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Promoting Urban Innovation through Smart Cities: Evidence from a Quasi-Natural Experiment in China

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Abstract: It is of great theoretical and practical significance to investigate the influence of intelligent city construction on urban innovation. Based on the data of 238 cities in China from 2006 to 2019, this paper utilizes the staggered difference-in-differences (staggered DID) model and the mediating effect model to examine the impact and mechanisms of smart city construction on urban innovation. We find that China's smart city pilot policies significantly promote urban innovation. Mechanism analysis shows that this innovation promotion effect acts through improving urban informatization, government financial expenditure on science and technology, and the upgrading of the city's industrial structure. Further analysis shows that smart city construction has a stronger promoting effect on innovation in cities of a larger scale, that located in the eastern region, and have a lower level of science and education. Overall, our findings provide new insights into urban innovation and objectively assess the impact of smart city construction in China.

Keywords: smart city; urban innovation; informatization; difference-in-differences; China

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1. Introduction

Innovation is the primary driving force driving the transformation and development of the economy. The theory of endogenous growth proposes that the economy cannot rely on external forces to achieve sustained growth and that its determining factor is endogenous technological progress [1,2]. Economists have since studied the endogenous origins of economic growth more thoroughly, and a large body of literature provides evidence of a causal relationship between innovation and economic growth [3,4]. Cities are the spatial carriers of innovation activities [5], the gathering place of innovation resources and elements, and important places for knowledge creation and application [6]. Therefore, building an innovative country cannot be separated from urban innovation. Releasing the vigor of urban innovation and improving the level of urban innovation are vital to cities playing basic and supportive roles in the construction of a national innovation system. As cities are innovation machines, exploring how to enhance urban innovation capability is of non-negligible meaning for countries around the world seeking to improve their innovation capability and enhance sustainable economic development [7].

Smart cities underpinned by information and communications technology (ICT) are now an advanced form of urban development [8,9]. With the rapid progress of information technology, such as the Internet of Things (IoT), cloud computing and the Internet, smart cities have emerged, and countries around the world such as Switzerland, Norway, Australia, the United Kingdom, and China are committed to the construction of smart cities and to making them a sustainable and essential policy tool to improve urban resilience [10–12]. A large body of research on this "booming" phenomenon has yielded rich outputs [13].

Some studies have attempted to clarify the concept and characteristics of smart cities, pointing out that smart cities cannot simply be equated with technology but should be composed of a series of elements such as land, citizens, technology, and governance [14,15], as well as the idea that the smart city is innovation composed of technology, management, and policy [16]. However, the city is a complex and dynamic assemblage of relationships and technologies, and the smart city is also a dynamic concept, a fully consistent definition of which has not yet been established. Many scholars focus on the functions and performance of smart cities, exploring how they can be used to support higher quality urban spaces, better public service delivery, and citizen well-being. For example, smart cities enable the public sector to more effectively utilize information technology infrastructure and smart devices, which can increase the value of public services to communities [17]. Smart cities also help to address the challenges of social exclusion and environmental pollution faced in urban development, strengthen the scientific and technological level of government and the efficiency of resource allocation, and improving the regional environment [18,19]. In addition, others are concerned with the participation and interaction of stakeholders in the process of smart city construction and development [20–22], and have endeavored to enrich the theoretical framework of smart city research [23]. Still others have shifted their research focus to practices inside cities, shedding light on the different paths taken by different cities around the world in interpreting and applying the notion of the smart city [24]. In summary, these studies have emphasized the use of ICT and the importance of effectively integrating different city management systems, sharing information resources and promoting operational synergies among city systems [25,26]. Smart cities advocate intelligent city management and services, enhance city operations and management, improve public services, and contribute to the welfare of residents, with the ultimate goal of achieving the sustainable development of innovative cities. Exploring the causal relationship and mechanisms between smart cities and urban innovation is essential for advancing urban innovation, promoting national economic development, and planning for the future construction of smart cities [27].

The concept of urban innovation may vary according to different research perspectives. There are studies in the field of public administration that classify urban innovation into four dimensions including the agenda, process, product, and symbolic innovation of different policies [28]. In the economic sphere, cities have become key units of innovative activity, bringing together various elements such as enterprises, talent, capital and institutions, and innovation refers primarily to scientific and technological progress [29]. Urban innovation means the processes and products of innovative activities in cities that are primarily centered on scientific and technological progress. Urban innovation is characterized by significant temporal and spatial structure from the point of view of urban innovation networks or urban innovation systems [30,31]. The determined factors of urban innovation have long been in the spotlight, the early literature has highlighted the role of intra-city factors on innovation, such as city size [32], public infrastructure [33,34], educational resources [35,36], and fiscal decentralization [37]. With the advancement of research methods such as quasi-natural experiments, studies have begun to extend the boundaries of factors influencing urban innovation beyond the city to explore the role of macroeconomic policies and institutions [38]. A body of literature has empirically examined the promotional effects of macro-environmental regulation on urban innovation [39,40], some have found that innovative city policies stimulate urban innovation by raising the level of government fiscal expenditures, the degree of urban industrial agglomeration, and the level of human capital [41], and others have provided evidence that the innovative growth effect of such policies has significant spillover effects on neighboring cities [42]. However, only limited research has investigated the effects of smart cities on urban innovation as an important urban development paradigm. A study based on data from 309 European metropolitan areas proved that smart city development has a positive impact on urban innovation [43]. Some evidence from China that there is heterogeneity in the impact of smart city policies on urban innovation depending on geographic location [44].

