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Original Research

Are Smart Cities Smarter? The Impact of Smart City Policy on Digital Autonomy of Cities in China

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Abstract

Urban digital autonomy refers to the autonomous innovation capability of cities in the field of digital technology, which directly determines whether cities can achieve high-quality development in the urban digital economy. Using Chinese prefecture-level data from 2009 to 2018, this paper takes the smart city policy as a quasi-natural experiment to analyze the impact of the smart city policy on digital autonomy of cities empirically. The research results show that the smart city policy has significantly improved the digital autonomy of cities, which is 28.25% higher than that of other cities. After a series of robustness tests, such as the placebo test and propensity score matching DID (PSM-DID) test and using different samples, this research conclusion still holds. Heterogeneity shows that the promotion effect of the smart city policy on digital autonomy of cities is greater in eastern regions, cities with higher rank and larger population size. The research of influence mechanism shows that the smart city policy can promote digital autonomy of cities through the effect of digital human capital and digital material capital. Finally, this paper puts forward policy suggestions from the perspectives of developing digital industries, promoting the construction of smart cities, increasing the cultivation of digital talents, and paying attention to fairness and efficiency, so as to promote the digital autonomy of cities.

Keywords: digital autonomy, smart city, digital human capital, digital material capital

Introduction

The Chinese economy has indeed experienced remarkable growth over the past four decades, people have entered the era of digital economy, driven by advancements in science and technology, such as big data and artificial intelligence [1-2]. To fully capitalize on the opportunities brought by the development of the digital economy, cities worldwide have embarked on high-quality urban development planning and construction with the goal of "digital transformation", including improving green ecological space [3-5], building data centers to improve the level of intelligent computing power [6]. Urban digital autonomy refers to a city's capacity for autonomous innovation in the digital technology realm. It stands as a pivotal factor in driving the digital transformation of cities and significantly influences their ability to seize opportunities in the digital economy era while achieving high-quality development of the urban digital economy [7]. At present, how to further enhance the level of autonomous innovation is still a difficult problem for

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China to solve. The Information and communication technology (ICT) industry is characterized by high technology intensity and constant technology upgrading [8]. Its integration with traditional industries has emerged as a new engine for advancing the digital economy. To achieve technological breakthroughs in key areas, especially in information technology [9], China must prioritize scientific and technological self-reliance as a strategic pillar for national development and bolster its digital autonomy. Smart city construction, a comprehensive system engineering endeavor utilizing the latest digital technology to transform urban operations, plays a fundamental role in digital infrastructure construction and serves as a significant catalyst for the digital economy [10]. It serves as the primary choice for cities to achieve digital autonomy. Smart city construction plays a crucial role in promoting the transformation and upgrading of the industrial structure, optimizing resource allocation efficiency, improving human capital, and elevating the level of economic development [11-15].

Numerous studies have examined the impact of smart city construction on urban development across various dimensions. For instance, research has explored the influence of smart city construction on urban innovation [16-17], environmental pollution and green development [18-20], and high-quality urban development [21]. However, there is still little research on the impact of smart city construction on digital transformation and digital autonomy of cities. Smart city construction relies heavily on information and communication technologies, such as big data and cloud computing, which directly influence the digital autonomy of cities. Smart city policy plays a pivotal role in the digital economy and contribute significantly to a nation's global competitiveness. They leverage hyper-connectivity to address a spectrum of critical challenges, including managing urbanization, infrastructure demands, environment sustainability, safety, and economic opportunities [22-23]. Then, does the smart city policy promote the level of digital autonomy of cities? What are the mechanisms of influence? Is there heterogeneity in this effect? Such research holds significant importance in accelerating the high-quality development of digital economy, which is closely linked to China's further advancement in the digital industry. It will facilitate the digital transformation of various industries, inject new vitality into China's economic development, and contribute to realizing the goal of becoming a digital powerhouse.

Therefore, leveraging the quasi-natural experiment of the "smart city" pilot, this paper uses the panel data of 274 prefecture-level cities from 2009 to 2018 to quantitatively investigate the impact of smart city policies on the digital autonomy of cities using a difference-in-difference model. The potential contributions of this paper are as follows: First, building upon the practice of urban digital transformation, this study introduces the concept of urban digital autonomy, providing a novel perspective. It compiles and organizes ICT patent data from Chinese cities, constructing a dataset of digital technology innovation patents based on the digital economy database of enterprise research technology. This dataset serves as a reflection of the digital autonomy level at the city level in China. Second, this study examines the influence mechanism of smart city policies on the digital autonomy of cities from two perspectives: digital human capital and digital material capital, which fills the gap of existing research. Third, multiple measurement methods are employed to evaluate the impact of smart city policies on the level of digital autonomy of cities. The analysis confirms the presence of heterogeneity in terms of city location, rank and size, providing valuable insights and recommendations for reducing the disparities among cities.

