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The Ramification of Broadband Infrastructure Construction on Urban Development Efficiency Based on Computer Simulation

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Abstract: - Computer-simulated broadband infrastructure construction is crucial for enhancing urban development efficiency. In this study, we examine the effects of the Broadband China pilot policy as a quasi-natural experiment on urban development efficiency. Employing a multi-period difference-in-difference (DID) model, we analyze panel data from 284 cities in China from 2009 to 2019 for insights on the impact of computer-simulated broadband infrastructure construction on urban development efficiency. Results indicate that post-Broadband China policy implementation, representing computer-simulated broadband infrastructure construction, the urban development efficiency of the treatment group is approximately 6.77% higher than the control group. Computer-simulated broadband infrastructure construction enhances urban development efficiency by improving factor resource allocation, expanding technology spillovers, and upgrading industrial structure. Temporally, computer-simulated broadband infrastructure construction significantly drives efficiency for up to 4 years, while spatially, it positively impacts surrounding urban development within 50-300 km. Continued Broadband China policy implementation is recommended for fostering high-quality urban development.

Keywords: Broadband Infrastructure Construction, Urban Development Efficiency, Computer Simulation, Total Factor Productivity.

I. INTRODUCTION

Enhancing the efficiency of urban development is crucial for promoting the high-quality advancement of regional economies. Presently, China's urban development faces numerous structural challenges, chiefly manifested in inefficient allocation of factor resources, inadequate spillover effects of technological innovation, and sluggish industrial structural upgrading. Addressing these structural issues, the adoption of computer-simulated broadband infrastructure construction, guided by the new development paradigm, has emerged as a pivotal strategy to ameliorate shortcomings and enhance urban development efficiency.

In the realm of infrastructure development, the integration of computer-simulated broadband infrastructure stands out as a transformative force. Leveraging advanced computer simulation techniques, broadband infrastructure can be meticulously planned, optimized, and deployed to cater to the evolving needs of urban environments. This computational approach heralds a paradigm shift in infrastructure development, enabling precise modeling of network architectures, traffic patterns, and user behaviors, thereby facilitating more efficient resource allocation and deployment strategies. Significantly, the rise of a new wave of technological advancements, driven by emerging general-purpose technologies such as fifth-generation mobile communication (5G), artificial intelligence, and the vast capabilities of big data, has presented unparalleled opportunities for urban development in China. These technological advancements serve as the backbone for infrastructure development, offering novel prospects for resolving the structural challenges encountered by Chinese cities.

Compared to traditional infrastructure, the integration of computer-simulated broadband infrastructure is characterized by a focus on digital transformation, intelligent upgrading, integrated innovation, and other value-added services, primarily revolving around information, integration, and innovation. The development in these domains necessitates robust support from broadband information networks. From a demand perspective, broadband information networks enhance information transmission speed between cities, reduce information transaction costs, and mitigate barriers stemming from information asymmetry [1]. On the supply side, broadband information networks endow machinery and equipment with enhanced identification, calculation, and collaboration capabilities [2]. The incorporation of network-enabled machine operations accelerates the digitization and intelligence of capital, enhancing the productivity of capital-intensive industries and enabling the evolution of conventional sectors into high-tech domains. Consequently, this drives the refinement and modernization of industrial structure. Consequently, computer-simulated broadband infrastructure emerges as the linchpin for urban development in the context of advancing technological frontiers.

To hasten the deployment of broadband infrastructure, the State Council of China promulgated the Broadband China Policy in 2013, accompanied by an Implementation Plan. Subsequently, the Ministry of Industry and

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Information Technology (MIIT) and the National Development and Reform Commission (NDRC) designated 120 cities across three batches in 2014, 2015, and 2016 as demonstration cities for China's Broadband Policy. The Broadband China policy delineated clear objectives for the selected pilot cities, encompassing the promotion of coordinated regional broadband network development, acceleration of broadband network optimization, and enhancement of broadband network security capabilities. Consequently, we selected the Broadband China policy as the focal point of our study for evaluating the implementation of computer-simulated broadband infrastructure.

This paper contributes to the field of economic analysis in China by addressing two primary objectives arising from the Broadband China initiative. Initially, it conducts a quantitative assessment of the policy's impact by treating its implementation as akin to a quasi-natural experiment. Applying a DID approach with staggered intervals, this research evaluates the effects of computer-simulated broadband infrastructure construction on urban development efficiency, duration, and spatial range using a balanced panel dataset comprising 284 regional cities in China from 2009 to 2019. Subsequently, it investigates the influencing mechanisms of computer-simulated broadband infrastructure construction on urban development efficiency through a bootstrap method [3]. Through this analysis, insights are derived into how it enhances factor resource allocation efficiency, influences the extent of technology spill-in, and fosters industrial structure optimization.

II. Literature review and Research hypothesis

A. Literature Review

The effect of infrastructure investment on total factor productivity (TFP) has attracted widespread attention from local and international scholars, mainly revealing a positive impact on of traditional infrastructure construction on TFP. Reference [4] investigated the impact of infrastructure construction on TFP into a production function model and concluded that infrastructure construction can improve TFP from the following two aspects. The first aspect was that considerable externalities generated by infrastructure construction have positive spillover effect on production factors, which can improve the marginal efficiency of factors. However, Hulten et al. only reported the spillover effect of infrastructure in one location (i.e., India) on TFP. What Hulten and colleagues overlooked was that the spatial externalities of infrastructure investment could well occur in geologically adjacent and or economically connected regions. To account for this shortcoming, [5] estimated the infrastructure construction externalities using panel data encompassing 31 Chinese provinces spanning from 2013 to 2020. Specifically, these externalities mainly included local effect within provinces and spatial effect between provinces. Their research showed that infrastructure construction improved the TFP of the city itself from the perspective of local effect, which was in line with the conclusion by [4]. From the perspective of spatial effect, infrastructure construction hindered the TFP between cities, with siphoning characteristics. To verify the validity of the above conclusions, [6] investigated the spatial diffusion effects of infrastructure networks on urbanization, employing a road network-centric approach. The temporal diffusion impact of infrastructure investment effectiveness is more pronounced in highly developed regions, whereas the spatial diffusion impact of infrastructure investment efficacy is minimal in less developed areas. The second aspect raised by Khanna et al. was that infrastructure construction could expand the scope of the production possibility curve, enabling the industry to achieve economies of scale, which gradually increases returns to scale and subsequently improve TFP. Reference [7] uncovered that the contribution of transportation infrastructure construction to TFP was higher than that of energy infrastructure construction in developed countries. However, this finding was less noticeable in developing countries or regions. Reference [8] uncovered a noteworthy association between the Internet and the enhancement of China's TFP through industrial technological progress, which prompted the authors to recommend several practical strategies for China to keep developing the Internet. Reference [9] investigated the TFP of China in high-tech industry and reported that the average asset scale and research and development (R&D) expenditure of high-tech enterprises had a significant restriction on the growth of TFP. Our literature search indicated infrastructure construction can improve the total TFP by expanding the economic scale of both traditional and high-tech industries.