Nonetheless, the mechanism by which smart cities affect urban innovation is still unclear and needs to be supplemented by further quantitative analyses and empirical evidence, especially as evidence from developing countries is scarce.

China offers unique conditions for empirically analyzing how smart cities affect urban innovation. First, in order to explore scientific approaches to the construction, operation, management, services, and development of smart cities, China began a national smart city pilot program in 2012 and expanded the scope of the pilot program in 2013 and 2014. The gradual implementation of smart city pilot policies has been characterized as a "quasi-natural experiment", creating an opportunity to open the black box of causality between smart city development and urban innovation [45]. Second, compared with studies based on cities in other countries, China has a large sample of cities, with as many as 293 prefecture-level cities, which makes a rich sample for the study. Therefore, based on China's smart city pilot policy, this paper establishes a staggered DID model to examine the impact of smart city construction on urban innovation and its specific mechanisms, utilizing data from China's city yearbooks from 2006 to 2019.

This study contributes to related research in three ways. First, we use data from Chinese cities to demonstrate the extent to which smart city construction promotes urban innovation. Our findings add evidence from developing countries to existing studies and are relevant to urban development in other developing countries around the world. Second, we contribute to the existing literature by analyzing in depth the mechanisms through which smart city construction affects urban innovation. We find that smart city pilot policies promote urban innovation through improving urban informatization, government financial expenditure on science and technology, and industrial structure upgrading. Third, we present a rich heterogeneity of results that help deepen our knowledge of how smart city policies affect urban innovation.

The rest of the paper is organized as follows. Section 2 introduces the institutional background of smart city construction in China and develops the research hypotheses. Section 3 presents the research design, including data sources, variables, and empirical models. Results are provided in Section 4. Section 5 presents conclusions and policy implications.

2. Institutional Background and Research Hypotheses

2.1. Institutional Background

The smart city is an urban form supported by a new generation of information technology and a knowledge society based on a next-generation innovation environment, stressing the role of ICT in improving the functioning of the urban system, facilitating knowledge transfer, constructing innovation networks [46], etc. In order to drive the construction of new urbanization and enhance the management capacity and service level of cities, the Ministry of Housing and Urban-Rural Development (MoHURD) of the People's Republic of China officially launched a notice on the development of national smart city pilot projects in November 2012, and issued the "Interim Measures for the Management of National Pilot Smart Cities", which guided and encouraged the construction of smart cities across the country, and identified 90 national pilot smart cities. In March 2014, China released the National New Urbanization Plan (2014–2020), which explicitly put forward "promoting smart cities" as one of the three major objectives of promoting the construction of new cities. In August of the same year, China's National Development and Reform Commission and eight other departments jointly formulated the guiding opinions on the healthy development of smart cities, proposing that by 2020, China should build a number of smart cities with distinctive features, significantly improve the comprehensive competitive advantages of cities, and achieve remarkable results in terms of livelihood services, innovative management, and cybersecurity. In November 2015, China finalized the framework of the smart city standard system and evaluation index system. In March 2016, China's 13th Five-Year Plan clearly states that it will make full use of big data and modern information technology to build a batch of demonstration-type smart cities featuring smart infrastructure, convenient public services, and fine-grained social governance. In 2018, China successively released national standards on top-level design, information technology operation, and information security guarantees for smart cities, which are used to standardize the order of smart cities and advance the higher-level of smart cities. In general, the scope of smart cities in China has been expanding, with China's MoHURD and Ministry of Science and Technology (MOST) announcing three batches of smart city pilot lists in 2012, 2013, and 2014, respectively, comprising a total of 290 pilot districts (including pilot municipalities, prefectures, counties, and cities at the county level).

From the perspective of relevant policies, the objectives of China's pilot smart cities are mainly in the areas of raising the efficiency of the supply of public services, improving the administrative efficiency of the government and the level of urban management, improving the urban living environment, upgrading the level of intelligence of public infrastructure, and developing a sophisticated system of urban safety and security networks. The main contents of China's smart city pilot policy can be summarized as follows: First, in the area of public services, the policy calls for the establishment of a modern information service system covering all people, the improvement of government administrative efficacy by means of smart applications, and the provision of convenient, efficient, and personalized smart medical care, education, and other public services. Secondly, in the area of social management, the policy requires the creation of a smart application system, strengthening data integration, information sharing, and business synergy, strengthening the ability of urban operation monitoring and intelligent security and emergency response, and ensuring the safe and efficient operation of the city. Third, in terms of the industrial system, the policy aims to give full play to the advantages of a new generation information and communication technologies, promote the digital, networked, and intelligent transformation of existing industries, develop new business forms such as smart logistics, smart agriculture, smart tourism, etc., and make industries more competitive.

2.2. Hypothesis Development

From the main objectives and contents of China's smart city pilot policy, the government's adoption of the smart city pilot policy should theoretically provide a significant boost to the innovation level of the pilot cities, which may be achieved by upgrading the level of informatization, increasing financial support, and optimizing the industrial structure.

First of all, the smart city pilot policy helps to bring the effects of information technology to cities, thereby promoting urban innovation. First, smart city construction places an emphasis on the use of a new generation of information technology, such as the IoT, cloud computing, big data, and spatial geographic information integration, to improve urban infrastructure, accelerate innovation in urban public services, promote the government's use of intelligent means to optimize the allocation of resources, improve the efficiency of resource utilization and the level of urban governance, and enhance urban resilience, which contributes to the creation of a favorable innovation environment for enterprises, colleges and universities, and other innovation bodies [47]. Second, the construction of smart cities is accompanied by the open sharing of substantial information resources, which reduces the information asymmetry, lowers transaction costs, and boosts the efficiency of innovation [48]. Third, in the process of smart city development, enterprises and other interested parties will accelerate the creation of new technologies and products through the application of ICT, and enhance the overall innovation capacity of the city.