Policy Background and Theoretical Hypothesis

Policy Background of Smart City Policies

The concept of a smart city is primarily associated with Information and Communication Technologies (ICTs), which leverage cloud computing and other next-generation technologies to enhance cities' intelligence, thereby improving their aesthetics and operational efficiency [24-26]. The term "smart city" was first introduced in 1994 with the aim of promoting the development of strategic emerging industries within cities through the construction of smart infrastructure [27]. Smart city assessments build upon previous experiences in measuring environmentally friendly and livable cities. These assessments encompass sustainability and quality of life while incorporating technological and informational components [28]. As a result, numerous countries worldwide have initiated the smart city policy trend, including the Chinese government. The Chinese government has explicitly defined a smart city as a new model for strengthening urban planning, construction and management through the comprehensive application of modern science and technology, integration of information resources, and the overall planning of business application systems. Proactive smart city construction enhances urban management capacity and service levels while promoting industrial transformation and development. On December 5, 2012, the Ministry of Housing announced the first batch of smart city construction pilot cities. Subsequently, the second batch and third batches of smart city pilot lists were published in 2013 and 2014, respectively, leading to over 290 cities, districts and towns being included in the national smart city pilot areas. According to the research sample in this paper, a total 146 cities were approved as smart cities between 2013 and 2015. A detail list is shown in Table 1. With the implementation of pilot policies, digital technologies such as big data, the Internet of Things, artificial intelligence and cloud computing are expected

Table 1. List of smart cities.

Year	City
2013	Shanghai, Dongying, Wuhai, Foshan, Jiamusi, Liupanshui, Beijing, Nanjing, Nanping, Nanchang, Wuzhong, Xianyang, Daqing, Dalian, Tianjin, Taiyuan, Weihai, Changzhou, Guangzhou, Langfang, Dezhou, Chengdu, Wuxi, Kunming, Shuozhou, Hangzhou, Zhuzhou, Wuhan, Shenyang, Taizhou, Ji'nan, Huainan, Huaian, Shenzhen, Wenzhou, Zhuhai, Yancheng, Shijiazhuang, Fuzhou, Qinhuangdao, Wuhu, Suzhou, Pingxiang, Bengbu, Liaoyuan, Handan, Chongqing, Jinhua, Tongling, Zhenjiang, Changzhi, Yaan
2014	Dongguan, Zhongshan, Wulumuqi, Baoding, Kelamayi, Lu'an, Baotou, Nanning, Nantong, Hefei, Jilin, Xianniang, Siping, Datong, Ningbo, Yichang, Baoji, Suqian, Yan'an, Xuzhou, Xinyu, Jincheng, Liuzhou, Guilin, Jining, Huaibei, Weinan, Weifang, Yantai, Mudanjiang, Baishan, Shizuishan, Mianyang, Zhaoqing, Putian, Heze, Xiangyang, Guigang, Guiyang, Lianyungang, Suining, Zunyi, Chenzhou, Eerduosi, Yinchuan, Changchun, Changsha, Fuyang, Yangquan, Qingdao, Huanggang, Huangshan, Qiqihaer
2015	Shangrao, Linyi, Leshan, Bozhou, Xinyang, Nanyang, Ji'an, Lvliang, Huhwhaote, Haerbin, Tangshan, Tianshui, Anshun, Yibin, Suzhou, Changde, Guang'an, Kaifeng, Zhangye, Xinzhou, Rizhao, Zaozhuang, Yongzhou, Hanzhong, Chizhou, Heyuan, Quanzhou, Luzhou, Luoyang, Chuzhou, Luohe, Zhangzhou, Yulin, Yuxi, Jingzhou, Xuchang, Yuncheng, Tonghua, Zhengzhou, Qinzhou, Hebi, Yingtan

to be deeply integrated into the construction of smart cities. Driven by the demand and policy focus of smart city construction, pilot regions are strongly motivated to carry out independent innovation and enhance digital autonomy, ultimately achieving comprehensive digital transformation within their cities.

Theoretical Hypothesis that the Smart City Policy Affects Digital Autonomy

The concept of a smart city is intrinsically connected to the support of new-generation Information and Communication Technologies, including big data, the Internet of Things and cloud computing. Each of these technologies constitutes a complex system that encompass various disciplines. Relevant studies have confirmed the innovation effect spurred by the development of information infrastructure [29-30]. Information infrastructure construction serves as the foundation of smart city policies, with data collection, accumulation and application being integral to the entire process. Data plays a crucial role in empowering urban innovation stakeholders and driving various innovative behaviors [31]. On the one hand, the development and application of big data overcome existing innovation challenges and create new opportunities for innovation [32]. On the other hand, the establishment of a scientific and technological innovation cloud platform facilitates the pooling of innovation resources from various parties, enabling efficient resource management. This promotes the open sharing of scientific and technological resources, streamlines the supply of innovation services, reduces innovation costs for universities, research institutions and businesses, and facilitates data-driven innovation. Furthermore, smart city construction leverages accumulated big data and emerging technologies to realize intelligent advancements across the economy, communications, environment, daily life, government services and other fields [33]. By harnessing these resources, smart cities achieve intelligent development and improve the efficiency and effectiveness of various sectors.

H1: The smart city policy will improve the level of digital autonomy of cities.

The implementation of smart city policies holds the potential digital autonomy levels by fostering the concentration of digital talent and promoting the development of digital human capital. From a labor perspective, both the quantity and quality of digital talent are pivotal factors in driving digital autonomy. In a competitive labor market, digital workers have the flexibility to relocate across cities based on price signals, seeking maximum returns on their investments. On one hand, smart city policies generally enhance the network infrastructure and improve the overall quality of life in cities, rendering them more appealing for both work and residence [34]. An increase in the city's population can stimulate companies to expand production, create job opportunities, and generate added value for their products, consequently raising the level of digital autonomy [35]. On the other hand, smart city policies contribute significantly to the advancement of urban research and development. With improved network infrastructure, the digital technology industry tends to gravitate toward these cities, attracting a larger pool of digital human capital [36]. In summary, smart city policies bolster the level of digital autonomy in cities by harnessing the influence of digital human capital.

