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How Can the Digital Economy and Human Capital Improve City Sustainability

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Abstract: With the advent of the digital age and urbanization in China, the digital economy (DE) has gradually become a new engine for city sustainability (SUS). DE and SUS rely on human capital (HC) accumulation and development. It is necessary to study the linear and non-linear impact of DE on SUS, and the moderating effect of HC on the relationship between DE and SUS. The data of 278 prefecture-level cities from 2011 to 2019 were collected. The fixed-effect model and panel threshold regression model were adopted. The results show that DE can significantly promote SUS, and there is a single threshold of HC. In areas with a low level of HC, DE significantly inhibits SUS, and in areas with a high level of HC, DE particularly promotes SUS. There is a regional heterogeneity about the role of DE on SUS. The innovation is that DE, HC, and SUS are first brought into the same research framework. Furthermore, the impact of specific stages of HC development on the relationship between DE and SUS was quantitatively investigated.

Keywords: digital economy; human capital; city sustainability; fixed-effect model; panel threshold regression model

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1. Introduction

Leading technological progress such as the Internet, big data, and artificial intelligence (AI) technologies accelerates the rapid development of the digital economy (DE). From an international perspective, the United States and China account for 90% of the market value of the world's 70 most significant digital platforms. From a domestic perspective, China's Digital Economy Development Report (2022) notes that China's DE will reach 45.5 trillion yuan in 2021. The nominal year-on-year growth rate was 16.2%, 3.4 percentage points higher than the nominal GDP growth rate in the same period, accounting for 39.8% of GDP. DE has become the most active field in China's economic development. DE adjusts the structural contradictions between the supply and demand side. DE stimulates investment in urban infrastructure construction. Therefore, DE has a profound impact on city sustainability (SUS). How to effectively release the boosting power of DE to SUS has become an essential topic of academic research in recent years. What is the mechanism behind it? Thinking about these questions is also the study motivation.

The role of DE in promoting China's economic development is reflected in three aspects. First, as a new resource factor, digital elements can improve the total factor productivity through the combination with other production factors, and then promote the development of the social economy. Second, sustainable development is a dynamic, open, and complex system. It involves three subsystems of nature, economy, and society. Connotation of sustainability includes long-term social development, high-quality economic growth, and suitable environmental sustainability. Digital development, with DE as a typical feature, as an important influencing factor, plays an increasingly apparent role in sustainable economic development. SUS relies heavily on industry structure. New high value-added industries are created by DE, and traditional industries are digitized. Third, enterprises could use

technical means to improve production efficiency and reduce the waste of resources. The aim is to provide products to meet social needs and realize the adjustment of the supply side.

Existing literature provides views of DE on environmental pollution [1], low-carbon development [2], and circular development [3]. However, the mechanism of DE in promoting SUS has a research gap. We are exploring the path of China DE in promoting SUS based on relevant theories and China reality. This also provides the opportunity for the marginal contribution in this paper.

Human capital (HC) is the internal driving force of economic growth. HC promotes old growth drivers of SUS to new ones and helps the industry upgrade. In the past, the rapid development of Chinese cities has relied on an abundant labor force. However, now China's aging process is accelerating. The labor population is showing a negative growth trend. Economic growth is relatively weak. City development is increasingly dependent on the quality of the labor force. DE typically characterizes the digital development. Information technology helps upgrade traditional industries. Information technology changes conventional production methods in an all-round way. Information technology significantly improves labor productivity and social performance. HC provides the necessary labor for the sustainability of both the economy and society. The educational level of China's overall labor force is gradually improving. However, there is still massive room for upgrading HC. China's high-quality HC is in shortage. The labor population continuously declines. It is urgent to improve the advanced level of the HC structure to form a long-term driving force. DE is booming and HC is aging. It is of practical significance to select HC as the research object, which is also an innovation of this paper. We tried to explore how DE promotes SUS based on a complete framework. In addition, we selected Chinese cities as the research object, which can conduct more detailed research on DE, HC, and SUS.

We adopted a fixed-effect model and a panel threshold regression model to explore relationships between DE, HC, and SUS at the city level. The aim is to provide empirical support for sustainability theories in the digital age. Specifically, this paper constructs a theoretical analysis framework with HC as the threshold. From 2011 to 2019, 278 cities were selected as samples. A variety of measurement methods were used. The research results show that the DE significantly promotes SUS. HC is a vital threshold variable. Below the threshold value, DE suppresses SUS. Above the threshold value, DE elevates SUS. Regional heterogeneity exists in the effect of DE on SUS.

The possible marginal contribution of this paper lies in two aspects. First, drawing on the existing literature, this paper conducts a more comprehensive study on DE and SUS at the urban level. Second, the effect of DE on SUS is discussed from an HC perspective. This paper discusses the threshold role of HC in DE's promoting effect on SUS under a unified framework. This shows that the level of HC can affect promotion direction and level of DE. Therefore, this paper helps to deepen the existing literature. Compared with other related papers, the innovation is that DE, HC, and SUS are put in a framework. Different levels of HC development on the relationship between the DE and SUS are quantitatively investigated.

2. Literature Review

The current research results of DE and SUS provide a valuable reference for studying the internal logic of both. However, the impact of DE on SUS and the mechanism of this impact are rarely studied at the city level. This paper aims to explore whether DE can promote SUS in Chinese cities, and to explore the internal mechanism from the perspective of HC. The relevant literature can be reviewed from the following aspects.