Secondly, the smart city pilot policy will make the government increase its investment in innovation activities in science and technology and enhance the level of urban innovation. On the one hand, the financial expenditure of the government is an important tool for the construction of smart cities, and the pilot policy stresses that local governments should pay attention to funding planning and financial security when carrying out top-level design and planning for smart cities and, at the same time, they should include in their industrial planning the innovation costs of industrial transformation and upgrading and the aggregation of industrial elements, which means that the government's scientific and technological expenditures will grow as a result. On the other hand, the government's increased investment in R&D may assist enterprises in reducing R&D costs and avoiding R&D risks, stimulate enterprises and other organizations to strengthen long-term R&D, and encourage more investment in innovation, thus raising the level of urban innovation [49,50].

Finally, the smart city pilot policy places great emphasis on the development of smart industries and the economy, promotes the upgrading of existing industries and the development of new industries in the city, optimizes the industrial structure, and is conducive to promoting the gathering of all kinds of innovative elements in the city and stimulating the vitality of innovation in the city.

Based on the above analysis, this paper proposes the following research hypotheses:

Hypothesis 1. *Smart city construction can significantly promote urban innovation.*

Hypothesis 2. *Smart city construction can promote urban innovation by enhancing the level of informationization.*

Hypothesis 3. *Smart city construction can promote urban innovation by prompting governmental investment in science and technology.*

Hypothesis 4. *Smart city construction can enhance urban innovation by contributing to the upgrading of the industrial structure.*

3. Data and Methods

3.1. Variables

3.1.1. Explained Variable

The explanatory variable in this paper is the level of urban innovation. Patent data are an important indicator of a region's inventive capacity and are characterized by their accessibility and timeliness, so plenty of studies have used them to measure a region's innovation level [51]. However, as there are differences among different cities in various aspects of innovation, such as input of innovation factors, allocation of innovation resources, and the outputs of innovation, measuring the level of innovation of a city only by the number of patents fails to take into account the problem of heterogeneity between cities, and may make it difficult to reflect the true value of the city's innovation activities. Unlike the number of patents, some scholars and organizations are committed to constructing more objective and comprehensive measures of innovation. The Index of Regional Innovation and Entrepreneurship in China (IRIEC) is led by Peking University's Enterprise Big Data Research Center and jointly developed by Peking University's National Development Research Institute and Longxin Data Research Institute to examine the actual outputs of innovation and entrepreneurship activities, rather than the inputs. The index covers all industries and enterprises of different sizes in a region, and not only incorporates patent data into consideration, but also integrates and standardizes innovation data from different fields, such as technology and capital, given that innovation and entrepreneurship are complementary to each other. Hence, we adopt the IRIEC to measure the level of urban innovation.

3.1.2. Explanatory Variable

The smart city pilot policy is the core explanatory variable, which is set as a dummy variable in this paper, assigned a value of 1 if a city belongs to the smart city pilot as the treatment group subject to policy shock; conversely, other cities serve as the control group and are assigned a value of 0.

3.1.3. Control Variables

In order to reduce the endogeneity problem caused by omitted variables, this paper controls for the following variables: (1) The level of urban infrastructure. Urban infrastructure is an indispensable foundation for the development of urban economic and social undertakings, and is the basic condition for the survival and innovative development of modern cities [38]. The construction of urban roads is the basis for the city's economy and open interaction with the outside world, and to a certain extent, can reflect the city's level of development and innovation, so we adopt the ratio of urban road area to land area to reflect the level of local infrastructure. (2) Level of foreign direct investment (FDI). FDI can stimulate the technological innovation effect of the host country and has an obvious technology spillover effect [52]. We use the ratio of the actual amount of utilized FDI to the regional GDP as an indicator of the level of foreign investment, and because of the large differences between the ratios, the data are logarithmized. (3) Financial development level. Innovation cannot be separated from financial support, which plays a pivotal role in reducing financing costs and promoting risk management [53]. This variable is measured using the logarithm of the ratio of the balance of deposits of financial institutions to regional GDP. (4) Population size, measured using the logarithm of the number of permanent urban residents. (5) Level of economic development, measured using the logarithm of urban GDP.

3.1.4. Mediating Variables

The mediating variables of concern mainly include the level of urban informatization, the level of advanced and rationalized urban industrial structure, and the degree of government financial support.

The promotion and application of ICT represented by the Internet has become an effective way for policy makers to enhance innovation [54], so we adopt the ratio of the number of Internet broadband access subscribers to the resident population to measure the level of urban informatization.

The financial support of the Chinese government acts as an integral part in fostering the development of high-tech industries and strategic emerging industries, which is favorable to urban innovation activities. In this paper, the science and technology expenditure component of the government's financial expenditure is selected to measure the degree of government support for innovation, and the indicator is logarithmized.

Optimization of the industrial structure refers to the process of transforming and upgrading an economy to more high-end, highvalue-added, and high-technology industries in the process of economic development, consisting of an advanced industrial structure and industrial structure rationalization as two key dimensions [55,56]. An advanced industrial structure refers to the process of gradually increasing the proportion of non-agricultural industries in an economy, which generally implies a shift in the economy's industries from traditional agriculture and light industry to higher-end, high-technology, high-value-added manufacturing and services, as measured by the coefficient of the hierarchy of the industrial structure. Rationalization of the industrial structure, meaning the dynamic process of strengthening the coordination capacity and increasing the level of association between different industries, reflects the degree of effective utilization of resources and the degree of coordination between the input and output structures of factors among different industries, and is measured by the Theil index of industrial structure.