Smart cities can also enhance digital autonomy by fostering the development of strategic emerging industries and promoting the growth of digital material capital. Firstly, the implementation of smart city policies relies on digital technologies, such as cloud computing, which form a comprehensive industrial chain encompassing computer communication, electronic equipment manufacturing, software and information technology services, and internet-based support industries [37]. The growth of strategic emerging industries, including other information technology services and software design, significantly contributes to the development of digital material capital, thus promoting digital autonomy [38]. Secondly, when a city attains the designation of a smart city, the local government often introduces industrial policies to attract more enterprises to establish a presence in the city [39]. This influx of businesses contributes to the accumulation of digital material capital, ultimately enhancing the city's digital autonomy. In summary, the focus of smart city policies on developing strategic emerging industries and attracting businesses enhances digital autonomy by promoting the growth of digital material capital. Additionally, the integration of digital technologies within the industrial ecosystem plays a crucial role in driving the progress.

H2: The smart city policy will indirectly improve the level of digital autonomy by promoting the level of digital human capital and digital material capital.

Methodology and Measurements

Model Construction

In the paper, smart city construction is regarded as a quasi-natural experiment, and the differences-in-differences model is utilized to examine the impact of smart city construction on digital autonomy of cities. Since smart city construction is determined in batches, a multi-stage differential model is constructed [40] as follows:

$$digital_{it} = \alpha_0 + \alpha_1 did_{it} + \alpha_2 controls_{it} + \delta_i + \sigma_t + \varepsilon_{it} \quad (1)$$

Where, the variable $digital_{it}$ represents the index of digital autonomy level for city i in period t, the variable *did* represents the virtual variable for smart city construction, and $controls_{it}$ contains a range of control variables that influence the digital autonomy at the city level. The term δ_i represents the city-fixed effect, σ_t represents the time-fixed effect, and ε_{it} represents the random error term.

To further identify the intermediate mechanism of smart city construction affecting digital autonomy of cities, this paper test the mediating effect model [41]. Based on Model (1), the following two recursive models are constructed:

$$med_{it} = \beta_0 + \beta_1 did_{it} + \beta_2 controls_{it} + \delta_i + \sigma_t + \varepsilon_{it} \quad (2)$$

$$digital_{it} = \lambda_0 + \lambda_1 did_{it} + \lambda_2 med_{it} + \lambda_3 controls_{it} + \delta_i + \sigma_t + \varepsilon_{it} \quad (3)$$

Among them, med_{it} is the intermediary variable, which is respectively represented as digital human capital and digital material capital, and the meanings of other variables are the same as model (1). Testing the mediation effect model is divided into three steps. First, the coefficient α_1 of model (1) is estimated to test the effect of the smart city policy on digital autonomy of cities. If α_1 is significantly positive, it indicates that the smart city policy can significantly enhance the level of digital autonomy in cities. Secondly, the coefficients β_1 and λ_2 are estimated separately on model (2) and model (3). If both coefficients are statistically significant, it suggests the presence of a mediation effect. On this basis, if λ_1 is not significant, it indicates a complete mediating role of the mediator; if λ_1 is significantly positive and smaller than α_1, it suggests a partial mediating role of the mediator. To ensure the accuracy of the results, a Sobel test can be further employed to determine the existence of the mediation effect.

Sample Selection and Data Sources

In this paper, 274 cities at prefecture level and above in China from 2009 to 2018 were selected as research samples. The explained variable data came from enterprise research technology and CnOpenData, the explanatory variable data came from Chinese government, the Intermediary variable data came from China urban statistical yearbook and enterprise research technology and the control variable data came from China urban statistical yearbook and Express Professional Superior database.

Variable Selection

Explained variable: digital autonomy (*digital*). Digital transformation has penetrated into all fields of economy and society, profoundly changed the global production organization and trade structure, and is reshaping the way of urban life. However, there is no unified standard for the definition and calculation of digital autonomy of cities. This paper considers that digital autonomy of cities refers to the autonomous innovation capability of a city in the digital field, which is represented by the number of ICT patent applications of digital economy enterprises. This data is derived from a match between the digital economy enterprise database and the patent database. Specific practices are as follows: First of all, according to the Zhejiang province introduced the catalog of digital core economic industry in Zhejiang province statistical classification, divisions of digital economy industry enterprise business scope keywords, according to the preliminary screening keywords from the industry and commerce registration enterprise business scope including keywords, according to the names of enterprises and industry groups, the preliminary screening for the digital economy enterprise for further screening, A total of 4.41 million enterprises were obtained, and then the enterprise location

Table 2. Variable description.