2.1. DE

"Digital economy" was proposed in the 1990s [4]. Initially, DE emphasizes effective technology utilization in social value creation. With the integration of DE and complex economic activities, the connotation of DE has been constantly completed [5–8]. The influence of DE has gradually attracted the attention of scholars. DE can connect different

production subjects and consumption subjects through the flow of data elements, thus affecting the coordinated development of various industries. From the micro point of view, the speed and transparency of digital information dissemination put higher requirements for the public reporting of enterprises [9]. The new education channels and models provide convenience for expanding employment channels and employment choices [10,11]. From the industrial perspective, AI applied to traditional agriculture can significantly improve agricultural efficiency and transfer to modern agriculture [12,13]. The investment and upgrading of urban digital infrastructure construction have promoted smart cities [14]. From a macro perspective, DE is a new tool for sustainable resource utilization in traditional resource-based countries [15]. The development of DE varies in different countries and regions and its degree of integration with society [16,17].

2.2. SUS

Research on sustainable development has gone through several stages in China. Society, economy, and natural environment are relatively independent subsystems. The three subsystems are related and restrict each other. Therefore, the three subsystems must be regarded as a complex composite system [18]. Subsequently, scholars began to study sustainable development from the definition and the construction of metrics. SUS is measured with the sustainability index. This index is formulated by United Nations. Scholars have explored the effectiveness of this index. Mori et al. [19] reviewed whether the current SUS index is adequate. And a new global index should be built to evaluate SUS better. Tanguay et al. [20] found existing problems in assessing SUS in cities. Random indexes selected and methods will bring out different outcomes. Various ways are adopted in measuring SUS. Newman [21] used the metabolism concept to demonstrate SUS. An objective coupling weighting method is used to evaluate nine central cities in China. Generally, economic sustainability is not good. Only one of nine cities performs well in economy, society, and natural sustainable development [22].

Detailed studies mainly focus on micro-factors that will influence SUS. A green infrastructure is a helpful tool for SUS [23]. Food, energy, and water are three material components in SUS. Technological innovation will help manage food, energy, and water, and therefore helps increase SUS level [24]. Public participation can push SUS by increasing residents' willingness to urban garbage classification [25].

With the deepening of research, the research on macro sustainability mainly aims at sustainable states in current China. Pan et al. [26] found that innovation, industry, energy, and economy subsystem have mutual effects on each other when analyzing the sustainable development subsystem. The sustainable development at the macro level focuses on countries and cities. Zeng et al. [27] took the mega-city Beijing as an example to integrate population growth and natural resource composite sustainable development into the same framework. They concluded that policy intervention is an essential factor in sustainable development changes. Yang et al. [28] (2021) constructed a measure of urban resilience and evaluated the development of urban resilience from the two dimensions of time and space. Sustainable development at the micro level focuses on industries and enterprises. Zhao et al. [29] discussed the willingness of the government to decentralize power in the context of mixed ownership reform, which will help promote state-owned enterprises' sustainability. Niu et al. [30] proposed that entrepreneurship and management power can promote the sustainable development of enterprises.

2.3. DE and SUS

In the study field of DE promoting SUS, two viewpoints are summarized. First, from optimizing the factor allocation, the development of DE contains a vast new digital momentum. Zeng et al. [31] studied the process of China DE with factor endowment. Heterogeneity exists in digital economic sustainability across different regions. Based on the powerful link platform of the Internet, the diffusion and spillover of technological innovation can help achieve SUS. The practical ways are optimizing the traditional produc-

tion mode [32] and promoting the reallocation of traditional production factors. Digital technology accelerates innovation elements flow and upgrade. While digital infrastructure investment increases social costs [33], disruptive technologies improve the social benefit-cost ratio and transfer society into a new product life cycle [34]. DE can enhance innovation by improving economic openness, optimizing the industrial structure, and expanding the market potential [35]. Applications of cloud computing and AI can reduce the production losses of enterprises and improve energy efficiency [36] and total factor productivity [37]. Second, DE changes economic development mode. According to the emission accounting of carbon dioxide at the production side, digital infrastructure export trade enhances the intensity of ecological footprint. Digital infrastructure import trade reduces the intensity of ecological footprint [38]. DE creates more jobs, provides more vocational education opportunities, absorbs more jobs, and promotes the sustainable development of the labor force [39,40]. Connectivity and sharing are two primary characteristics of the Internet. They have four advantages. Firstly, the Internet can reduce the information processing cost of enterprises, enrich the traditional trading methods, and break the business boundary of enterprises. Secondly, the Internet can improve social production and consumption efficiency, and deepen the recycling of social material resources. Thirdly, the Internet can help the construction of smart cities by enabling a circular economy [41–43]. Fourthly, the Internet can optimize the traditional value chain, consolidate the digital supply chain [44–46], and reduce the risk of supply chain interruption [47].

2.4. DE and SUS in the View of HC

Scholars have explored the role of HC in sustainable development. Pan et al. [48] studied the role of HC advancement on sustainable economic growth in China, revealing that industrial upgrading is an essential path for HC to promote sustainable economic growth in China. Wang et al. [49] studied the impact of HC on regional sustainable development. Some scholars have explored the relationship between HC and sustainable development from different industries. Zhang [50] studied the role of agricultural HC in promoting sustainable agricultural development. Cheng [51] studied the promotion effect of tourism HC on sustainable tourism development. Shimamura et al. [52] used an integrated prediction simulation model including production, human, and natural capital to evaluate the sustainability of capital city relocation. Relocation will result in income decrease and production capital depreciation. Therefore, educational and healthy human capital receives adverse shocks, resulting in unsustainable investment. In the era when DE is a new driving force for economic growth, a relationship between DE and SUS is inevitable to be explored. Since DE is inseparable from labor support, SUS also requires labor. Learning how HC affects the relationship between DE and SUS is unavoidable.

Existing literature provides a broad idea and solid theoretical foundation for the study of this paper. It is mainly summarized as follows. First, the research on the concept of DE and the improvement of the DE index system is thorough. Second, the influence of DE on the economy, environment, and social subsystems is relatively rich, including the impact on specific industries, education, and employment. The following literature gaps exist in the existing studies. Firstly, the heterogeneous research of DE on SUS mainly focuses on the national or regional level, and less on the city level. Secondly, the mechanism research between DE and SUS is not deep enough. DE and SUS are inseparable from the labor force. The mechanism research from the HC perspective is lacking. The possible marginal contribution is twofold. First, drawing on the existing literature, this paper conducts a more comprehensive study on the DE and SUS from the urban level. Second, the effect of DE on SUS is discussed from the threshold perspective of HC.