3.2. Data

First, the data on urban innovation came from the IRIEC published by Peking University's Open Research Data Platform, which contains the innovation and entrepreneurship index for 292 cities in China. Second, the data on smart city pilots were established based on the list of smart city pilots published by MoHURD and MOST in 2012, 2013, and 2014. Since we are mainly studying the impact of this policy on urban innovation, the four municipalities (Beijing, Shanghai, Tianjin, and Chongqing are at the same administrative level as the provinces) and counties in the list were deleted, and the final sample consisted of 238 prefectural-level cities, of which 84 cities were in the experimental group and the remaining 154 were in the control group. Third, all other data were obtained from the China Urban Statistical Yearbook. Eventually, after combining, cleaning, and standardizing all the data, we arrived at a total of 3332 valid samples from 2006 to 2019, and the descriptive statistics of each variable are shown in Table 1.

Table 1. Descriptive statistics.

Variables	N	Mean	S.D.	Min	Max
City Innovation Index	3332	0.555	0.272	0.02	1
Infrastructure Level	3332	1.205	1.363	0.009	12.707
Foreign Investment Level	3332	−3.629	2.909	−13.337	8.288
Financial Development Level	3332	0.713	3.137	−9.82	10.69
Population Size	3332	5.912	0.613	3.85	7.413
Economic Development Level	3332	14.829	2.677	4.163	19.374
Informatization Level	3332	1.608	1.239	0.001	14.074
Government Investment	3332	9.889	1.539	4.205	15.529
Degree of Advanced Industrial Structure	3332	6.448	0.35	5.517	7.836
Rationalization of Industrial Structure	3332	−1.704	1.06	−8.321	5.332

3.3. Empirical Model

The difference-in-differences method can simultaneously control for group effects (experimental and control groups) and time effects (before and after the pilot), and identify the net effect from exogenous policy shocks as much as possible. Considering that smart city construction is carried out in batches, this paper constructs the following staggered DID model [45]:

$$cityinno_{it} = \alpha + \beta smartcity_{it} + \sum \delta x_{it} + \mu_i + \eta_t + \varepsilon_{it} \quad (1)$$

In the above equation, i represents the city and t represents the year. $cityinno_{it}$ is the explanatory variable, representing the city's innovation level. $smartcity$ is a dummy variable representing smart city construction and $smartcity_{it} = treat_i * post_{it}$. $treat_i$ = 1 if city i is a pilot smart city, $treat_i$ = 0 otherwise, and $post_{it}$ = 1 if city i becomes a pilot city during the policy implementation period, and $post_{it}$ = 0 otherwise. Thus, $smartcity_{it}$ = 1 means that city i was a pilot smart city in year t, $smartcity_{it}$ = 0 means that city i was not a pilot smart city in year t. β is the estimated coefficient of smart city construction, which is the core parameter of interest in this paper. If the obtained estimate $\hat{\beta} > 0$, it indicates that there is a significant positive impact of smart city construction on urban innovation. If $\hat{\beta} < 0$, it indicates that smart city construction has a negative impact on urban innovation, which is manifested as unfavorable to urban innovation. x_{it} is a set of control variables. μ_i is the city-fixed effect to control for inherent characteristics that do not change over time at the city level. η_t is the time-fixed effect to control for time-level factors that do not vary with area. ε_{it} is the random error term.

Further, in order to test the mechanism of smart city construction acting on urban innovation, we also constructed the following model:

$$MV_{it} = \alpha_1 + \beta_1 smartcity_{it} + \sum \delta_1 x_{it} + \mu_i + \eta_t + \varepsilon_{it} \quad (2)$$

$$cityinno_{it} = \alpha + \beta_2 smartcity_{it} + \beta_3 MV_{it} + \sum \delta_2 x_{it} + \mu_i + \eta_t + \varepsilon_{it} \quad (3)$$

In Equation (2), MV_{it} is the mediating variable, if the estimated $\hat{\beta}_1$ of the coefficient β_1 passes the significance test at the 10% level, then it suggests that there is a significant effect of smart city construction on the mediating variable.

In Equation (3), if the estimates of coefficients β_2 and β_3 both pass the significance test at the 10% level and coefficient β_2 turns out to be smaller, it explains that the mediating variable MV_{it} is an important transmission mechanism for smart cities to influence urban innovation. The mediating effect is an indirect effect, i.e., $\beta_1 * \beta_3$; β_2 is a direct effect. The relationship between mediating effect and total effect should satisfy the equation: $\beta = \beta_2 + \beta_1 * \beta_3$.

4. Results and Discussion

4.1. Baseline Estimated Results

Benchmark regression results are reported in Table 2, Column (1) demonstrates the results with no control variables and fixed effects added, Column (2) includes time-fixed effects and city-fixed effects, and Column (3) continues to include control variables. It can be seen that after incorporating fixed effects and control variables, the regression result coefficient of column (3) is 0.0307, which is still statistically significant at 1%, indicating that the construction of smart cities has a significant positive impact on urban innovation, and that Hypothesis 1 has been verified, which is also consistent with the conclusions of existing studies [43,57,58].

Table 2. Effects of smart city construction on urban innovation.

