindly pushing forward the development policies of the digital economy should be avoided. Each city should implement the development policies of the digital economy according to its development and fully release the driving role of the digital economy for sustainable urban development. Third, importance should be given to the position green technology innovation and industrial structure upgrading in the digital economy in promoting sustainable urban development, actively responding to the development of government regional integration and eliminating the digital economic divide. Due to the positive spatial spillover effect of the digital economy on sustainable urban development, the radiation effect of the digital economy on neighboring areas should be actively brought into play to accelerate regional integrated development and sustainable urban development.

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