An optimal infrastructure system would broaden the spatial reach of production factors and industrial goods, bolster interregional economic ties, stimulate regional economic expansion, and enhance the efficacy of regional economic advancement. However, with the gradual increase of infrastructure investment, a series of social and economic problems, such as repeated construction and government debt, will seriously restrict the overall development efficiency. Broadband infrastructure not only has the externality of public goods comparable to traditional infrastructure. More importantly, broadband infrastructure also has the spatial spillover effect. Specifically, the broadband infrastructure has the effect of trading network connectivity [10]. Such effect can effectively reduce transaction and transportation costs between regions and ensure accessibility across different locations. Due to the ease of access, economic interactions among cities will engender a spatial diffusion phenomenon, fostering regional integration markets. This beneficial impact can help reduce repeated construction and mitigate government debt problems. In view of this situation, the establishment of high-speed broadband networks, emblematic of broadband infrastructure, is regarded as a paramount objective within China's agenda for new infrastructure construction [11]. The evolution of broadband infrastructure is instrumental in fostering efficient investment practices, promoting digital economy, encouraging development mode transformation, and building a well-off society. With the ongoing evolution of information and communication technology, broadband infrastructure is expected to serve as an essential catalyst in accelerating the circulation of inventive activities, reducing the barriers of information dissemination space, and fostering transregional collaborative innovation. Therefore, broadband infrastructure has been recognized as the strategic foundation of new economic formats such as digital economy.

In this background, numerous scholarly works have focused on the effects of provincial-level broadband network expansion on TFP, urban industrial structure upgrade, and regional collaborative innovation development. For instance, Reference [12] found that the high-speed network had exerted a notable influence on the advancement of China's TFP through technological innovation. Reference [13] found that Internet infrastructure construction significantly promoted economic growth and industrial structure upgrading directly and indirectly. Reference [14] built a spatial econometric model at the firm level to reveal that the Internet promoted regional collaborative innovation as a new form of infrastructure. A more recent study asserted that both new and traditional infrastructure played a pivotal role in facilitating the optimization and modernization of industrial sectors [15]. However, these studies solely assessed the economic ramifications of provincial-level broadband infrastructure construction in China. Though the provincial level of economic studies can produce reasonable findings, the lack of precision and depth in their conclusions limits their impact on mechanistic research and practical utility. Therefore, there is a strong need to evaluate broadband infrastructure development studies at the urban level. When we zoom in on theoretical and empirical analysis at the city level, embark on an investigation into the complex mechanisms governing the impact of broadband infrastructure deployment on the efficacy of urban development.

B. Research Hypotheses

Theoretically, broadband infrastructure construction mainly drives urban development efficiency through the following three ways.

The establishment of broadband infrastructure enhances the efficiency of urban development through optimizing factor resource allocation efficiency. On one aspect, the deployment of broadband infrastructure facilitates the optimization of factor resource allocation efficiency. Primarily, the enhancement of factor resource allocation efficiency through broadband infrastructure construction stems from the mitigation of spatial and temporal constraints on regional production factors. By integrating the advanced technological advancements with the existing infrastructure, an efficient transportation network system can be built and maintained across different regions that were limited tremendously by traditional infrastructure. Hence, the spatial and temporal limitations of regional production factors can be overcome. On another aspect, the enhancement of TFP is facilitated by the optimization of resource utilization efficiency. Reference [16] proposed that the TFP of China's heavy industry sector could be increased if China's factor resources were reasonably allocated.

Broadband infrastructure construction drives the efficiency of urban development by expanding the scope of influence of technology spillover. For one thing, the establishment of broadband infrastructure facilitates the amplification of the urban technology spillover effect. Firstly, broadband infrastructure can spread information across space, bringing the spillover effect of technological innovation. Secondly, the broadband infrastructure can create a good business environment for enterprises by building a public service platform, which can effectively reduce the information cost of communication between regional enterprises. For another, technology spillover is beneficial to improve urban TFP. The neoclassical economic growth model demonstrated that technological progress is the core of improving TFP [17]. As the contribution of traditional production factors to the improvement of TFP weakens, [18] emphasized that expanding the technology spillover innovation effect matching the local factor endowment and institutional environment should be treated as the key factor to focus on for TFP improvement.

Broadband infrastructure construction drives the efficiency of urban development by fostering the refinement and modernization of industrial structure. The deployment of broadband infrastructure utilizes information technology to enhance the optimization and advancement of the industrial structure. With the advancement of new infrastructure, the amalgamation of established industries with emerging information technologies has substantially enhanced the precision of supply and demand allocation within traditional sectors [19]. In this way, the operation efficiency of the traditional industry will be greatly improved, thus p facilitating the evolution and modernization of the conventional industry. The advancement of high-speed network infrastructure can accelerate the growth of emerging industries such as industrial internet and artificial intelligence, providing a good technological basis for the industrial structure upgrade. Furthermore, the enhancement of urban development efficiency is facilitated by the refinement and modernization of industrial organization. Specifically, the refinement and enhancement of industrial organization enable the internal division of labor between different industries to become more professional and more collaborative with each other, thus reducing production costs and improving the production efficiency between different industries.