	(1)	**(2)**	**(3)**
smartcity	0.0436 ***	0.0527 ***	0.0307 ***
	(3.5537)	(4.5997)	(4.3235)
Infrastructure Level			0.0163 ***
			(7.6541)
Foreign Investment Level			0.0317 ***
			(17.6369)
Financial Development Level			0.0353 ***
			(11.2886)
Population Size			0.1560 ***
			(30.6473)
Economic Development Level			0.0973 ***
			(34.6467)
Constant	0.5471 ***	0.5455 ***	−1.7462 ***
	(105.3784)	(125.6951)	(−42.8866)
City-fixed effect	No	Yes	Yes
Time-fixed effect	No	Yes	Yes
N	3332	3332	3332
R-squared	0.0035	0.3413	0.7498

Notes: *** indicates significance at the 1% level. Numbers in parentheses are *t*-values.

From the results of the control variables, the estimated coefficient of the level of urban infrastructure is significantly positive at the 1% level, indicating that the construction of urban roads significantly affects the level of urban innovation, and the government should give attention to urban infrastructure. The estimated coefficient of the level of foreign investment is significantly positive at the 1% level, which means that investment attraction is conducive to the development of urban innovation, and the government should deregulate, increase the level of openness of the other side of the city, and emphasize on outreach and interoperability to promote the development of urban innovation. The regression coefficients of the level of financial development, population size and economic development are all significantly positive at the 1% level, suggesting that the government should emphasize the development of urban finance and economy on the basis of securing the population base, and promote innovation and urban innovative development by economy.

4.2. Parallel Trend Test

The key premise in using staggered DID is to satisfy the parallel trend assumption, that is, the change in the level of innovation in the cities in the treatment and control groups was not significantly different before the announcement of the list of smart city pilots. To test this trend, we constructed an event analysis model as follows [45]:

$$cityinno_{it} = \alpha + \sum_{t=-8}^{7} \lambda_t D_{it} + \sum \delta x_{it} + \mu_i + \eta_t + \varepsilon_{it} \quad (4)$$

In Equation (4), D_{it} is a set of dummy variables that takes the value of 1 if city i becomes a pilot smart city in year t, and vice versa takes it the value of 0. λ_t is the coefficient of interest, reflecting the difference in innovation between the cities that have carried out smart city construction and those that have not, in year t when the list of pilot smart cities was issued.

We use data from 2006 to 2019, and the smart city pilots include three phases in 2012, 2013, and 2014, so the time difference before and after the policy pilots is 8 years before the policy and 7 years after the policy. In graphing, we summarize data from 5–8 years before the pilot list was announced to 4 years before the policy presentation, and data from 7 years after the pilot list was announced to 6 years after the policy presentation. Figure 1 shows that the coefficient estimates of the smart city construction effect are not significant in the pre-implementation periods, demonstrating that there is no significant difference in innovation levels between the cities that have carried out smart city construction and those that have not before the announcement of the pilot list, and thus the sample passes the parallel trend test.

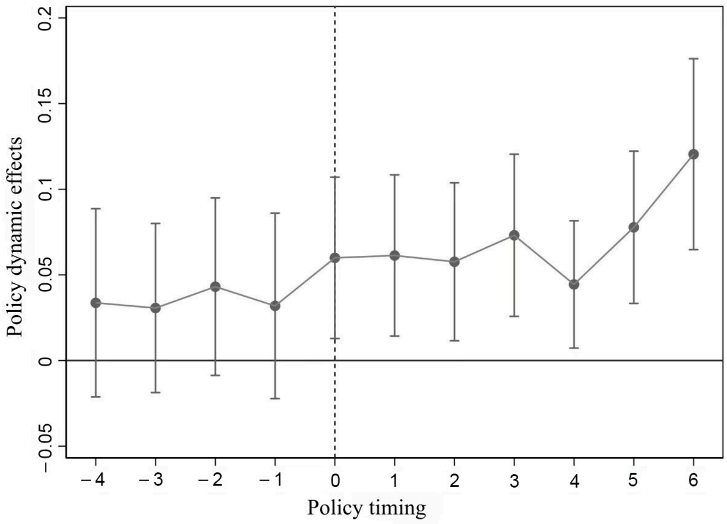

Figure 1. Parallel trend test.

4.3. Placebo Test

4.3.1. Time Placebo Test

This study employs a time placebo test to rule out the effect of time variation on the differences in urban innovation between the treatment and control groups [59]. Specifically, we constructed spurious exogenous shock times, denoted by $smartcity_{t-3}$ and $smartcity_{t+3}$, for the announcement of the smart city pilot list with a three-year lead and a three-year lag, respectively, and brought them into Equation (1) for regression analysis.

The regression results are shown in Table 3, where the estimated coefficient of $smartcity_{t-3}$ fails the significance test, which shows that there is no systematic difference in the time trend between the treatment and control groups, which is further evidence of the facilitating effect of smart city construction on urban innovation. The estimated coefficient of $smartcity_{t+3}$ is significantly positive at the 1% statistical level, indicating that the promoting effect of smart city construction on urban innovation is still significant three years after execution (although the regression coefficient is reduced compared to the baseline estimation), which may be attributed to the government's other priorities in terms of its smart city construction goals, such as putting more emphasis on the construction of smart communities and the provision of smart public management and services, among others.

Table 3. Time placebo test results.