3. Hypotheses

3.1. The Mechanism of DE on SUS

SUS involves innovation and economic-social performance. DE is an integrated economy. DE has become a new engine of SUS. The mechanisms for the DE to increase the

city's sustainable development can be divided into two channels. The first one is that DE can enhance the innovation capability of cities. The second one is that DE can improve the development efficiency of cities.

The DE can enhance a city's innovation ability. Four possible ways are city's innovation platform, innovation environment, innovation subject, and innovation path. Under the condition of DE, the new technology paradigm promotes the innovation paradigm. The essence of DE is innovation. The essential characteristics of DE, such as disruptive innovation and optimized resource allocation, effectively break the contradiction of inefficient allocation of factors in the process of SUS [53]. Cyberspace can map the relationship between things and things, people and people. Cyberspace creates conditions for the creation, transfer, and application of various innovative elements (especially the service elements based on data, information, and knowledge). Intensive knowledge creation and extensive empowerment are reshaping the economic structure and promoting the reform of the way of innovative resource allocation [54]. Firstly, the improvement of digital infrastructure, the rise of Internet penetration, and universal digital inclusive finance can provide necessary infrastructure support for urban innovation. Under the condition of DE, with the mutual support and development of edge computing and cloud computing, cyberspace is more integrated into economic activities. The digital platform provides a channel for the development of industry and commerce. This can broaden business communication channels and expand the supply chain of industrial enterprises. Secondly, to attract high-tech and low-polluting enterprises, local governments have created a good business environment. E-commerce is encouraged. A favorable business environment actively promotes the revitalization of digitally empowered rural areas and the development of digitally empowered manufacturing industries under the competition of local governments that seized the fashion driving force for economic sustainability, digital empowerment of service industry development. Thirdly, DE has boosted a substantial increase in Internet users. Compared with labor and capital-intensive industries in the past, digital initiatives highlight the educational quality of workers, thereby increasing HC level. Innovation activities result from multiple innovation subjects and their interconnection and interaction with the environment. Data factors optimize apportion between traditional production elements with knowledge and technology. Digital technology also promotes the generation of new business models. New business models promote the development of new industries, thus producing a multiplier effect on the economy and society [35]. Finally, the path to encourage innovation promotion is embodied in three aspects: original innovation increase, the rapid transformation of innovative achievements, and collaborative innovation in multiple fields.

DE can improve the efficiency of urban development. City dwellers pursue environmental protection and high-quality sustainable development. DE reduces city environmental pollution and brings high value-added returns to urban economic development [55]. In addition, employment is the foundation of SUS. The development of cities is inseparable from the support of employment. The Internet improves the labor mobility [56], labor productivity, and the level of innovation [6]. DE can reduce production costs [57] and improve labor productivity [7,58,59], thus promoting SUS. SUS not only refers to the accumulation of GDP, but also the production efficiency. The diversified integration, open sharing of DE, and decentralization of the organization can deeply integrate with production factors, achieving cross-border production [60]. Under the general rule of diminishing marginal returns in traditional elements, DE can improve productivity [61]. The path to promote economic efficiency is summarized as three views. First, information flows quickly on the value chain. Informed decision-making is more scientific and forward-looking with the help of digital technology. Second, market participants are more active in the era of DE. The efficiency of market resource allocation is improved. Third, the flow of factors is more convenient. Data factors are deeply integrated with various industries, promoting traditional industries transfer to automatic ones [37]. Total factor productivity is elevated.

Hypothesis 1. *DE will promote SUS through enhancing innovation and increasing economic-social performance.*

3.2. Threshold Effect of HC

The development of DE brings about changes in the relations of production, economic structure, and education, which affects HC to SUS [62].

Firstly, HC can promote the SUS. This promotion effect is mainly manifested in three aspects. First, innovation enables SUS. HC can absorb and transfer advanced technologies, thus fostering innovation [63]. Innovation is an inexhaustible source of SUS. High-level HC contributes the most to the technological innovation capacity [63]. Second, labor productivity boosts SUS. The labor force management model affects labor productivity [64]. Labor quality and HC drive up the labor productivity levels by expanding the production possibility curve [65]. The labor productivity of low-level HC is low, and its effect on economic growth is not apparent or even damaging [66]. Third, economic growth promotes SUS. According to the human capital theory, the labor force can improve labor productivity and increase the marginal income of capital, thus promoting economic development [67]. HC has higher returns than material capital. Therefore, increasing HC investment can promote economic growth [68]. High-level HC is more potent for the economic growth [69,70].

Secondly, the level of HC can enhance the role of DE in promoting SUS. The structure and function of the labor force are changing during digital development. First, DE is changing labor force from quantitative style to quality style. This reflects the requirements of sustainable development. DE can provide more HC [71]. DE accelerates the replacement of low-level human resources by automation technology. New jobs will be created, including senior jobs, flexible unskilled jobs, and low-level jobs [72]. Information and communication technology is developing, and digital infrastructure is being upgraded. Traditional job opportunities are lessened in this process. These new conditions have higher requirements for HC. A lot of high-quality labor force enters into the market. DE has accelerated marginal labor productivity. Internet popularity helps promote labor education level and upgrade worker skills. This will help unlock innovation and promote SUS [73–76]. Manifestations are concluded as the following three aspects. First, industrial digitalization and digital industrialization requires the labor force to have considerable skills and knowledge [77]. The easy accessibility of the Internet education platform provides a large number of educational resources for the labor force. The labor force uses Internet technology to improve general work skills and special work skills to improve the level of HC [78]. Second, DE has greatly liberated the productive forces and promoted high-tech industries characterized by innovation. DE has been shutting down traditional outdated labor-intensive industries and the low-skilled labor force, but it also provides more jobs for the innovation workforce in emerging sectors [79–82]. Third, inclusive digital finance and digital infrastructure incredibly reduce the stickiness of the flow of factors. Workers who need digital technology training can improve their work skills through Internet loans.