Drawing from the theoretical analysis presented earlier, this study formulates Hypothesis 1: Broadband infrastructure development drives urban development efficiency by optimizing factor resource allocation, extending the impact of technology spillover, and fostering the enhancement and modernization of industrial organization.

The impact of deploying broadband infrastructure on the efficacy of urban development exhibits heterogeneity across various stages of pilot city establishment. As China's reform and opening-up continue to advance, the relative advantages exhibited by the Broadband China pilot cities in policy implementation may begin to attenuate when compared to non-pilot cities, concurrently witnessing a gradual erosion of the institutional benefits accrued in these pilot cities until reaching a point of depletion. As a result, the stimulatory impact of broadband network expansion on urban development efficiency is expected to exhibit heterogeneity. The year-to-year performance after implementing the broadband initiative in China is anticipated to be quite different in different years in pilot cities.

From a spatial standpoint, the efficacy of broadband infrastructure development in driving urban efficiency is likely to attenuate with distance from pilot cities. Spatial economics theory suggests that agglomeration externalities exhibit diminishing returns over distance, leading to a gradual reduction in the positive spillover effects of broadband infrastructure on neighboring urban development efficiency. Hence, spatial heterogeneity may characterize the impact of broadband infrastructure deployment on urban efficiency.

Building upon temporal and spatial considerations, this paper posits Hypothesis 2: The driving force of deploying broadband infrastructure on urban development efficiency displays substantial spatial and temporal heterogeneity.

III. RESEARCH DESIGN

A. *Model and Variable*

In this paper, the Broadband China policy is considered a quasi-natural experiment, with its implementation since 2014 regarded as an exogenous policy intervention. Cities subject to this policy form the treatment group, while those not affected serve as the control group. The investigation into the impact of deploying broadband infrastructure on the efficacy of urban development adopts a multi-period DID method.

Since the Broadband pilot cities in China is launched at different times, this paper employs a multi-period comparative analysis approach method [20] to set the econometric regression model in Equation (1):

$$TFP_{it} = \beta_0 + \beta_1 DID_{it} + \lambda Z_{it} + v_i + \mu_t + \varepsilon_{it} \tag{1}$$

In Equation (1), *i* is the city and *t* is the year in the subscripts of each variable. The interpreted variable *TFP* is urban development efficiency, which is measured by urban total factor productivity. The method in [21] is applied to compute urban TFP by comprehensively considering the Slack Based Model [22] and the Malmquist productivity index [23]. If city *i* implements policy in year *t*, Variable DID_{it} is treated as 1. Otherwise, the variable DID_{it} is considered 0. If the coefficient β_1 in front of the explanatory variable DID_{it} in Equation (1) is statistically significantly greater than 0, the evaluation of Hypothesis 1 regarding broadband infrastructure's impact on urban development was undertaken.

Across 2014, 2015, and 2016, MIIT and NDRC endorsed three batches of 120 Broadband China pilot cities respectively. Hence, this study set the time nodes 2014, 2015 and 2016 as the specific years of broadband infrastructure construction.

In Equation (1), Z_{it} is the control variable composed of other contributing factors pertaining to the efficiency of urban development. Combined with the current research, the following five variables as marked by (1) to (5) are specifically included to Equation (1) to evaluate the robustness of the variable DID_{it} coefficient β_1. (1) Employment is quantified by the tertiary industry's share of total employment, indicating the significant contribution of tertiary industry employment to enhancing urban development efficiency. (2) Estate is measured in logarithmic form with base e as the natural constant of urban real estate investment. Throughout real estate development, its investment augments capital stock, enhances the efficiency of production factors, thereby fostering urban development efficiency. (3) Information is gauged through the count of urban Internet users. The Internet, characterized by its ubiquity, serves to mitigate information asymmetry inherent in social and economic production and exchange processes. It expedites the swift dissemination and circulation of information, knowledge, and other forms of capital, at reduced transaction costs, thereby enhancing urban development efficiency. (4) Foreign Direct Investment (FDI) is quantified by the proportion of foreign direct investment to the Gross Domestic Product (GDP) within each urban area. The augmentation of foreign direct investment precipitates an upsurge in the overall investment within the urban locale. Stimulated by the spill-over effects, the developmental efficiency of the urban area will progressively ameliorate. (5) Financial dimension is assessed by aggregating the urban deposits and loans balance and the ratio to urban GDP. The financial system possesses the capacity to translate a significant portion of savings into investment, thereby enhancing capital allocation efficiency and exerting influence on the savings rate to bolster urban development efficiency. In addition, v_i and μ_t represent the fixed effects specific to urban individuals and time periods, correspondingly.

Utilizing Equation (1) as the foundation, this study formulates the subsequent models at both temporal and spatial scales to examine Hypothesis 2. Referring to the event research method in [20], the econometric model Equation (2) is established to assess whether the impact of deploying broadband infrastructure on the efficacy of urban development exhibits notable temporal heterogeneity:

$$TFP_{it} = \alpha_0 + \sum_{k\geq-5,k\neq-1}^{5} \alpha_k D_{it}^k + \lambda Z_{it} + v_i + \mu_t + \varepsilon_{it} \quad (2)$$

In Equation (2), D_{it}^k represents the dummy variable of this event in pilot cities. It is assumed that the launching year of the Broadband China policy by city i is y_i. Assigning $k=t-y_i$, D_{it}^k equals to 1 when $k\leq-5$. Otherwise, D_{it}^k is treated as 0; Correspondingly, when $k=-4,-3,\ldots,3,4$, D_{it}^k equals to 1, otherwise it is 0; When $k=5$, D_{it}^5 equals to 1, otherwise it is 0. In the specific regression analysis, this work takes $k=-1$ (i.e., one year before the introduction of the Broadband policy in pilot cities in China) as the base period, so the dummy variable D_{it}^{-1} is not included in Equation (2). By comparing the statistical significance of parameter α_k in Equation (2), the temporal variability in the impact of broadband infrastructure construction on urban development efficiency can be examined.