	(1)	(2)
$smartcity_{t-3}$	0.0027	
	(0.4165)	
$smartcity_{t+3}$		0.0282 ***
		(2.7346)
Control variables	Yes	Yes
City-fixed effect	Yes	Yes
Time-fixed effect	Yes	Yes
N	3332	3332
R-squared	0.9006	0.7489

Notes: *** indicates significance at the 1% level. Numbers in parentheses are *t*-values.

4.3.2. Urban Placebo Test

We continue to employ a commonly used placebo test to ensure the reliability of the baseline regression results. Referring to Cai et al. [60], we randomly selected 84 cities in our sample as the false treatment group and the rest of the cities as the false control group in order to assess the impact of smart city construction as a placebo on urban innovation. After repeating the above process 500 times, we obtained the corresponding regression coefficients and *p*-values and plotted the kernel density distribution of the 500 estimated coefficients (See Figure 2). The baseline regression coefficient estimates, on the other hand, are located in the distal position of the tail of the distribution of spurious regression coefficients, which is a small probability event in the urban placebo test, illustrating that our baseline estimation results are significant rather than due to unobservable factors, which further validates and ensures the reliability and credibility of the findings.

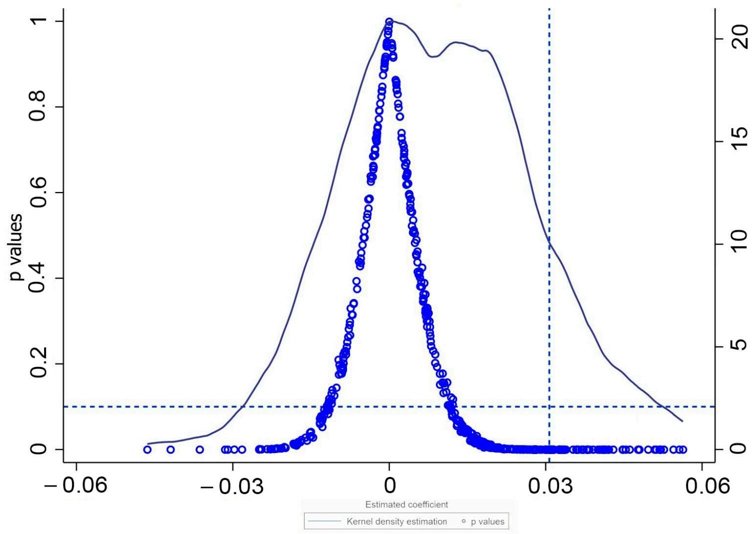

Figure 2. Urban placebo test results.

4.4. Robustness Test

The previous analysis has shown that smart city construction significantly promotes urban innovation. To further ensure the robustness of the estimation results, we continue the regression analysis in terms of the two dimensions of screening the sample data and replacing the explanatory variables.

Sample adjustment. In order to avoid the impact of extreme values on the benchmark regression results, we winsorized the sample by 1% up and down and re-adopted Equation (1) for the regression. The regression results are reported in Column (1) of Table 4, and we can see that the estimated coefficients of the smart city pilot policy are still statistically significantly positive at 1% after excluding extreme values, which is basically consistent with the benchmark estimation results.

Table 4. Results of robustness tests.

	Sample Adjustment	Replacement of Explained Variables	
	(1)	(2)	(3)
smartcity	0.0281 ***	0.0360 ***	0.0423 ***
	(3.9750)	(4.4447)	(6.3214)
Control variables	Yes	Yes	Yes
City-fixed effect	Yes	Yes	Yes
Time-fixed effect	Yes	Yes	Yes
N	3332	3332	3332
R-squared	0.7513	0.6836	0.7729

Notes: *** indicates significance at the 1% level. Numbers in parentheses are *t*-values.

Replacement of explained variables. The Peking University Open Research Data Platform also released the per capita innovation index and the per unit area innovation index of cities. We incorporate these two indexes into the benchmark regression model to further examine the impact of smart cities on urban innovation, and the regression results are reported in Column (1) and Column (2) of Table 4, respectively. The estimated coefficients of the pilot smart city policies are all significantly positive at the 1% significance level, further verifying the positive contribution of smart city construction to urban innovation.

4.5. Mechanism Analysis

4.5.1. Effect of Informatization Level

Smart city construction includes advancing the application of modern information and communication technologies such as big data, cloud computing, and IoT, which contributes to the enhancement of the urban information infrastructure and the process of urban informatization [61,62], which is crucial for facilitating the agglomeration of urban innovation factors, stimulating urban innovation activities, and bolstering the city's innovation capacity. The popularization and application of information technology can change the economic structure, increase science and technology-intensive industries, and improve the technological level and competitiveness of cities [63]. We introduced the city informatization level into the mediation effect model for analysis, and the regression results are reported in Columns (1) and (2) of Table 5. Column (1) reports the effect of smart city construction on the level of city informatization, and the regression coefficient of smart city construction is 0.161 and passes the significance test of 1%, which indicates that smart city construction significantly promotes the construction of a city's informatization. The results in Column (2) indicate that smart city construction and city informatization level have a significant positive impact on urban innovation, suggesting that the mediating effect is significant and that improvements in smart information facilities resulting from the pilot policy deliver innovative benefits to the city [57]. The direct effect of smart city construction affecting urban innovation is 0.0259, and the mediating effect through urban informatization construction is 0.0048, and Hypothesis 2 is verified.

Table 5. Mechanism analysis.