Endogenous growth theory emphasizes labor input and material accumulation are core elements for economic growth. Advanced HC can become a critical carrier of the DE. DE upgrades the industrial digital transformation. The accumulation of digital elements helps realize industrial structure upgrades by integrating labor and other capital elements. Due to the heterogeneity of developing endowments around China, HC presents different characteristics. Where HC is high-quality, the labor resources are also rich. DE is more conducive to promote sustainable development. When HC reaches a certain advanced level, the effect of the DE on sustainability changes. There exists a threshold effect at this time.

Hypothesis 2. *HC has a positive moderating effect on the relationship between DE and SUS.*

4. Methodology and Data

4.1. Methodology

In order to test Hypothesis 1, The specific model settings are as follows:

$$SUS_{it} = \alpha_1 DE_{it} + \alpha_2 HC_{it} + \alpha X_{it} + \mu_i + \varepsilon_{it} \quad (1)$$

where i represents city, t is for year, SUS is for city sustainability, DE is the digital economy, and HC is human capital. X is the control variable matrix, including economic development level, industrial structure, trade openness, urbanization level, and highway density. α represents the regression coefficient, μ is for the fixed effect of city i, and ε is the residual term. Limited to the period of the research object, only the individual effect is controlled, and the time effect is not controlled.

The economic rule between DE and SUS may be nonlinear, and its functional form may depend on the level of HC. In order to test Hypothesis 2, a rigorous statistical threshold regression is used to estimate parameters and hypotheses [83]. For the panel data $\{SUS_{it}, DE_{it}, HC_{it}: 1 \leq i \leq n, 1 \leq t \leq T\}$, where i represents city, and t represents year. In order to avoid the deviation of the subjective division interval, panel threshold model [84] helps clarify the heterogeneous influence of the DE on SUS at different HC levels. The basic equation is set as follows:

$$SUS_{it} = \alpha_1 DE_{it} \times I(HC_{it} \leq \gamma) + \alpha_2 DE_{it} \times I(HC_{it} > \gamma) + \alpha X_{it} + \mu_i + \varepsilon_{it} \quad (2)$$

Among them, HC is a threshold variable. γ represents threshold value. $I(\cdot)$ is Indicator Function. When the condition is true, 1 is chosen, 0 is chosen otherwise.

The following steps are taken to eliminate individual effect μ and obtain the parameter estimate. First, for city i, both sides of Equation (2) are averaged over time:

$$\overline{SUS}_i = \alpha_1 \overline{DE}_i \times I(HC_{it} \leq \gamma) + \alpha_2 \overline{DE}_i \times I(HC_{it} \geq \gamma) + \alpha \overline{X}_i + \mu_i + \overline{\varepsilon}_i \quad (3)$$

In Equation (3), $\overline{SUS}_i \equiv \frac{1}{T}\sum_{t=1}^{T} SUS_{it}$, $\overline{DE}_i \equiv \frac{1}{T}\sum_{t=1}^{T} DE_{it}$, $\overline{X}_i \equiv \frac{1}{T}\sum_{t=1}^{T} X_{it}$, $\overline{\varepsilon}_i \equiv \frac{1}{T}\sum_{t=1}^{T} \varepsilon_{it}$. Equation (2) less Equation (3) equals Equation (4):

$$SUS^*{}_{it} = \alpha_1 DE^*{}_{it} \times I(HC_{it} \leq \gamma) + \alpha_2 DE^*{}_{it} \times I(HC_{it} > \gamma) + \alpha X^*{}_{it} + \varepsilon^*{}_{it} \quad (4)$$

In Equation (4), $SUS^*{}_{it} \equiv SUS_{it} - \overline{SUS}_i$, $DE^*{}_{it} \equiv DE_{it} - \overline{DE}_i$, $X^*{}_{it} \equiv X_{it} - \overline{X}_i$, $\varepsilon^*{}_{it} \equiv \varepsilon_{it} - \overline{\varepsilon}_i$.

The panel threshold model is generally estimated by the two-stage least squares method. For a given threshold value of γ, the parameter estimate $\hat{\alpha}(\gamma)$, and the corresponding residual squared sum $SSR(\gamma)$ can be valued. The threshold estimates can be obtained by minimizing $SSR(\gamma)$:

$$\hat{\gamma} = \text{argmin} SSR(\gamma) \quad (5)$$

Is there a threshold effect of HC? The initial hypothesis is $H0$: $\alpha 1 = \alpha 2$, which means there is no threshold effect. According to the likelihood ratio principle, statistics F can be constructed as:

$$F = [SSR^* - SSR(\hat{\gamma})]/\sigma^2{}_{\varepsilon} \quad (6)$$

If the null hypothesis is rejected, a threshold effect exists, which can be further tested for γ. The second initial hypothesis is $H0$: $\gamma = \gamma 0$. Statistics $LR(\gamma)$ can be constructed as:

$$LR(\gamma) = [SSR(\gamma) - SSR(\hat{\gamma})]/\sigma^2{}_{\varepsilon} \quad (7)$$

The confidence interval of γ can be computed. If the significant level is θ, the initial hypothesis should be rejected when $LR(\gamma) > -2\ln(1 - \sqrt{1 - \theta})$.

4.2. Data Sources

Explained variable: city sustainability (SUS). According to the definition of sustainable development, sustainable development includes social, economic, and environmental sustainability. We mainly discuss how DE pushes city sustainable development in China. Therefore, this paper focuses more on the role of city society and economy. Economic and social sustainability are used as the measurement scope of sustainable development. Referring to Shao et al. [85], a sustainable development evaluation system is constructed, as shown in Table 1. Referring to Zhu et al. [86], the linear extreme value standardization method is used to carry out dimensionless processing of sustainable development indicators. The arithmetic average equal weight method is adopted to measure the indicators.