Variable Category	Variable Name	Variable Definition
Explained variable	*digital*	The number of Information Communication and Technology patent
Explanatory variable	*did*	the smart city policy variable
Intermediary variables	*dhp*	The number of information transmission and computer service and software employees
	dmp	The number of digital economy enterprises
Control variables	*lnpgdp*	Per capita GDP at the end of the year
	fin	The ratio of outstanding loans of bank institutions to GDP at the end of the year
	gov	Government spending as a percentage of GDP
	stru	The proportion of added value of tertiary industry in GDP
	density	The number of people per square kilometer
	pop_MT	Number of mobile phones per person
	internet	Per capita international Internet users
	pop_TC	The total amount of telecommunication service per capita

information was obtained by using Baidu regional API, and the information of the province, city and county (district) where the enterprise was located according to the enterprise address. Then, to the national patent data processing, according to the OECD patent statistical bulletin of ICT in each field, international patent classification number definition range of the IPC, field of ICT sector can be divided into four subsystems, namely telecom/radio, computer/office machinery, consumer electronics and other ICT technology, according to the IPC code in the field of four subsystems, With the help of "Patent Information Analysis" software developed by the State Intellectual Property Office, all patents applied for in the ICT field in China are retrieved. Further, the digital economy enterprises are matched with the ICT patents to obtain the ICT patents of each digital economy enterprise. According to the city where the digital economy enterprises are located, the ICT patents of each year are summed up to obtain the ICT patent data of digital economy enterprises in the city. In the empirical analysis, the patent data were expressed logarithmically, but in the parallel trend test, the patent data were not expressed logarithmically, thus we could better reflect the change of the patent data.

Core explanatory variable: the smart city policy (*did*). This paper uses the form of policy dummy variable to set. Specifically, *did* is set to 1 in the year and years after a city is determined as a smart city. Otherwise, *did* is set to 0. China set up the first batch of smart city pilot in 2012, and the second and third batch of pilot cities were set up in 2013 and 2014 respectively. Since the first batch of pilot cities were set up at the end of 2012, this paper takes 2013 as the first year when the policy effect occurred. As some smart cities are county-level cities or some regions of cities, the prefecture-level cities where these county-level cities or some regions are located are deleted in this paper when determining the experimental group.

Mediating variables. According to the above theoretical analysis, this paper selects digital human capital and digital material capital as the intermediary variables to test the indirect influence mechanism of the smart city policy on digital autonomy of cities. Among them, Digital human capital (*dhp*) is represented by the number of information transmission and computer service and software employees in prefecture-level cities. Digital material capital (*dmp*) is represented by the number of digital economy enterprises in each city.

Control variables. In order to analyze the influence of the smart city policy on digital autonomy of cities more accurately, the following variables are also controlled in this paper: economic development level (*lnpgdp*), financial development level(*fin*), level of government spending(*gov*), level of industrial structure(*stru*), population density(*density*), regional contact level(*pop_MT*), Internet development level(Internet), telecommunication service level(*pop_TC*). Table 2 shows a description of the variables.

Empirical Analysis

Table 3 presents the descriptive statistics for all variables in our sample. The descriptive statistics for each variable fall within reasonable limits, which, to a certain extent, indicates the accuracy and validity of the sample selection in our study.

Analysis of Regression Results

The estimated results regarding the impact of smart city construction on urban digital autonomy are represented in Table 4. In column (1), the regression

Table 3. Descriptive statistics of the variables.

Variable	N	Mean	SD	Min	Max
digital	2740	1.9299	2.1326	0	10.1888
did	2740	0.2712	0.4446	0	1
dhp	2740	0.4554	0.5182	0.0198	4.4430
dmp	2740	7.4506	1.1373	4.7958	12.2517
lnpgdp	2740	10.5866	0.6386	4.5951	15.6752
fin	2740	0.8868	0.5666	0.1037	7.4502
gov	2740	0.1848	0.0951	0.0439	1.1485
stru	2740	0.3951	0.0995	0.0976	0.8183
density	2740	6.9941	0.6873	4.5370	9.5700
internet	2740	0.1933	0.1900	0.0001	3.6635
pop_MT	2740	0.9934	0.8262	0.1062	10.1656
pop_TC	2740	988.8204	1437.52	6.7371	30329.78

result is displayed without the inclusion of control variables. It can be observed that the estimated coefficient of the smart city construction variable is 0.3227, indicating a significantly positive at the 1% level. This finding provides initial evidence suggesting that the smart city construction enhances the level of urban digital autonomy. Column (2) to (5) are listed as regression results of join in turn control variables, which can be found that estimates of wisdom city construction variable coefficient in addition to some small changes. Others did not have substantial change with a positive and significant under 1% level. The above results have once again proven wisdom city construction improve the level of the city digital democracy, which have well verified hypothesis 1, indicating that smart city construction is an important driving force to improve the level of urban digital autonomy in China.

In the process of estimating the impact of smart city construction on the digital autonomy of cities, it is inevitable to be interfered by other policies, which makes the estimated effect of smart city policy overestimate or underestimate. To identify and address the issue, this study searches for other policy events related to the smart city policy. We find that the Broadband China policy may also be one of the reasons affecting the digital autonomy of cities. To identify the effect, the Broadband China policy dummy variables is added to the baseline regression, the result is displayed in column (6). After adding the Broadband China policy variable, the smart city policy significantly improves the digital autonomy of cities, and the Broadband China policy also significantly improves the digital autonomy of cities. This conclusion indicates that the promotion effect of smart city construction on digital autonomy is indeed overestimated, but the promotion effect still exists and is significant, indicating that the conclusion is relatively robust.

Robustness Test

The aforementioned baseline regression confirms the significant improvement of the level of digital autonomy in cities due to the implementation of the smart city policy. To ensure the reliability of the baseline results, this paper will assess the robustness of the benchmark model from four different perspectives.