According to the stress test research method in [24], the Equation (3) is employed to assess whether the impact of deploying broadband infrastructure on urban development efficiency exhibits substantial spatial heterogeneity:

$$TFP_{it} = \beta_0 + \beta_1 DID_{it} + \sum_{s=50}^{400} \delta_s N_{it}^s + \lambda Z_{it} + v_i + \mu_t + \varepsilon_{it} \quad (3)$$

Equation (3) introduces a new set of dummy variables $\mathrm{N}_{\mathrm{it}}^{\mathrm{s}}$ based on Equation (1). In this context, the variable s signifies the geographical span between cities in kilometres ($s\geq50$), although its determination relies on the spherical distance between any pair of cities in this research. For example, $\mathrm{N}_{\mathrm{it}}^{50}$ indicates whether there are Broadband China pilot cities within the 50 km radius from city i in year t. Therefore, the coefficient δ_s of the variable $\mathrm{N}_{\mathrm{it}}^{\mathrm{s}}$ quantifies the influence of cities adopting the Broadband China policy on the developmental efficiency of neighbouring urban areas. The regression results of Equation (3) are reported in Section 4 (Figure_2) when varying the geographical distance s from 50 km to 400 km with 50 km increment level. The examination of spatial disparities in the impact of broadband infrastructure construction on urban development efficiency is conducted by comparing the economic and statistical significance of parameter δ_s under different thresholds.

The data utilized in this study are derived from the Statistical Yearbook of Chinese Urban Areas and the statistical bulletins of Chinese provinces for the specified time frames. If the data used in the paper involves price factors, the price deflator will be processed, and the missing data will be filled up by interpolation. Finally, the balanced panel data are obtained encompassing 284 cities from 2009 to 2019.

IV. RESULTS

A. Baseline Regression Analysis

Table_1 reports the estimation results of Equation (1), in which Model_6 only controls the variable DID and individual and time fixed effect, while Model_1 to Mod-el_5 are the regression results after subtracting control variables one by one. The results in Table_1 show that the coefficients of variable DID in the estimation process of Model_1 to Model_6 are significantly positive using a 0.01 significance level ($p<0.01$). The regression results demonstrate a noteworthy influence of the pilot policy on the enhancement of urban development efficiency. The core conclusion of this paper is well-founded. The robust standard errors of the corresponding variable coefficients are shown in parentheses below the variable coefficients in Table_1. In addition, the estimation results of other control variables are also consistent with theoretical expectations. In Table_1, Model_1 the average urban development efficiency of the treatment group is about 0.0677 higher than that of the control group every year.

Figure_1 depicts the impact of the pilot policy implementation over the decade under scrutiny in this investigation. The average urban development efficiency of the treatment group has increased by about 27.08% compared with the control group between years 1 to years 4. Consequently, the observed impact of broadband network deployment on urban development efficiency is empirically robust, affirming the validity of model Equation (1).

Table 1: Baseline Regression Results

	Model_1	Model_2	Model_3	Model_4	Model_5	Model_6
Variables	TFP	TFP	TFP	TFP	TFP	TFP
DID	0.0677***	0.1092***	0.1008***	0.1163***	0.1884***	0.2159***
	(0.0176)	(0.0177)	(0.0178)	(0.0160)	(0.0134)	(0.0170)
employment	0.0124***	0.0139***	0.0137***	0.0138***	0.0138***	
	(0.0013)	(0.0013)	(0.0013)	(0.0013)	(0.0013)	
estate	0.0000***	0.0000***	0.0000***	0.0000***		
	(0.0000)	(0.0000)	(0.0000)	(0.0000)		
information	0.0000*	0.0000*	0.0000**			
	(0.0000)	(0.0000)	(0.0000)			
FDI	0.3090***	0.2654**				
	(0.1095)	(0.1226)				
financial	0.1273***					
	(0.0238)					
Constant	0.7820***	0.8951***	0.9441***	0.9535***	0.9964***	1.7266***
	(0.0738)	(0.0772)	(0.0708)	(0.0713)	(0.0712)	(0.0022)
Individual fixed effect	YES	YES	YES	YES	YES	YES
Time fixed effect	YES	YES	YES	YES	YES	YES
Observations	4,260	4,260	4,260	4,260	4,260	4,260
R-squared	0.3754	0.3135	0.3092	0.2875	0.2354	0.0927

Note: ***, **, and * indicate significance levels of 1%, 5%, and 10%, respectively. Robust standard errors are listed in parentheses.

B. Test of Spatial and Temporal Heterogeneity

1) Time heterogeneity test.

Regarding hypothesis 2, this study aims to test whether the Broadband China policy brought on significant time heterogeneity in the driving effect of urban development efficiency. Figure_1 reports the change of the coefficient of variable D_{it}^{k} in Equation (2) with time (Error bars: 95% the confidence interval). The driving effect on urban development efficiency showed a general increasing trend over the course of 10 years. More specifically, the trend started off with an initial modest increase at year -3 to -2 followed by a slight dip at around year 0. The year immediately following the enactment of the policy, the efficiency returned to its previous peak value 0.0215 ($p<0.1$), rising steadily to a much higher peak 0.0841 ($p<0.01$) at year 4. At the very last year investigated in this study, the estimated efficiency dropped to a mean value of 0.0532 ($p>0.1$). In conclusion, the temporal heterogeneity in the impact of the pilot policy has been confirmed.

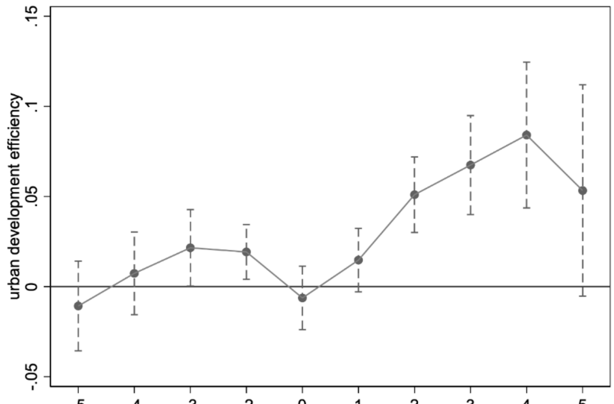

Figure 1: Temporal Heterogeneity

2) Spatial heterogeneity test.