Table 1. SUS assessment system.

Sub-Index	Assessment Indicators	Indicator Properties
Innovation-driven level	Research and experimental development (R&D expenditure to GDP)	positive
	Invention patents per 10,000 people	positive
	Contribution rate of scientific and technological progress	positive
Economic-social performance	total labor productivity	positive
	Annual growth rate of regional GDP	positive

Explanatory variables: digital economy (DE). Refer to Zhao et al. [53] to build a DE evaluation system, as shown in Table 2. In the specific index construction process, principal component analysis is used in standardizing data of five indicators and then reduce the dimension.

Table 2. DE evaluation system.

Sub-Index	Assessment Indicators	Variable Unit	Indicator Properties
Internet penetration	Internet users per 100 people	Household/100 person	positive
Number of Internet-related employees	Proportion of employees in computer services and software	%	positive
Internet related output	Total telecom services per capita	yuan/person	positive
Number of mobile internet users	Number of mobile phone users per 100 people	Department/100 person	positive
Digital financial inclusion development	China Digital Financial Inclusion Index	index	positive

Human capital (HC). The measurement of HC usually includes the income output method and the education input method, which are measured from the perspective of labor output and input, respectively. From the perspective of input cost, there is a problem in that the sunk cost of education input is difficult to separate. Therefore, this paper uses the vector angle method to measure advanced HC from income and output perspectives [72]. First, human labors are divided into five categories based on education level. The proportion of the city's patent authorizations to the national patent authorizations is used as the weight. This weight is multiplied by the provincial-level intellectual human capital structure advanced index to obtain the city's intellectual human capital structure advanced index. Multiplying this advanced index by training rate (number of undergraduate students in cities to all employment) aims to obtain the final, human capital structure advanced index.

Control variables: The economic and social sustainable development of a city will be affected by economic growth level, industrial structure, trade opening degree, urbanization, and infrastructure construction. The economic development level (PER), the industrial struc-

ture (STR), trade openness (FDI), urbanization level (urban), and highway density (DEN) are collected as control variables. Definitions and descriptions are presented in Table 3.

Table 3. Variable definition and description.

Variable Type	Variable Name	Variable Symbol	Variable Description	Variable Unit
Explained variable	city sustainability	SUS	index system construction	index
Explanatory variables	digital economy	DE	index system construction	index
threshold variable	human capital	HC	Advanced human capital	index
control variable	economic development level	PER	GDP per capita	yuan/person
	Industrial structure	STR	The added value of the tertiary industry as proportion of GDP	%
	trade openness	FDI	The proportion of total imports and exports to GDP	%
	urbanization level	URBAN	Urban population as a percentage of total population	%
	highway density	DEN	The total number of road miles per square kilometer	kilometer/square kilometer

Due to data accessibility, finally, 278 Chinese cities from 2011 to 2019 were selected. Missing data were processed with interpolation. Data were collected from China Urban Statistics Bureau, the China Urban Statistical Bulletin, the China Economic Net Industry Database, the China Science and Technology Statistical Yearbook, the China Statistical Yearbook, and the China Urban Statistical Yearbook.

5. Empirical Results and Analysis

5.1. Descriptive Statistics

Results are presented in Table 4. Minimum, maximum, mean, and standard deviation values of DE are respectively 0.3306, 363.3917, 9.9086, and 20.3143. DE varies significantly between different cities. Minimum, maximum, standard deviation, and mean values of HC advancement are 0.0002, 71.9486, 8.0564, and 3.8350, respectively. There exists a big difference of HC advancement in different cities. Minimum, maximum, mean and standard deviation values of SUS are 0.0485, 0.7454, 0.3329, and 0.1003, respectively. The difference between SUS is small. Minimum, maximum, mean, and standard deviation values of PER are 6.4570, 467.7490, 52.5133, and 34.2621, respectively. The PER of different cities varies greatly. Minimum, maximum, mean, and standard deviation values of the STR are 10.1500, 83.5200, 41.2070, and 10.0429. The STR of different cities varies greatly. Minimum, maximum, mean, and standard deviation values of FDI are 0, 249.1304, 17.8079, and 29.1177. FDI in different cities varies greatly. Minimum, maximum, mean, and standard deviation values of DEN are 0.0680, 2.6279, 1.0749, and 0.4982, respectively. The difference of DEN in different cities is small. Minimum, maximum, mean, and standard deviation values of the URBAN are 21.4, 100, 55.3203, and 14.6446, respectively. The URBAN of different cities varies greatly. In a word, significant differences in DE, HC, STR, PER, and URBAN between different cities.

Table 4. Descriptive statistics results.

Variable	*N*	Mean Value	Standard Deviation	Minimum Value	Maximum Value
DE	2502	9.9086	20.3143	0.3306	363.3917
HC	2502	3.8350	8.0564	0.0002	71.9486
SUS	2502	0.3329	0.1003	0.0485	0.7454
STR	2502	41.2070	10.0429	10.1500	83.5200
PER	2502	52.5133	34.2621	6.4570	467.7490
FDI	2502	17.8079	29.1177	0.0000	249.1304
DEN	2502	1.0749	0.4982	0.0680	2.6279
URBAN	2502	55.3203	14.6446	21.4000	100.0000

5.2. Correlation Analysis

Pearson correlation analysis is conducted. Correlation results between the main variables are presented in Table 5. At a 1% significant level, a positive correlation relationship between the DE and SUS. This preliminarily shows that DE can promote the SUS. In this paper, the variance inflation factor analysis indicates that all VIF coefficients are lower than 10. There was no severe multicollinearity among variables.

Table 5. Pearson correlation coefficient matrix.