(1) Parallel trend test. In the context of this research, it is essential for the differences-in-differences model to assume that the digital autonomy data satisfies the parallel trend assumption. This implies that the digital autonomy levels of both the experimental group and the control group cities exhibit similar growth patterns before the influence of the smart city policy. To assess the parallel trend assumption, this paper employs both regression analysis and the graphical analysis methods.

The parallel trend test is conducted using the regression method to ensure the validity of the results. Following the approach [40,42], this study employs the event analysis method for a more rigorous assessment. In this analysis, the digital autonomy data selected represents the total number of ICT patents of urban digital economy enterprises, rather than the logarithmic value. The benchmark year is set as the fourth year before the policy implementation, and regression results are obtained for the four years before and after the policy implementation, as presented in Table 4. The results indicate that during the initial four years of policy implementation, the policy coefficient was not statistically significant. However, in the subsequent four years after the implementation of the smart city policy, the policy coefficient becomes significantly positive. This suggests that there was no systematic difference in the trend of digital autonomy levels between the treatment group and the control group before policy implementation, but a significant difference emerged

Table 4. Analysis of the regression results.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
did	0.3227***	0.3235***	0.3065***	0.2836***	0.2825***	0.2614***
	(0.0842)	(0.0843)	(0.0839)	(0.0829)	(0.0815)	(0.0813)
lnpgdp		0.2816**	0.1988*	0.2536**	0.2275**	0.2293**
		(0.1238)	(0.1145)	(0.1204)	(0.1129)	(0.1146)
fin		0.0875	0.1203	0.0997	0.0752	0.0680
		(0.0737)	(0.0735)	(0.0685)	(0.0651)	(0.0642)
gov			-1.3011	-1.3844	-1.3519	-1.2267
			(0.9082)	(0.9177)	(0.8940)	(0.8364)
stru			-1.0033	-0.8666	-1.0614*	-1.1380*
			(0.6316)	(0.6264)	(0.6217)	(0.6199)
density				1.6823**	1.4217**	1.1997*
				(0.7275)	(0.7029)	(0.7226)
p_IW				0.0967	0.0423	0.0241
				(0.1141)	(0.1141)	(0.1154)
p_MT					0.3987***	0.4073***
					(0.1026)	(0.1030)
p_TC					0.0001	0.0001
					(0.0001)	(0.0000)
BC						0.1683*
						(0.0869)
Constant	0.9941***	-1.8851	-0.4997	-12.7881**	-10.9224**	-9.3898*
	(0.0445)	(1.2567)	(1.2226)	(5.2237)	(5.0232)	(5.1454)
City FE	YES	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES	YES
Observations	2740	2740	2740	2740	2740	2740
Adj R^2	0.4946	0.4979	0.5015	0.5048	0.5098	0.5150

Note: ***, ** and * represent the significance level of 1%, 5% and 10% respectively. The following tables are the same.

following the policy's implementation. Consequently, the parallel trend assumption can be considered satisfied.

This paper also employs a graphical method to compare the trend of digital autonomy in cities before and after the implementation of the smart city policy, as depicted in Fig. 1. The figure clearly demonstrates significant differences in digital autonomy levels before and after the policy intervention. This further corroborates that the parallel trend assumption has been satisfied.

(2) The placebo test. To exclude interference from some random factors, the pilot cities were randomly selected for the placebo test [43]. Specifically, according to the number of pilot cities for the smart city policy determined every year, cities with the same number are randomly selected as the treatment group. And construct the virtual policy variable to estimate the model (1), repeat the process 1000 times, draw the 1000 regression virtual policy variable estimation coefficient of kernel density diagram, as shown in Fig. 2. It can be found that the mean of the estimation coefficient of the virtual policy variable is around 0, which is much less than the benchmark regression coefficient of 0.2825. At the same time, the distribution of the estimation coefficient is relatively close to the normal distribution, indicating that the influence of the smart city policy on digital autonomy of cities is not driven by other random factors, which further proves the robustness of the estimation results in this paper.

(3) Estimation based on PSM-DID method. In the smart city construction process, the selection of pilot cities may not be random. Cities with superior network

Table 5. Parallel trend test-regression method.

Variable	Coefficient values	Variable	Coefficient values
pre_4	36.0437	*post_1*	79.4891**
	(52.0800)		(38.4318)
pre_3	-4.9108	*post_2*	135.9049**
	(40.1849)		(70.9386)
pre_2	-38.1809	*post_3*	216.7075**
	(20.8164)		(101.3172)
pre_1	-3.4213	*post_4*	588.3793***
	(23.1675)		(191.7348)
Constant	YES		
Observations	2740		
Adj R^2	0.1943		

infrastructure are more likely to be chosen as pilot cities for smart city policies. This potential bias has the potential to introduce deviations in the baseline regression results. To address this issue, the PSM-DID method is employed to estimate the benchmark model in this paper. Specifically, the digital autonomy of cities is considered as the outcome variable, while the control variables in the baseline regression model are taken as the covariates. The nearest neighbor matching, radius matching, and kernel matching methods are utilized to conduct the matching process. Based on the matched samples, this paper re-estimated the influence of the smart city policy on digital autonomy of cities. The estimated results shown in Table 6 indicate that regardless of the matching method employed, the estimated coefficient for the DID remains significantly positive. In other words, the smart city policy has a significant positive impact on enhancing the level of digital autonomy in cities. These findings further confirm the robustness of the benchmark regression results.