The variation trend of variable N_{it}^{s} coefficient with spatial distance is plotted in Figure_2 drawing upon the estimation outcomes derived from Equation (3) (Error bars: 95% the confidence interval). Overall, the impact on the development efficiency of neighboring cities shows a pattern of gradual diminishment as the distance from pilot cities increases. Specifically, over 50 km away from the Broadband pilot cities, the driving effect has been reduced by nearly 42 % ($p<0.05$). Between 100 to 200 km, the driving effect remains stable and significantly above zero with a mean of 0.05242 ($p<0.05$). Between 200 to 300 km, the efficiency continued to fall from 0.0461 (at 200 km) to 0.0285 (at 250 km), to nearly zero (at 300 km spatial distance) ($p<0.05$). Over 300 km, the driving effect diminished, potentially indicating an adverse influence on the development efficiency of neighboring cities. Therefore, the spatial disparity in the driving effect of the Broadband China policy posited in Hypothesis 2 is substantiated, as illustrated in Figure_2.

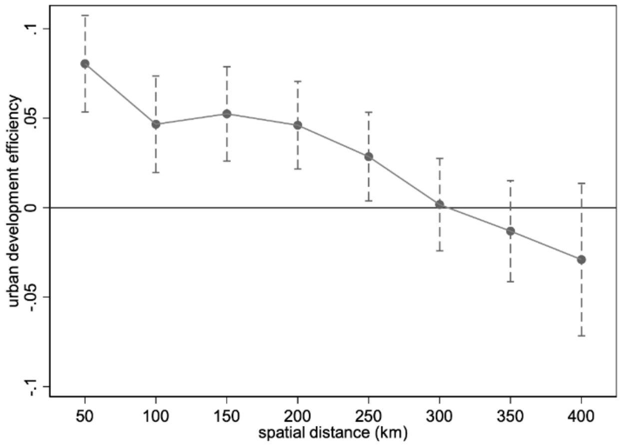

Figure 2: Spatial Heterogeneity

C. Placebo Test

This paper conducts a placebo test in terms of random substitution of groups and random changes in the launching time of the pilot policy. It is imperative to examine these two counterfactual scenarios to ascertain the robustness of the model employed in this study. Initially, the examination involves randomizing the treatment and control groups. The specific approach is to designate pilot cities in the original treatment group as the new control group. Assuming the time of setting up Broadband China pilot cities remains the same, this approach takes the numbers of pilot cities implement the policy in 2014, 2015 and 2016 in the new control group as the benchmark. At the same time, it also randomly selects another group of cities from the pilot cities that did not launch the policy before 2014, 2015, 2016 respectively as the new treatment group. On this basis, re-estimation was performed using Model_1 as shown in Table_1. The randomization placebo test is repeated 500 times, generating 500 DIDs (coefficients). The estimation outcomes reveal a mean DID coefficient value of 0.0367 ($p<0.01$, data not shown), less than what Model_1 estimates as 0.067 ($p<0.01$; see Table_1). This indicates that the policy exerts a notable impact on the development efficiency of the pilot cities. The second counterfactual pertains to the initiation timing of the pilot policy. The starting year is randomly chosen between 2009 and the recorded starting year for a given city in the balanced panel data. The newly selected time remains a constant for the following estimation process. If in reality city i launched Broadband China policy in year t, the test randomly selects any year from the time range between 2009 and t-1 before the Broadband China policy has been implemented. The new samples [2009, t-1] are input into Model_1. Similarly, the random sampling of time test is iterated 500 times to obtain the distribution of the core density of the virtual estimation coefficient as shown in Figure_3. As depicted in Figure_3, the distribution pattern of the estimated coefficients of the pseudo pilot policy closely approximates a normal distribution, with the estimated mean value being proximate to zero. Notably, this value markedly deviates from the baseline regression's coefficient of 0.0677 (see Model_1 in Table_1). Hence, random adjustments to the onset timing of the pilot policy are expected to precipitate a notable decrease in the impact of broadband infrastructure construction on urban development efficiency. This comparison demonstrates that the implementation of the pilot policy indeed enhances the development efficiency of the cities, as evidenced by the two counterfactual analyses conducted herein. Therefore, the fundamental conclusion of this paper remains robust.

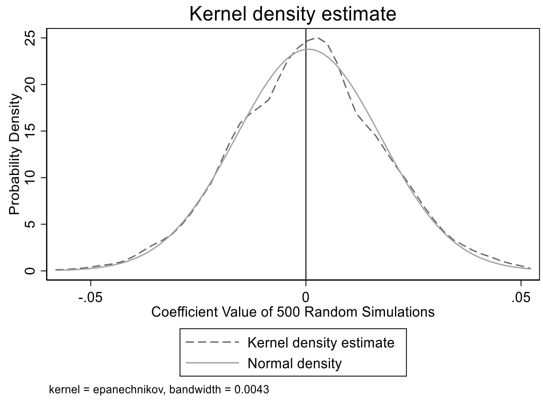

Figure 3: Placebo Test

D. Endogenous Issues

The designation of pilot cities for the broadband policy is not arbitrary; rather, it may be influenced by the economic development status of the city, the number of Internet users, and other relevant factors. These variables can influence urban development efficiency, giving rise to endogenous issues in the implementation of the policy and potentially leading to biased estimation results. Accordingly, this research utilizes the standard deviation of altitude within each city, known as Relief Amplitude, as an instrumental variable to mitigate endogeneity concerns in assessing the impact of infrastructure development on urban efficiency. There are two supporting reasons. The first one is that as an instrumental variable, topographic relief amplitude, meets the correlation condition, which will affect the construction cost and operation quality of new infrastructure. The larger the relief amplitude, the greater the expenses incurred in constructing broadband infrastructure. Another corroborating factor is that relief amplitude, as an instrumental variable, satisfies the exogeneity requirement. As an inherent geographic factor, relief amplitude is independent of the disturbance term in this analysis and exerts no influence on urban development efficiency, thereby satisfying the exogeneity criteria. This property ensures the validity of its instrumental role in the model estimation process. The findings from the two-stage ordinary least squares regression reveal that the positive impact of broadband infrastructure construction on urban development efficiency remains statistically significant. In comparison to the baseline regression, the coefficient has notably risen from 0.0677 ($p<0.01$, as indicated in Table_1) to 0.3085 ($p<0.05$, as shown in Table_2). This suggests that the positive impact of broadband infrastructure construction on urban development efficiency remains significant even as the endogenous influence diminishes. Additionally, the degree of impact has been improved. The F statistic value in the first stage of instrumental variables analysis is 176.11 (refer to Table_2), significantly exceeding the threshold of 10, thereby mitigating concerns regarding weak instrumental variables. Collectively, these results affirm the positive and robust contribution of broadband infrastructure development to the efficiency of urban development, further proving the central point of the article.