	SUS	DE	HC	STR	PER	FDI	DEN	URBAN
SUS	1							
DE	0.222 ***	1						
HC	0.246 ***	0.881 ***	1					
STR	0.283 ***	0.456 ***	0.445 ***	1				
PER	0.398 ***	0.417 ***	0.545 ***	0.317 ***	1			
FDI	0.188 ***	0.440 ***	0.511 ***	0.268 ***	0.476 ***	1		
DEN	0.171 ***	0.188 ***	0.216 ***	0.041 **	0.127 ***	0.135 ***	1	
URBAN	0.267 ***	0.401 ***	0.515 ***	0.410 ***	0.735 ***	0.460 ***	0.082 ***	1

Note: **, and *** represent the significance levels of 5%, and 1%, respectively.

5.3. Benchmark Regression

Before the empirical estimation, to avoid pseudo regression, all variables were subjected to the panel unit root test using the Fisher test method, and the test results showed that the variables were stable sequences.

Outcomes from basic benchmark regression are displayed in Table 6. According to the hypothesis, stepwise regression is performed on model (1). Explanatory variables are added step by step. DE obviously positively promotes SUS. After adding control variables, the result still remains the same. HC also positively promotes SUS. Assumption 1 is proved.

5.4. Threshold Regression

Panel threshold regression can explain whether HC can affect the role of DE on SUS. More importantly, to what extent can HC reach? Therefore, a panel regression model was selected to test relationships between DE, HC, and SUS. To reflect the impact of DE on SUS depending on the HC value range, firstly, the threshold number of HC was tested, and both triple and double thresholds were eliminated. A single threshold model was selected. Referring to Tang [87], the Bootstrap self-sampling method was used. The single threshold value of HC is 0.7257 after repeated sampling 300 times, and the confidence interval of the 95% level is [0.7097, 0.7431]. In column (1) of Table 7, when HC is less than 0.7257, DE has a significant negative correlation with SUS. It shows that DE in low HC advanced areas will hinder the sustainable process of cities to a certain extent. The workers' education level in low-level HC areas is relatively insufficient. Labor capital cannot better match digital elements. This is not conducive to city innovation and labor productivity. When HC exceeds 0.7257, DE has a significant positive correlation with SUS. Development of DE

in high HC areas can significantly promote SUS. A possible reason is that areas with high HC are rich in labor capital. This can meet the talents needed for the development of DE at different levels, thus contributing to SUS.

Table 6. Benchmark regression.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	SUS	SUS	SUS	SUS	SUS	SUS	SUS
DE	0.0021 ***	0.0019 ***	0.0008 ***	0.0004 **	0.0002	0.0002	0.0004 **
	(0.002)	(0.004)	(0.006)	(0.023)	(0.215)	(0.209)	(0.087)
HC		0.0108 ***	0.1512 ***	0.0092 ***	0.0085 ***	0.0085 ***	0.0080 ***
		(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)
STR			0.0058 ***	0.0046 ***	0.0045 ***	0.0045 ***	0.0023 ***
			(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
PER				0.0014 ***	0.0013 ***	0.0013 ***	0.0009 ***
				(0.000)	(0.000)	(0.000)	(0.001)
FDI					−0.0005 **	−0.0005 **	−0.0006 **
					(0.048)	(0.049)	(0.025)
DEN						0.0097	−0.0416 **
						(0.564)	(0.019)
URBAN							0.0064 ***
							(0.000)
_cons	0.3119 ***	0.2726 ***	0.0290	0.3394 **	0.0505 ***	0.4336 **	−0.1454 ***
	(0.000)	(0.000)	(0.120)	(0.027)	(0.004)	(0.033)	(0.000)
time fixed effects	N	N	N	N	N	N	N
individual fixed effects	Y	Y	Y	Y	Y	Y	Y
Observations	2502	2502	2502	2502	2502	2502	2502
R^2	0.1365	0.1856	0.1828	0.2651	0.2498	0.2570	0.1918

Note: *p* values in parentheses, **, and *** represent the significance levels of 5%, and 1%, respectively.

Table 7. Panel threshold regression results.

	(1)	(2)	(3)	(4)	(5)
	SUS	EAST	MIDDLE	WEST	NORTHEAST
DE(HC < 0.7257)	−0.0082 ***	−0.0088 ***	−0.0063 ***	−0.0219 **	−0.0155 ***
	(0.000)	(0.000)	(0.004)	(0.023)	(0.000)
DE(HC > 0.7257)	0.0006 ***	0.0003	0.0009	0.0002	0.0058 ***
	(0.006)	(0.225)	(0.488)	(0.550)	(0.000)
STR	0.0023 ***	0.0033 ***	0.0040 ***	0.0014 **	0.0026 ***
	(0.000)	(0.002)	(0.000)	(0.024)	(0.005)
PER	0.0010 ***	0.0005 **	0.0019 ***	0.0012 ***	0.0013 **
	(0.001)	(0.012)	(0.002)	(0.000)	(0.040)
FDI	−0.0006 **	−0.0012 ***	−0.0030 ***	0.0005 *	−0.0002
	(0.026)	(0.000)	(0.000)	(0.074)	(0.954)
DEN	−0.0387 **	−0.0253	−0.0793 ***	−0.0157	−0.2526
	(0.026)	(0.291)	(0.001)	(0.690)	(0.100)
URBAN	0.0067 ***	0.0083 ***	0.0047 ***	0.0056 ***	0.0017
	(0.000)	(0.000)	(0.007)	(0.000)	(0.199)
_cons	−0.0082 ***	−0.2585 ***	−0.0135	−0.0520	0.1482
	(0.000)	(0.000)	(0.817)	(0.145)	(0.136)
Observations	2502	801	666	738	297
R^2	0.2362	0.3191	0.3616	0.1756	0.1168

Note: *p* values in parentheses, *, **, and *** represent the significance levels of 10%, 5%, and 1%, respectively.