	Effect of the Level of Informatization		Effect of Government Science and Technology Investment		Effect of Industrial Structure Upgrading			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
smartcity	0.1610 *** (4.4975)	0.0259 *** (3.6784)	0.1240 *** (3.6614)	0.0204 *** (3.1222)	0.0138 *** (1.4801)	0.0278 *** (4.0701)	−0.1192 *** (−3.1171)	0.0276 *** (3.9149)
Informatization Level		0.0298 *** (8.7037)						
Government Investment				0.0831 *** (24.7348)				
Degree of Advanced Industrial Structure						0.2136 *** (16.7007)		
Rationalization of Industrial Structure								−0.0263 *** (−8.2094)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	3332	3332	3332	3332	3332	3332	3332	3332
R-squared	0.6938	0.7554	0.8222	0.7890	0.7401	0.7693	0.5225	0.7548

Notes: *** indicates significance at the 1% level. Numbers in parentheses are *t*-values.

4.5.2. Effect of Government Investment in Science and Technology

We introduce governmental science and technology investment into the mediated effect model for analysis, and the regression results are reported in Columns (3) and (4) of Table 5. Column (3) reports the effect of smart city construction on governmental science and technology investment, and the results show that the estimated value is 0.124 and is significant at a 1% statistical level, showing that the implementation of the smart city pilot policy leads to an increase in the city's science and technology expenditure. The results in Column (4) indicate that smart city construction and urban science and technology investment can both significantly promote urban innovation, which means that the mediating effect is significant. Specifically, the direct effect of smart city construction affecting urban innovation is 0.0209, and the mediating effect through governmental science and technology investment is 0.0103, which verifies Hypothesis 3. Pilot smart city policies have led governments to increase financial investment in science and technology, injecting more financial support for urban innovation. The finding also somewhat adds to the body of related research that explores the relationship between government subsidies and innovation performance [64]. In China, the government is the main driver of smart city development. When a city is established as a national pilot smart city, local governments tend to invest in the city's R&D activities, especially in science and technology R&D activities related to making the city smarter, in ways such as establishing smart city R&D centers and providing tax incentives for enterprises, which serve to boost the transformation and application of scientific and technological achievements, and to enhance the city's scientific and technological level and innovation capacity [65].

4.5.3. Effect of Industrial Structural Upgrading

We analyze the mediating effect of industrial structure upgrading from the dimensions of industrial structure advancement and industrial structure rationalization, respectively. The results of the analysis of the mediation effect of an advanced industrial structure are shown in Columns (5) and (6) of Table 5, and the results show that the regression coefficient of smart city construction on the level of industrial structure advancement is significantly positive, and at the same time the regression coefficients of smart city construction, and advanced industrial structure in Column (6) pass the test of significance at the level of 1%, which indicates that the mediation effect of an advanced industrial structure is established, and the coefficient of the mediation effect is 0.0029. Columns (7) and (8) are tests of the mediating effect of industrial structure rationalization, and the results show that the regression coefficient of smart city construction on the level of rationalization of industrial institutions is significantly negative, which means that the Theil index of industrial structure is reduced, illustrating that the construction of a smart city helps to optimize the allocation of resources, improve the efficiency of resource utilization, accelerate the flow of information between industries, contribute to the fusion of industries, and coordinate the development of various industries in the city [56], all of which are advantageous to enhancing the overall innovation competence of the city. Consequently, Hypothesis 4 is verified, expanding the existing knowledge of the channels through which smart city construction contributes to urban innovation.

4.6. Heterogeneity Analysis

4.6.1. City Size

City size refers to the number of people in a city or the size of the city's area, which to a certain extent reflect the condition of the city's resources, such as population, economy, finance, and infrastructure; important elements affecting urban innovation [32]. Therefore, there may be differences in the effect of smart city construction on urban innovation among cities of different sizes. We divide the sample into four groups: small- and medium-sized cities with a resident population of less than 1 million in the urban area, large cities with a resident population of more than 1 million and less than 5 million, supercities with a resident population of more than 5 million and less than 10 million, and megacities with a resident population of more than 10 million, based on the criteria for categorizing the size of cities published by the State Council of China. The regression results (1)–(4) in Table 6 show that the innovation effect of smart city construction is greater for larger cities, which is more obvious for large cities and supercities. However, when the size of the city is too large, the coefficient of the impact of smart city construction on urban innovation decreases, which may be due to the fact that after a certain degree of city size, the cost of urban innovation will gradually increase with the expansion of the size, while the innovation effect of smart city implementation also gradually decreases. For one thing, megacities require a higher level of infrastructure and public services to support urban development, which can entail significant investment and management costs and reduce the cost-effectiveness of innovation. In addition, the increased complexity and diversity faced by megacities in the course of their development increases the difficulty of urban management and decision-making, as well as the risk and uncertainty of innovation, which may reduce the benefits of innovation brought about by the construction of smart cities.

Table 6. Heterogeneity analysis.

	City Size				**City Location**		**Science and Education Level**	
	Small and Medium-Sized Cities	**Large Cities**	**Supercities**	**Megacities**	**East**	**Midwest**	**High**	**Low**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
smartcity	−0.0168	0.0278 ***	0.0297 ***	0.0212 **	0.0436 ***	0.0159 *	0.0228 ***	0.0259 ***
	(−0.6474)	(3.2251)	(2.6405)	(2.0224)	(3.7889)	(1.9286)	(3.0230)	(3.3657)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	68	2185	969	109	1274	2058	490	2842
R-squared	0.9227	0.7150	0.7758	0.9554	0.7122	0.7456	0.9258	0.7081

Notes: *, ** and *** indicate significance at the 10%, 5%, and 1% levels, respectively. Numbers in parentheses are *t*-values.