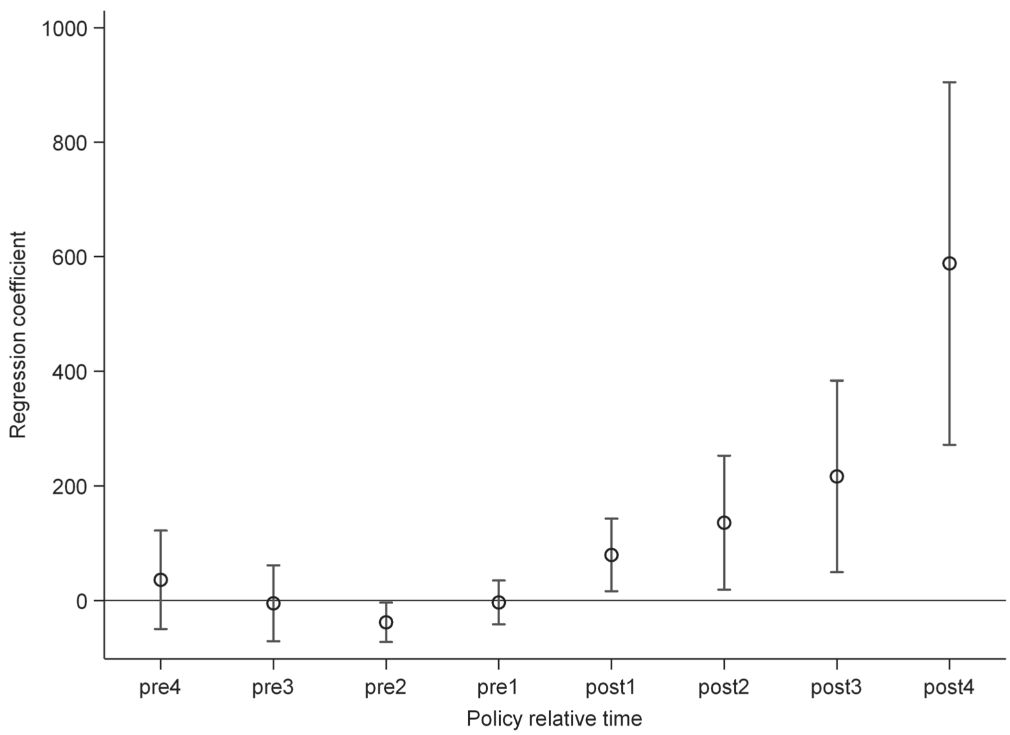

Fig. 1. Parallel trend test-drawing method.

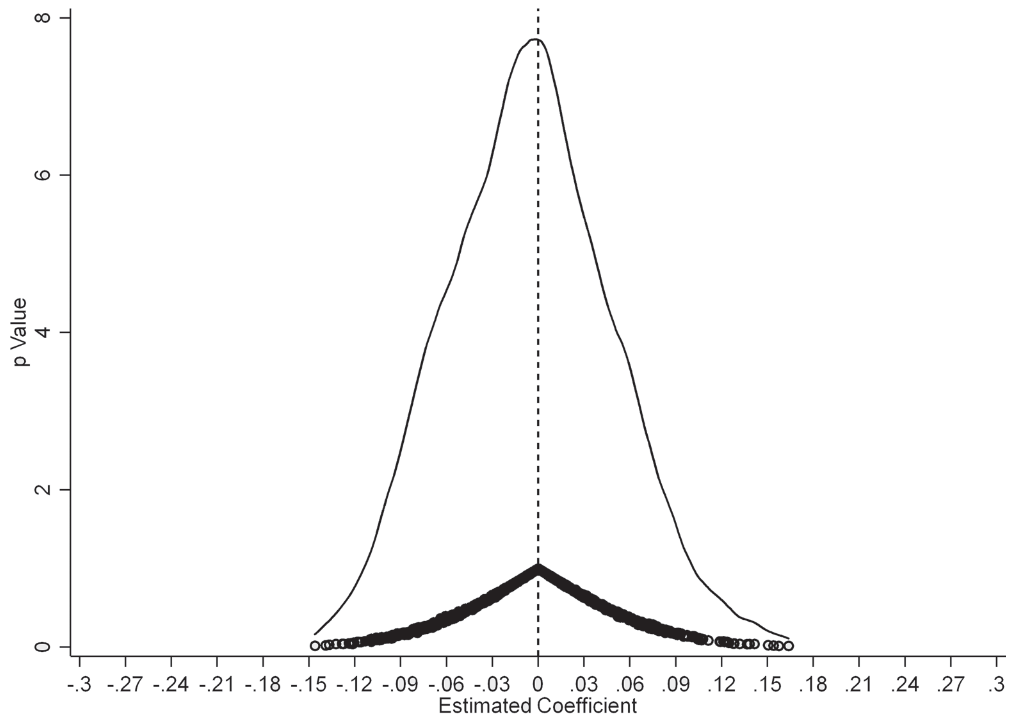

Fig. 2. Placebo test.