Table 2: Regression Results of Instrumental Variables

	Model_7
Variables	TFP
DID	0.3085**(0.0829)
Constant	1.2870***(0.1921)
F-value（first stage）	176.11

Note: *** and ** indicate significance levels of 1% and 5%. Robust standard errors in parentheses.

E. Analysis of Influencing Mechanism

The findings from Section 4 suggest that the pilot policy can significantly enhance urban development efficiency. The subsequent inquiry pertains to elucidating the mechanisms through which the policy enhances urban development efficiency. Drawing from the theoretical underpinnings of Hypothesis 1, this study integrates factor resource allocation efficiency, technology spillover effects, and industrial structure upgrades as mediators within the mediation effect framework [25], aiming to elucidate the intricate mechanisms at play. This analytical approach serves to validate the underlying influence and elucidate the intricate pathways through which these variables interact, thereby enriching our understanding of the causal relationships within the economic landscape. Therefore, this study builds the mediation effect model as shown in Equation (4), (5):

$$M_{it} = \delta_0 + \delta_1 DID_{it} + \theta Z_{it} + v_i + \mu_t + \varepsilon_{it} \quad (4)$$

$$TFP_{it} = \gamma_0 + \gamma_1 DID_{it} + \gamma_2 M_{it} + \varphi Z_{it} + v_i + \mu_t + \varepsilon_{it} \quad (5)$$

Where M denotes a mediating variable and Z represents control variables. Adapted from [25], this paper tests the mediation effect through three steps: Firstly, Equation (1) $TFP_{it} = \beta_0 + \beta_1 DID_{it} + \lambda Z_{it} + v_i + \mu_t + \varepsilon_{it}$ calculates urban development efficiency using TFP as the dependent variable and the construction of broadband infrastructure based on the Broadband China policy as the explanatory variable. Regression was done through Equation (1) to obtain the Broadband China policy correlation coefficient β1. Secondly, In Equation (4), this paper considers the mediating variables as the endogenous variable, while maintaining consistency with the remaining variables in the initial stage. We can get the Broadband China policy correlation coefficient σ1. Three different methods were chosen accordingly to quantify the following three mediating variables, including factor resource allocation efficiency, technology spill-over effect and industrial structure upgrading. The methodology was modified to assess the efficiency of factor resource allocation, emphasizing the quantification of factor market misallocation through the application of a production function characterized by constant returns to scale[26]. For technology spill-over, the method was improved by constructing indicators of R&D expenditure and the number of patents per capita in each city[27]. To evaluate industrial structure upgrading, the method was applied by using the high level and rationalization of industrial structure[28]. Thirdly, this paper incorporates the pilot policy (as an independent variable) and intermediary variables into Equation (5) for regression. This allows one to observe their impact on urban development efficiency and obtain the Broadband China pilot policy correlation coefficient γ1. Upon completing three steps, if the coefficients β1, σ1 and γ1 are statistically significant when γ1 decreases significantly than β1, it proves the existence of mediation effect.

The regression results of factor resource allocation efficiency as an intermediary variable are shown in Model_1, Model_8, and Model_9 in Table_3.

Table 3: Resource Allocation Efficiency

	Model_1	Model_8	Model_9
Variables	TFP	misallocation	TFP
DID	0.0677***	-0.1884***	0.0583**
	(0.0176)	(0.0134)	(0.0134)
misallocation	—	—	-0.0318***
			(0.013)
Constant	0.7820***	1.9238***	0.9964*
	(0.0738)	(0.2731)	(0.0712)
Observations	4,260	4,260	4,260
R-squared	0.7354	0.2354	0.0124

Note: ***, **, and * indicate significance levels of 1%, 5%, and 10%, respectively. Robust standard errors are listed in parentheses.

The findings from Model_1 demonstrate that the regression coefficient associated with the Broadband China policy is 0.0677 ($p<0.01$), signifying a statistically significant positive impact of broadband infrastructure construction on urban development efficiency. In contrast, Model_8 results indicate a regression coefficient of -0.1884 ($p<0.01$) for the Broadband China policy concerning the level of resource allocation distortion, implying a mitigating effect of the policy on urban resource misallocation. Model_9 integrates both the Broadband China policy and the degree of resource distortion in the analysis, revealing a regression coefficient of 0.0583 ($p<0.05$), lower than the estimate from Model_1 (0.0677, $p<0.01$). Furthermore, Model_9 highlights a significantly negative regression coefficient for the degree of resource allocation distortion (-0.0318, $p<0.01$). The results unveiled by Model_9 suggest the presence of an intermediary effect of resource allocation distortion, indicating that the enhancement of urban development efficiency through broadband infrastructure construction is mediated by the alleviation of resource misallocation. This verifies the role of resource allocation efficiency as an intermediary variable in supporting Hypothesis 1.

The outcomes of Model_10 indicate a regression coefficient of 0.3469 ($p<0.01$) for the Broadband China policy's impact on technology spill-over effects, suggesting that the implementation of broadband infrastructure has enhanced the innovation landscape within cities. Furthermore, Model_11 incorporates both the Broadband China policy and technology spill-over effects in its analysis. The regression coefficient for the Broadband China pilot policy is estimated at 0.0098 ($p<0.1$) in Model_11, a decrease from the coefficient estimated in Model_1 (0.0677, $p<0.01$). Additionally, Model_11 reveals a significantly positive regression coefficient of 0.0619 ($p<0.05$) for technology spill-over effects, indicating the presence of an intermediary effect. The findings presented in

Table_4 provide support for the assertion that broadband infrastructure development enhances urban development efficiency through technology spill-over effects. Thus, the role of technology spill-over effects as an intermediary variable in supporting Hypothesis 1 is confirmed.