5.5. Heterogeneity Test

Different regions of China have different developing levels. Geographic heterogeneity was analyzed between DE, HC, and SUS. The results are shown in Table 7 (2)–(5). According to the regional division standard of the Chinese National Bureau of Statistics, the sample cities were divided into eastern, central, western and northeast regions (Appendix A). It can be seen from columns (2) to (4). When HC is less than 0.7257, DE in eastern, central, and western regions significantly negatively correlates with SUS. It shows DE in low HC advanced areas among eastern, central, and western will hinder the sustainable process of cities to a certain extent. The reason is that the labor education degree in areas with low HC is relatively low. Labor capital cannot better match digital elements, which is not conducive to urban innovation and labor productivity. When HC exceeds 0.7257, DE in eastern, central, and western is positively correlated to SUS. It shows that DE in high HC advanced areas can promote SUS at a certain level. Because areas with high-level HC are rich in labor capital. This can meet the talents needed for the development of DE at different levels, thus contributing to the sustainable development in cities. It can be seen from column (5) that when HC is less than 0.7257, DE and SUS in the northeast area have a significant negative correlation. It shows that DE in the low-level HC areas in the northeast will hinder the sustainable process of the city to a certain extent. The education level of workers in low-level HC areas is relatively insufficient. Labor capital cannot better match digital elements, which is not conducive to urban innovation and labor productivity. When HC exceeds 0.7257, DE and SUS in the northeast region show a significant positive correlation. This reflects DE in high HC advanced areas can significantly promote SUS. A possible reason is that areas with high HC are rich in labor capital, which can meet the talents needed for the development of DE at different levels, thus contributing to SUS.

6. Discussion

This article mainly discusses how HC plays a single threshold role in the promotion relationship between DE and SUS.

6.1. Discussion on DE and SUS

Based on the literature review and theoretical assumptions, DE is a new form of economy. DE relies on rapid Internet development. Due to the differentiated resource endowment, industrial structure, and the low level of innovation, the sustainability of China's urban development is facing a bottleneck. DE promotes SUS from the following three aspects. First, digital products have high added value, and fast upgrading speed. Enterprises need a lot of R&D investment. Once scientific research is converted into profitable products, companies can reap rich returns. DE has spawned many emerging industries, such as 3D printing, blockchain, and AI. These industries are characterized by high investment and high returns. These emerging industries mainly emerge in the capital, technology, and labor-intensive cities. Therefore, the development of DE can promote SUS. Second, the labor force is the inner driver for SUS. DE has eliminated traditional low-skilled jobs and created high-value-added jobs. The Internet platform provides opportunities for workers to communicate and learn. This helps to improve labor skills and labor productivity. The integration of HC and material capital jointly promote SUS. The improvement of labor productivity enables the labor force to make efficient use of social capital, integrate the production factors, and create social output to promote SUS. Third, DE creates substantial economic benefits for cities. From the perspective of direct benefits, the economic benefits of high-tech industries are much higher than traditional industries, such as 5G technology and chip technology. From the perspective of indirect benefits, DE realizes the digitalization of traditional industries. For example, AI in agriculture can improve chemical fertilizer use efficiency and increase crop yield per unit area. DE significantly increases SUS. This result supports the first hypothesis.

6.2. Discussion on the Threshold of HC

The existing literature lacks exploration of the mechanism of DE to promote SUS from the perspective of HC. According to the definition of Cobb Douglas production function, the labor force is an economic driver. Due to the deepening of China's aging degree and the weakening of the demographic dividend, the upgrading of HC has become an essential focus of economic development. HC moderates the process of promoting SUS. First, in the era of DE, the opportunity for the labor force to receive education increases significantly, such as online classrooms. The rise of online video platforms will help workers learn professional knowledge, improve their professional skills, and promote labor productivity. Second, the digital industry breaks the restrictions of working state of the labor force. Workers in the digital sector are flexible in the choices of working locations and working hours. This promotes the flow of labor elements. The flow of labor factors is conducive to enhancing the optimal allocation between different factors of production, thus fostering innovation. Therefore, in high-level HC conditions, workers can efficiently use digital platforms, improve labor productivity, and achieve a higher level of innovation, thus promoting SUS. When HC is below 0.7257, DE significantly suppresses SUS. When HC is above 0.7257, DE significantly promotes SUS. In the case of a high-level HC, the empirical results verify hypothesis 2, but at a low-level HC, it is surprising that DE curbs SUS. This is an interesting result. This can be explained by the crowding-out effect of DE. DE has not only spawned many emerging industries and jobs, but also squeezed out some traditional industries and jobs. For example, workers are replaced by robots in the construction industry. Skills training for the workforce requires a learning cycle. The labor force is facing a rapid developing DE. When the level of HC is low, workers cannot quickly acquire new knowledge and skills. Traditional industries cannot quickly change their development strategies and operation modes. As a result, these backward low-skilled workers and traditional industries were eliminated. Some of these industries may be supporting industries for SUS. Thus, DE suppresses the phenomenon of SUS. However, with the improvement of the HC level, DE will ultimately promote SUS.

6.3. Discussion on Heterogeneity

The levels of DE, HC, and SUS vary between the eastern, northeastern, central, and western regions. The eastern region is developed, with vibrant DE, sufficient well-qualified workers, new-type urbanization, and strong innovation ability. The northeastern, central, and western regions are underdeveloped. Testing of the heterogeneity is necessary. The results of the heterogeneity test show that when HC is lower than 0.7257, DE can significantly inhibit SUS. The inhibitory effect ranged from large to small as west, northeast, east, and central. In the west, Sichuan province and Chongqing city are selected as examples. SUS is relatively high, and DE plays a significant supporting role. Therefore, when the level of HC is low, DE cannot be fully transformed into a driving force to support SUS. There exists a strong inhibitory effect. The development degree of DE in the central region is relatively low. However, SUS mainly relies on the secondary industry dominated by heavy industry. Therefore, SUS is less affected by DE in the central region. When HC is higher than 0.7257, DE plays a role in promoting SUS. The promoting effect is in the central, east, and west. In northeast China, when HC is above 0.7257, DE can significantly promote SUS. The northeastern area is a traditional heavy industry base and is in the process of transformation of economic development mode. The development level of DE in the northeast is relatively low. Due to the influence of incentive policy and digital economy strategy, SUS urgently needs to rely on DE. Therefore, DE has had a significant effect on promoting SUS. However, due to the loss of innovative talents, the existing labor force cannot fully transform the achievements of DE development into a driving force for SUS in the west.