(4) Other robustness tests. On the basis of the above tests, robustness tests are also carried out from different samples and different methods. Under different sample conditions, robustness tests were conducted. In column (1), the robustness test involved the removal of municipalities directly under the central government. In column (2), the robustness test removed both municipalities directly under the central government and deputy provincial cities. In column (3), the robustness test removed municipalities directly under the central government, deputy provincial cities, and provincial capital cities. The regression coefficients remained significant, indicating that the effects of smart city construction on urban digital autonomy are still evident. Additionally, under different regression methods, column (4) employed the OLS regression method, column (5) used the random effects regression method, and column (6) utilized panel regression. It was observed that the different regression methods still resulted in significant coefficients for the differences-in-differences (DID) estimation. This indicates that smart city construction has a significant positive impact on the level of urban digital autonomy. Therefore, overall, the results remain significant across different samples and regression methods, demonstrating the robustness of the estimation results presented in this paper.

Table 6. Regression of PSM-DID.

Variable	(1)	(2)	(3)
	Near neighbors matching	Radius matching	Kernel matching
did	0.2576***	0.1500*	0.1984**
	(0.0812)	(0.0860)	(0.0826)
Control variables	YES	YES	YES
Constant	-10.4908*	-13.2729**	-11.4180*
	(5.6639)	(5.7785)	(5.8384)
City FE	YES	YES	YES
Time FE	YES	YES	YES
Observations	2671	2356	2546
Adj R^2	0.5044	0.4998	0.5076

Table 7. Robustness test.

Variable	Robustness tests for different samples			Robustness test of different methods		
	(1)	(2)	(3)	(4)	(5)	(6)
did	0.2821***	0.2759***	0.2261**	0.7364***	0.3237***	0.3095***
	(0.0826)	(0.0839)	(0.0907)	(0.0724)	(0.0824)	(0.0499)
Control variables	YES	YES	YES	YES	YES	YES
Constant	-12.5706**	-12.8780**	-6.7357	-16.3904***	-13.3888***	-15.3200***
	(5.2478)	(5.9323)	(6.1843)	(0.8568)	(1.3682)	(0.5528)
City FE	YES	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	NO	YES	NO
Observations	2700	2650	2400	2740	2740	2740
Adj R^2	0.5063	0.5020	0.4580	0.6547	0.5113	

Heterogeneity Analysis

Due to the vast territory of China, different cities are quite different in terms of geographical location, city rank and city size. Therefore, the smart city policy may have different effects on the digital autonomy in different cities. Therefore, this paper studies the heterogeneous influence of urban location, urban level and urban population size on the digital autonomy and ability of different cities. Among them, the total sample is divided into cities in the eastern region and cities in the central and western regions. This paper uses China Business Weekly to classify the city scale from five dimensions, namely, the degree of commercial resource concentration, the hub of the city, the activity of the city people, the diversity of life style and the plasticity of the future, and 121 cities of the first tier, new first tier, second tier and third tier were classified as higher grade cities. The 153 cities in the fourth and fifth tier are classified as lower grade cities for grouping test. According to the number of cities in 2018, cities with more than 5 million in 2018 and cities with less than 5 million in 2018. Specific regression results are presented in Table 8.

Columns (1) and (2) present the regression results based on city location, indicating a significant improvement in the level of digital autonomy due to the smart city policy. From the coefficient perspective, the impact of the policy on digital autonomy in the eastern region is more pronounced. Columns (3) and (4) display the regression results based on city rank. It can be observed that the estimated coefficient of DID for higher-ranked cities is 0.1801, which is significant at the 10% level. In contrast, the coefficient for lower-ranked cities is positive but not significant, suggesting that the promotion of digital autonomy primarily occurs in higher-ranked cities. Columns (5) and (6) represent the regression results based on urban population size. The estimated DID coefficient for larger cities is 0.2974, significantly positive at the 1% level. On the other hand, the coefficient for smaller cities is positive but not significant, indicating that the effect of smart city construction on digital autonomy promotion is mainly observed in larger population cities. These results can be attributed to the advantages that cities in the eastern region, higher-ranked cities, and larger population cities possess in terms of innovation elements, resources, and digital infrastructure.

Mechanism Test

The above analysis shows that the smart city policy can improve the level of digital autonomy of cities. Then what is the mechanism of the smart city policy to improve the level of digital autonomy of cities? According to hypothesis 2, the smart city policy mainly improves the digital autonomy of cities by promoting the level of digital human capital and digital material capital. To test hypothesis 2, the mediation effect model is used.

Table 9 presents the regression results for digital talent aggregation as a mediator variable. In column (1), the total effect of the smart city policy on digital autonomy of cities is reported, and the results align with the baseline regression findings. In column (2), the influence of the smart city policy on digital human capital is examined, revealing a regression coefficient of 0.0950, which is significantly positive at the 1% level. This indicates that the smart city policy has significantly improved the level of digital human capital. Column (3) displays the regression results of digital human capital as a mediator variable. It shows that the regression coefficient for digital human capital is 0.3984, significantly positive at the 1% level. This suggests that the enhancement of digital human capital contributes to the improvement of digital autonomy in cities. Additionally, the coefficient of DID in column (3) is smaller than that in column (1), indicating that digital human capital partially mediates the relationship. The Sobel test results further confirm the existence of

Table 8. Heterogeneity analysis.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	The eastern region	Central and western regions	High rank cities	Low rank cities	Large population scale	Small population scale
did	0.3798***	0.2320**	0.1801*	0.0975	0.2974***	0.1491
	(0.0992)	(0.1143)	(0.1072)	(0.1180)	(0.1113)	(0.1172)
Control variables	YES	YES	YES	YES	YES	YES
Constant	-7.1981	-10.9373	0.3631	-6.7615	-6.8414	-12.7031**
	(5.1678)	(7.8115)	(5.4779)	(7.7641)	(8.8578)	(6.0751)
City FE	YES	YES	YES	YES	YES	YES
Time FE	YES	YES	YES	YES	YES	YES
Observations	1000	1740	1210	1530	1020	1720
Adj R^2	0.6052	0.4669	0.6828	0.3652	0.6423	0.4347

Table 9. Mechanism test of digital human capital.