The regression results of technology spill-over effect as an intermediary variable are reported in Table_4

Table 4: Technology Spill-over Effect

	Model_1	Model_10	Model_11
Variables	TFP	spillover	TFP
DID	0.0677***	0.3469***	0.0098*
	(0.0176)	(0.0374)	(0.0134)
spill-over	—	—	0.0619**
			(0.013)
Constant	0.7820***	12.5639***	0.1872*
	(0.0738)	(0.5731)	(0.3521)
Observations	4,260	4,260	4,260
R-squared	0.7354	0.8354	0.0046

Note: ***, **, and * indicate significance levels of 1%, 5%, and 10%, respectively. Robust standard errors are listed in parentheses.

The regression results of industrial structure upgrading as an intermediary variable are demonstrated in Model_1, Model_12, and Model_13 (Table_5).

Table 5: Industrial Structure Upgrading

	Model_1	Model_12	Model_13
Variables	TFP	upgrading	TFP
DID	0.0677***	0.2748***	0.0498*
	(0.0176)	(0.0128)	(0.0561)
upgrading	—	—	0.0318***
			(0.013)
Constant	0.7820***	-1.5623***	0.9257***
	(0.0738)	(0.0831)	(0.1235)
Observations	4,260	4,260	4,260
R-squared	0.7354	0.2635	0.0074

Note: ***, **, and * indicate significance levels of 1%, 5%, and 10%, respectively. Robust standard errors are listed in parentheses.

In Model_12, the regression analysis yields a coefficient of 0.2748 ($p<0.01$) for the impact of the Broadband China policy on industrial structure upgrading, indicating that the implementation of broadband infrastructure has led to enhancements in the city's industrial structure. Model_13 incorporates both the Broadband China pilot policy and industrial structure upgrading into the regression analysis. The estimated regression coefficient for the Broadband China policy in Model_13 is 0.0498 ($p<0.1$), lower than the coefficient of 0.0677 ($p<0.01$) derived from Model_1. Furthermore, the regression coefficient for industrial structure upgrading is found to be significantly positive at 0.0318 ($p<0.05$), suggesting the presence of an intermediary effect. Consequently, industrial structure upgrading is deemed to play a significant role in augmenting the impact of broadband infrastructure construction on urban development efficiency. The validation of industrial structure upgrading as an intermediary variable in supporting Hypothesis 1 is thus established.

V. Research Conclusion and Policy recommendations

A. Research Conclusion

Utilizing a multi-period DID approach, we examined the impact of computer-simulated broadband infrastructure construction, treating the implementation of the Broadband China policy as a quasi-natural experiment, on urban development efficiency across 284 prefecture-level cities in China from 2009 to 2019.

In summary, the study results can be encapsulated as: Initially, post-policy implementation, urban development efficiency in the treatment group increased by approximately 6.77% compared to the control group. Chronologically, this effect persisted from year 1 to 4, with the overall treatment group showing a 27.08% higher average urban development efficiency than the control group. Spatially, computer-simulated broadband infrastructure construction exhibited a significant positive impact within a radius of 50 to 300 km, without causing detrimental effects on urban economic growth within a 350 km radius. This underscores the sustained positive influence of computer-simulated broadband infrastructure on urban development efficiency, aligning with the objectives of coordinated regional economic development. Additionally, we explored the specific mechanisms through which computer-simulated broadband infrastructure construction influences urban development efficiency, including factors such as market distortion, R&D costs, patent numbers per capita, and industrial restructuring. Results indicate that computer-simulated broadband infrastructure construction enhances urban development efficiency by enhancing resource allocation efficiency, broadening the reach of technology spill-over effects, and facilitating optimization and upgrading of industrial structures.

B. Policy Recommendations

Drawing from our conclusions, this paper puts forth a number of pivotal policy suggestions. Firstly, the utilization of computer-simulated broadband infrastructure is essential for enhancing urban development efficiency, affirming the government's efficacy in fostering broadband infrastructure development. As existing pilot cities progress, policymakers can gain invaluable insights, leading to the refinement of overarching rules and guidelines. This approach can prompt the identification of more eligible cities and the expansion of initial pilot city initiatives, thereby fostering high-quality urban development across China.

Additionally, it is imperative to tailor measures to local conditions to bolster the effectiveness of the computer-simulated broadband infrastructure initiative. Aligning with varying economic development levels and regional factors, establishing robust tracking, evaluation, and monitoring systems for pilot cities is crucial. Flexibility in adjusting measures and implementing withdrawal mechanisms for underperforming cities is advisable, although withdrawal criteria may require refinement over time.

Furthermore, exploring a multi-dimensional approach to the computer-simulated broadband infrastructure initiative is recommended to maximize urban development efficiency. Leveraging the influence mechanisms of broadband infrastructure, we suggest three policy levels: Firstly, harnessing internet platforms to dismantle market segmentation barriers, enhancing production factor allocation efficiency. Secondly, increasing government investment in education and research, focusing on nurturing innovative talents, optimizing the business environment, and fortifying intellectual property rights protection. Thirdly, harnessing cutting-edge technologies like big data technology, and blockchain to drive the optimization of industrial structures.

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Data Availability Statement

Please contact the corresponding author for access to the dataset used in this study.

References

[1] P. Almeida and B. Kogut, “Localization of Knowledge and the Mobility of Engineers in Regional Networks,” Management Science, vol. 45, no. 7, Art. no. 7, 1999.

[2] A. Berg, E. F. Buffie, and L.-F. Zanna, “Should we fear the robot revolution? (The correct answer is yes),” Journal of Monetary Economics, vol. 97, pp. 117–148, Aug. 2018.

[3] A. M. Zoubir and D. R. Iskandler, “Bootstrap Methods and Applications,” IEEE Signal Processing Magazine, vol. 24, no. 4, pp. 10–19, Jul. 2007.