The paper enriches the research of human capital theory from the perspective of the new economic momentum. Furthermore, HC level will affect the relationship between DE and SUS through improving economic growth, innovation, and factor productivity.

7. Conclusions and Implications

DE and the real economy are integrating. SUS is continuing to be facilitated by the development of the Internet. A certain level of HC is the key for DE in accelerating SUS. Using the fixed effect model and the threshold regression model, we empirically tested the relationship among DE, HC, and SUS of 278 cities from 2011 to 2019. Empirical results show DE significantly promotes SUS. The threshold effect model was adopted to effectively investigate HC plays a single threshold role between DE and SUS. The empirical results are as follows.

Firstly, stepwise regression is performed by adding explanatory variables step by step. DE positively promote SUS. This is the same as the conclusion of previous scholars [2,35]. After adding control variables, the result remains the same. HC also positively enables SUS. DE enables SUS from the following three aspects. First, DE has spawned many emerging industries with high investment and returns. These emerging industries are concentrated in the capital, technology, and labor-intensive cities. These emerging industries promote SUS through capital accumulation, technological progress, and labor productivity improvement. Second, the Internet provides opportunities for workers to communicate and learn online. The labor force makes more efficient use of social capital to promote SUS. Third, digital industrialization can not only make far higher economic benefits than traditional industries, but it can also empower traditional industries and digitize traditional sectors to promote SUS.

Secondly, a panel regression model was selected to test the impact of DE on SUS depends on the value range of HC. A single threshold model was selected. Using Bootstrap self-sampling, 300 repeated samples yielded a threshold value of 0.7257. When HC is below 0.7257, DE significantly inhibits the SUS. When HC is above 0.7257, DE significantly contributes to SUS. The labor force is facing a rapid developing DE. They cannot quickly acquire new knowledge and skills in a low-level HC condition. Traditional industries cannot quickly change their development strategies and operation modes. As a result, these backward low-skilled workers and traditional industries are eliminated. Some of these industries may be supporting initiatives for SUS. Thus, DE suppresses SUS. However, with the improvement of the HC level, DE will ultimately promote SUS. HC moderates in promoting SUS. First, the rise of online video platforms will help workers learn professional knowledge, improve their professional skills, and promote labor productivity. Second, DE enables workers enjoy flexible working locations and time. Thus, the flow of labor factors is enhanced. The allocation between different production factors is optimized to promote SUS.

Thirdly, heterogeneity test results show that in eastern, central, and western regions, when HC is lower than 0.7257, DE can significantly inhibit SUS. When HC is above 0.7257, DE promotes SUS. In northeast China, when HC is lower than 0.7257, DE can significantly inhibit SUS. When HC is higher than 0.7257, DE can significantly promote SUS. Heterogeneity between different areas depends on the existing development level of DE, quality of labor force, resource endowment, and local government-governing model. When HC is less than 0.7257, DE cannot be fully utilized by labor force in the west. Due to the restriction of fiscal revenue and economic increasing aim, local government pays more attention to traditional industries. DE cannot develop quickly and fails to become a strong driving force of SUS. Therefore, DE has a strong inhibitory effect. In the central area, the development degree of DE is relatively low, but SUS mainly relies on the secondary industry dominated by heavy industry. Therefore, SUS is less affected by DE and has a less inhibitory effect. When HC is more than 0.7257 in the northeast area, most cities are based on traditional heavy industries and are transforming economic development modes. Although DE is relatively low, due to governments' digital economy strategies, DE can be promoted actively and become a new SUS development force. However, in the western region, due to the loss of innovative talents, the existing labor force cannot fully transform the achievements of DE development into a driving force for SUS.

This paper integrates the labor force into the research framework. This paper complements the existing literature by creatively studying DE's promoting role in SUS from the HC viewpoint. HC plays an essential role in promoting DE and SUS. For the development of DE, the labor force has a dual role. Firstly, the labor force can be integrated with digital elements to improve the productivity of complex factors. Furthermore, this helps promote the integration of DE and the existing economic development mode. Secondly, the labor force uses digital technology to improve professional skills to provide the inexhaustible impetus for social innovation. As for SUS, DE drives the accumulation of urban production factors and industrial agglomeration. The integrated development of labor force agglomeration and industrial agglomeration jointly promote SUS. Due to the deepening of China's aging degree and the weakening of the demographic dividend, how to realize the upgrading of HC has become a problem that scholars need to consider. This is also the focus of future research on economic development.

Policy suggestions are introduced. As a development strategy and an economic driving force, DE requires local governments to grasp the opportunities in the digital age. First, local governments can stimulate the development of DE through fiscal and monetary policy means, such as tax cuts or financial subsidies to encourage DE industrial enterprises. Second, local governments can actively implement talent policies, use preferential policies to attract talent inflows, and empower the DE and SUS through talents. Third, labor training plays a huge role in the development of local DE. Local governments can provide labor training and encouraging school-enterprise cooperation to enable workers are suitable for digital industries.

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Appendix A

According to the regional division standard of the National Bureau of Statistics, the sample cities are divided into eastern regions (Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan), central regions (Shanxi, Anhui, Jiangxi, Henan, Hubei and Hunan provinces), the western region (inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang), and the northeast region (Liaoning, Jilin and Heilongjiang).

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