4.6.2. City Location

The development of cities is often shaped by their geographical location and the resulting resource endowment [66]. Compared to the central and western regions, cities in eastern China, with convenient transportation, abundant resources, and relatively high levels of human capital and foreign investment, have unique advantages regarding the agglomeration of innovation factors such as population, economy, finance, and infrastructure, and this difference in resources may cause heterogeneity in the effects of smart cities on urban innovation. We divide the sample into two groups of eastern developed cities and central and western less developed cities for regression. The regression results (5) and (6) in Table 6 show that compared with the central and western regions, the urban innovation effect brought about by smart city construction in the eastern region is more significant, suggesting that there are regional differences in the impact of smart city construction on urban innovation, and that smart city construction should be implemented according to the local conditions by taking full account of the geographic location and resource conditions of the cities, so as to better utilize its facilitating effect on urban innovation.

4.6.3. Level of Urban Science and Education

Smart city construction depends on high-tech practitioners, and colleges and universities are important bases for cultivating and nurturing scientific and technological innovation talent [35]. Examining whether the innovation effect of smart city construction varies according to the level of science and education in the city is helpful for us to clarify the focus of resource investment in smart city construction. Since 2017, China has formally proposed the construction of "double first-class" universities, which often reflect the higher quality of higher education resources and scientific research level of the cities they are located in. According to the possession of "double first-class" universities in a city, we classify the city as a city with a higher level of scientific and educational development with such universities and a city with a lower level of scientific and educational development. According to the results in Columns (7) and (8) of Table 6, there is no significant difference in the impact of smart city construction on urban innovation in different levels of science and education, and all of them show that they significantly promote urban innovation. From the regression coefficients, the promotion effect of smart city construction on urban innovation is slightly larger in cities with lower levels of science and education than in cities with higher levels of science and education, which is likely to explain why the marginal innovation effect brought about by smart city construction is relatively small in cities with "double first-class" universities, where human capital and innovation factors are fully utilized, and the marginal innovation effect is relatively small in cities with "double first-class" universities.

5. Conclusions and Policy Implications

Taking advantage of the exogenous shock brought by China's smart city pilot policy, this paper empirically analyzes the impact of smart city construction on urban innovation and its mechanism based on the panel data of 238 prefectural-level cities in China from 2006 to 2019, and mainly draws the following conclusions: First, the construction of smart cities can significantly enhance the level of urban innovation. Second, the mediating effect analysis shows that smart city construction can promote urban innovation development by improving the level of urban informatization, promoting government investment in science and technology, and optimizing industrial structure. Third, the heterogeneity analysis finds that the effect of smart cities on urban innovation varies according to the differences in city size, regional location, and science and education level. In particular, the innovation effect of smart city construction is more obvious in larger-scale cities, cities in the eastern region, and cities with lower levels of science and education. Overall, our main conclusions are in line with the findings of studies based on different cities internationally [43] and have the potential for broader implications. By elucidating the mechanisms through which smart city construction enhances urban innovation and identifying heterogeneity in the effects, our study offers valuable insights for international debate. Our conclusions provide a foundation for cross-national comparative analysis and policy exchange, facilitating a deeper understanding of the role of smart cities in fostering urban innovation globally, although the need for policy considerations tailored to the specific city characteristics of different countries must also be underscored.

Based on the conclusions of the study, there is a need to focus on the potential of smart city construction as a sustainable policy tool and to develop a policy mix that comprises the areas of smart infrastructure, industrial optimization, fiscal investment, and public governance. There are policy implications as follows:

First, the construction of modern information infrastructure in the region should be further strengthened and consolidated. The government can increase investment in information infrastructure such as data centers, cloud computing platforms, and high-speed Internet, so as to ensure that the level of informatization in the city matches the needs of the smart city.

Second, the structure of government investment in science and technology should be further optimized. The government should appropriately invest more in smart city-related scientific and technological research and development and innovation projects according to the needs of urban development, facilitating sustained breakthroughs in key technological areas. At the same time, policy measures such as financial subsidies and tax incentives can be used to encourage enterprises to increase their investment in science and technology R&D and promote scientific and technological innovation and transformation of products. However, an assessment mechanism should be established to mitigate the adverse effects of government intervention [67].

Besides, the role of modern information and communication technologies in optimizing industrial structure should be given full play. The industrial layout should be rationally planned according to the development needs and resource advantages of the city to promote industrial agglomeration and the improvement of the industrial chain, and to bring about a synergistic effect and overall competitiveness of the industries. On the one hand, the government should encourage the integration of digital technologies with traditional industries and explore intelligent paths for the development of traditional industries. On the other hand, it should actively cultivate new industries, boost the in-depth integration of modern ICT with new energy development, intelligent manufacturing, and other industries, and develop green, intelligent, and high value-added industries.

Finally, differentiated smart city construction strategies should be implemented for different types of cities according to local conditions. For example, for the more developed large-scale cities and cities in the eastern region, the main priority can be to advance the intelligent development of high-end manufacturing, modern service industries, and other fields, enhancing the intelligence level of urban governance, and accelerating the agglomeration of innovation factors. For cities with a lower level of science and education, further input into science and technology education can be increased on the basis of full consideration of their own development advantages, and scientific and technological innovation and talent cultivation can be strengthened. Future research is needed to understand alternative socioeconomic impacts of smart city construction, how governments can design smart city policies to reap benefits and avoid pitfalls, and the sustainability and scalability of smart city initiatives in a changing technological environment, in addition to investigating the role of stakeholders such as citizens, businesses, and others in shaping the effectiveness of smart city strategies.

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