[4] R. Khanna and C. Sharma, “Does infrastructure stimulate total factor productivity? A dynamic heterogeneous panel analysis for Indian manufacturing industries,” The Quarterly Review of Economics and Finance, vol. 79, pp. 59–73, 2021.

[5] P. Zhang, J. Wang, M. Li, and F. Xiao, “The impact of information infrastructure on upgrading industrial structure: The intermediary role of urbanization and technological progress,” 2022, Accessed: Mar. 08, 2024. [Online]. Available: https://www.researchsquare.com/article/rs-1760763/latest

[6] I. C. Álvarez-Ayuso, A. M. Condeço-Melhorado, J. Gutiérrez, and J. L. Zofío, “Integrating Network Analysis with the Production Function Approach to Study the Spillover Effects of Transport Infrastructure,” Regional Studies, vol. 50, no. 6, pp. 996–1015, Jun. 2016.

[7] D. Canning and M. Fay, “The Effects of Transportation Networks on Economic Growth,” Department of Economics, Columbia University, 1993. Accessed: Sep. 18, 2022. [Online]. Available: https://doi.org/10.7916/D80K2H4N

[8] J. Mao, S. Tang, Z. Xiao, and Q. Zhi, “Industrial policy intensity, technological change, and productivity growth: Evidence from China,” Research Policy, vol. 50, no. 7, p. 104287, 2021.

[9] X. Chen, X. Liu, and Q. Zhu, “Comparative analysis of total factor productivity in China’s high-tech industries,” Technological Forecasting and Social Change, vol. 175, p. 121332, 2022.

[10] C. T. Vidya and F. Taghizadeh-Hesary, "Does infrastructure facilitate trade connectivity? Evidence from the ASEAN," Asia Europe Journal, vol. 19, no. 1, Art. no. 1, Dec. 2021, doi: 10.1007/s10308-021-00614-6.

[11] X. Jia, B. Xie, and X. Wang, "The impact of network infrastructure on enterprise digital transformation ——A quasi-natural experiment from the 'broadband China' Strategy," Applied Economics, vol. 56, no. 12, pp. 1363–1380, Mar. 2024, doi: 10.1080/00036846.2023.2176450.

[12] W. Pan, T. Xie, Z. Wang, and L. Ma, "Digital economy: An innovation driver for total factor productivity," Journal of Business Research, vol. 139, pp. 303–311, Feb. 2022.

[13] J. Su, K. Su, and S. Wang, "Does the Digital Economy Promote Industrial Structural Upgrading?—A Test of Mediating Effects Based on Heterogeneous Technological Innovation," Sustainability, vol. 13, no. 18, Art. no. 18, Jan. 2021.

[14] A. Niebuhr, J. C. Peters, and A. Schmidke, "Spatial sorting of innovative firms and heterogeneous effects of agglomeration on innovation in Germany," The Journal of Technology Transfer, vol. 45, no. 5, pp. 1343–1375, 2020.

[15] M. I. Nadiri, B. Nandi, and K. K. Akoz, "Impact of modern communication infrastructure on productivity, production structure and factor demands of US industries: Impact revisited," Telecommunications Policy, vol. 42, no. 6, pp. 433–451, 2018.

[16] M. Yang, F. Yang, and C. Sun, "Factor market distortion correction, resource reallocation and potential productivity gains: An empirical study on China's heavy industry sector," Energy Economics, vol. 69, pp. 270–279, 2018.

[17] R. M. Solow, "Technical change and the aggregate production function," The review of Economics and Statistics, pp. 312–320, 1957.

[18] T. Ma and X. Cao, "FDI, technological progress, and green total factor energy productivity: evidence from 281 prefecture cities in China," Environ Dev Sustain, vol. 24, no. 9, pp. 11058–11088, Sep. 2022.

[19] M. I. Hanif, A. Kamran, and M. S. Hanif, "Collaborative innovation of strategic emerging industries: A case study of the new generation of information technology enterprises in China," IBT Journal of Business Studies (JBS), vol. 2, no. 2, 2017, Accessed: Mar. 14, 2024.

[20] T. Beck, R. Levine, and A. Levkov, "Big Bad Banks? The Winners and Losers from Bank Deregulation in the United States," The Journal of Finance, vol. 65, no. 5, Art. no. 5, 2010.

[21] C. Jiancheng, W. Huiyu, and H. Jian, "The Influence Mechanism of Industrial Agglomeration on Forestry Green Total Factor Productivity from the Perspective of Financial Support," Journal of Beijing Forestry University (Social Science), vol. 23, no. 1, pp. 11–20, 2024.

[22] F. Boloori, "A slack based network DEA model for generalized structures: An axiomatic approach," Computers & Industrial Engineering, vol. 95, pp. 83–96, May 2016.

[23] C. Zhang, "Measuring the Development Level of Digital Industrialization and Industrial Digitization using the SBM-Malmquist Model: Evidence from prefecture-level cities in China," Advances in Economics and Management Research, vol. 6, no. 1, pp. 311–311, 2023.

[24] X. Jin, B. Ma, and H. Zhang, "Impact of fast internet access on employment: Evidence from a broadband expansion in China," China Economic Review, vol. 81, p. 102038, Oct. 2023.

[25] L. Zhao, F. Liu, Han, T. Zhang, and C. Wei, "Mediation Effect Test Procedure and Its Application," Biotechnology World, no. 216, 2014.

[26] Md. Ferdous Alam and K. Murshed-e-Jahan, "Resource Allocation Efficiency of the Prawn-Carp Farmers of Bangladesh," Aquaculture Economics & Management, vol. 12, no. 3, pp. 188–206, Aug. 2008.

[27] J. Zhang, Y. Chang, L. Zhang, and D. Li, "Do technological innovations promote urban green development?—A spatial econometric analysis of 105 cities in China," Journal of Cleaner Production, vol. 182, pp. 395–403, May 2018.

[28] Y. Su and Q. Fan, "Renewable energy technology innovation, industrial structure upgrading and green development from the perspective of China's provinces," Technological Forecasting and Social Change, vol. 180, p. 121727, Jul. 2022.