Variable	(1)	(2)	(3)
	Digital autonomy	Digital human capital	Digital autonomy
did	0.2825***	0.0950***	0.2446***
	(0.0815)	(0.0229)	(0.0827)
dhp			0.3984***
			(0.1190)
Control variables	YES	YES	YES
Constant term	-10.9224**	-8.4177***	-7.5689
	(5.0232)	(2.1390)	(5.1279)
City FE	YES	YES	YES
Time FE	YES	YES	YES
Observations	2740	2740	2740
Adj R^2	0.5098	0.2574	0.5138
Sobel	0.129***(Z = 5.271, P = 0.000)		

a mediation effect. Thus, the transmission mechanism of the smart city policy → promotion of digital human capital → enhancement of digital autonomy in cities can be verified.

Table 10 presents the regression results for digital material capital as a mediator variable. In column (1), the total effect of the smart city policy on the digital autonomy of cities is reported, and the results are consistent with the baseline regression findings. In column (2), the influence of the smart city policy on digital material capital is examined, revealing a regression coefficient of 0.0758, which is significantly positive at the 1% level. This indicates that the smart city policy has significantly improved the level of digital material capital. Column (3) displays the regression results of digital material capital as an intermediary variable. It shows that the regression coefficient for digital material capital is 0.9432, significantly positive at the 1% level. This suggests that the enhancement of digital material capital contributes to the improvement of digital autonomy in cities. Additionally, the coefficient of DID in column (3) is smaller than that in column (1), indicating that digital material capital plays a part in the mediation role. The Sobel test results further confirm the existence of a mediation effect. Therefore, the transmission mechanism of the smart city policy → promotion of digital material capital → enhancement of digital autonomy in cities can be verified.

Table 10. Mechanism test of digital material capital.

Variable	(1)	(2)	(3)
	Digital autonomy	Digital material capital	Digital autonomy
did	0.2825***	0.0758***	0.2110***
	(0.0815)	(0.0217)	(0.0805)
dmp			0.9432***
			(0.1567)
Control variables	YES	YES	YES
Constant term	-10.9224**	-1.0228	-9.9576**
	(5.0232)	(1.5342)	(4.9737)
City FE	YES	YES	YES
Time FE	YES	YES	YES
Observations	2740	2740	2740
Adj R^2	0.5098	0.9313	0.5278
Sobel	0.5255*** (Z = 13.97, P = 0.0000)		

Conclusions and Suggestions

Conclusions

Based on theoretical analysis, this paper utilizes panel data from Chinese prefecture-level cities spanning from 2009 to 2018. By treating smart city construction as a quasi-natural experiment, the study empirically examines its impact on the digital autonomy of cities using the difference-in-differences model. The main findings are as follows: Firstly, the smart city policy has demonstrated a significant improvement in the level of digital autonomy across cities. This effect remains robust even after conducting various tests, such as the parallel trend test, placebo test, PSM-DID method, and employing different samples and methods. Secondly, heterogeneity analysis reveals that the promotion effect of the smart city policy on digital autonomy is more pronounced in cities located in the eastern region, as well as those with higher ranks and larger population sizes. Lastly, the regression results of mediation effects indicate that the smart city policy can indirectly enhance the level of digital autonomy in cities by improving the levels of digital human capital and digital material capital. Overall, these findings validate the positive impact of the smart city policy on the digital autonomy of Chinese cities, demonstrating its effectiveness in driving digital development.

Suggestions

To further advance digital autonomy in Chinese cities, this paper proposes policy recommendations in the following areas. First, digital talent serves as the foundation for digital autonomy in cities. The government should prioritize cultivating digital talent, harnessing the dividends effect of digital talent, and accelerate urban transformation and innovation. Second, the Chinese government should steadfastly pursue independent innovation and nurture a distinctive digital industry ecosystem within China. Emphasizing independent research and development is crucial for mastering technology and enhancing the capacity for technological innovation and supply. Chinese enterprises should continuously innovate and create cutting-edge products and platform services based on advanced technologies, particularly those rooted in the new generation of ICT technology, to significantly elevate the level of digital autonomy in China. Third, China should embrace the new wave of digital technological change by further advancing the construction of smart cities and transitioning from traditional city development modes to smart city development modes. In this process, the government should enhance the quality of digital government services, break down data and information barriers, promote data sharing, and foster the integration of the economy, society, and environment within smart cities. Finally, recognizing that the impact of smart city construction on digital autonomy varies across different cities, it is imperative to implement tailored policies and measures that align with the specific characteristics of each city's development. When implementing smart city policies, particular attention should be paid to guiding cities in the central and western regions, as well as cities with lower rankings and smaller population sizes, to reduce disparities in the level of urban digital autonomy.

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Conflict of Interest

The authors declare no conflict of interest.

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