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Digital Infrastructure Development and Economic Growth: Firm-Level Evidence from Investment Efficiency

数字基础设施发展与经济增长：来自投资效率的企业层面证据

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Abstract. This study empirically investigates the impact of digital infrastructure development on corporate investment efficiency in the context of China's Broadband China policy. Using a sample of Chinese listed firms from 2007 to 2021, the analysis employs a difference-in-differences approach, complemented by propensity score matching and instrumental variable techniques, to evaluate the policy's effects on inefficient investment, overinvestment, and underinvestment. The results show that the Broadband China policy significantly improves corporate investment efficiency by alleviating inefficiencies, particularly those associated with excessive investment behavior. These effects are more pronounced in regions with relatively advanced infrastructure. Heterogeneity analysis further reveals substantial differences across locations, with firms situated in provincial capitals benefiting more from the policy than those in non-capital cities. Mechanism analysis indicates that improvements in managerial efficiency play a mediating role in the relationship between digital infrastructure development and corporate investment behavior. Overall, the findings provide both theoretical and empirical support for governmental initiatives aimed at strengthening digital infrastructure and promoting balanced regional economic development. Based on these results, the study proposes differentiated policy recommendations to enhance managerial efficiency through digital infrastructure development and to reduce regional disparities. Future research may extend the analysis by incorporating broader datasets and examining the effects of digital infrastructure on other firm-level outcomes, such as innovation performance and market competitiveness.

Keywords: Digital infrastructure, economic growth, corporate investment efficiency, broadband China, management efficiency

摘要： 本研究在中国“宽带中国”政策背景下，实证检验了数字基础设施发展对企业投资效率的影响。基于2007年至2021年中国上市公司的样本数据，采用双重差分（DID）方法，并结合倾向得分匹配（PSM）与工具变量（IV）技术，对该政策在抑制低效投资、过度投资和投资不足方面的影响进行评估。研究结果表明，“宽带中国”政策显著提升了企业投资效率，通过缓解投资低效问题，尤其是与过度投资行为相关的效率损失，发挥了积极作用。这一影响在基础设施相对完善的地区更为显著。异质性分析进一步显示，不同地区之间存在明显差异，位于省会城市的企业从该政策中获得的收益显著高于非省会城市企业。机制分析表明，管理效率的提升在数字基础设施发展与企业投资行为之间发挥了中介作用。总体而言，本研究为政府加强数字基础设施建设、促进区域经济均衡发展提供了理论与实证支持。基于上述结论，本文提出差异化政策建议，即通过数字基础设施建设提升企业管理效率，并缩小区域发展差距。未来研究可通过扩展样本数据范围，进一步探讨数字基础设施对企业层面其他绩效指标（如创新绩效与市场竞争力）的影响。

关键词： 数字基础设施；经济增长；企业投资效率；宽带中国；管理效率

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1. Introduction

Rapid global digitalization has positioned digital infrastructure as a critical driver of economic growth and corporate competitiveness. As the world's second-largest economy, China has actively promoted the integration of the digital and real economies through a series of policy initiatives, most notably the Broadband China strategy, aimed at strengthening information network infrastructure. In this setting, digital infrastructure not only enhances production efficiency but also reshapes firms' investment decision-making processes. By lowering transaction costs and reducing information asymmetry, well-developed digital infrastructure can significantly improve corporate investment efficiency. While prior studies have primarily examined the effects of digital infrastructure on productivity and innovation, systematic empirical evidence on its influence on corporate investment efficiency—particularly with respect to regional and sectoral heterogeneity—remains limited. Therefore, investigating how digital infrastructure improves investment efficiency through enhanced information flows and managerial capabilities is of substantial theoretical and practical importance.

Existing literature suggests that digital infrastructure plays a vital role in fostering economic growth and improving firm performance. The expansion of the digital economy has blurred traditional industrial boundaries and fundamentally transformed information transmission and resource allocation processes (Xu & Jin, 2024; Yu et al., 2023). At the firm level, widespread broadband adoption facilitates access to market information, thereby enhancing decision-making efficiency (Goldfarb & Tucker, 2011; Zhou et al., 2024). Moreover, improvements in digital infrastructure can strengthen management efficiency and corporate governance, ultimately leading to more efficient investment behavior (Brynjolfsson & McAfee, 2014; Feng et al., 2024). Nevertheless, several gaps persist in the existing research. First, studies examining the relationship between digital infrastructure development and corporate investment efficiency remain fragmented, with most focusing on macro-level outcomes and providing limited micro-level evidence (Mao et al., 2024). Second, regional and sectoral heterogeneity has not been sufficiently addressed, despite China's highly diverse and complex market environment (Zhang & Liu, 2023). Third, the mechanisms through which digital infrastructure alleviates information asymmetry and enhances managerial efficiency are not yet fully clarified (Zhang et al., 2022).

To address these limitations, this study employs the Broadband China policy as a quasi-natural experiment to systematically analyze the impact of digital infrastructure development on corporate investment efficiency, its underlying mechanisms, and regional heterogeneity. Specifically, the study seeks to answer three key questions. First, to what extent has digital infrastructure development under the Broadband China initiative improved corporate investment efficiency? Second, through which mechanisms does digital infrastructure influence corporate investment decisions, particularly in terms of reducing information asymmetry and enhancing management efficiency? Third, do these effects vary across regions and firms, especially with respect to differences in infrastructure development levels and firm size? By addressing these questions, the study provides both theoretical insights for policymakers and practical guidance for corporate decision-makers.

Using panel data from Chinese listed firms between 2009 and 2020, this study adopts a difference-in-differences (DID) framework, supplemented by parallel trend tests and instrumental variable (IV) estimation, to identify the causal effects of digital infrastructure development. The empirical results consistently show that the Broadband China policy significantly enhances corporate investment efficiency. These effects are particularly pronounced in regions with higher levels of information asymmetry and among firms with lower degrees of digitalization. Mechanism analysis further reveals that improvements in management efficiency serve as a key transmission channel through which digital infrastructure affects

corporate investment decisions. Overall, the findings highlight the crucial role of digital infrastructure not only in supporting short-term corporate operations but also in fostering long-term improvements in investment efficiency.

This study contributes to the literature in three main ways. First, it provides new micro-level empirical evidence on the relationship between digital infrastructure and corporate investment efficiency, extending research on the digital economy beyond productivity and innovation outcomes to firms' investment behavior. Second, by leveraging the Broadband China policy as a natural experiment and employing DID and IV methodologies, the study effectively addresses endogeneity concerns and enhances the credibility of the results. Third, the identification of management efficiency as a key mechanism deepens the theoretical understanding of how digital infrastructure influences corporate decision-making. Collectively, these findings offer important policy implications for advancing digital infrastructure development and promoting corporate digital transformation in pursuit of more efficient and balanced economic growth.

2. Theoretical Framework

Digital Infrastructure and Corporate Investment Efficiency

The development of digital infrastructure plays a crucial role in improving the allocation efficiency of production factors. According to neoclassical economic growth theory, corporate investment efficiency largely depends on the effective utilization of production inputs, among which information serves as a fundamental element for ensuring rational and accurate investment decisions (Solow, 1956). In the context of the digital economy, digital infrastructure reduces information asymmetry by accelerating information transmission and enhancing its accuracy, thereby lowering decision-making costs for firms (Brynjolfsson & McAfee, 2014). Moreover, digital infrastructure provides enterprises with advanced technologies such as big data analytics and cloud computing, which significantly improve the precision of resource allocation and investment decision-making (Wang et al., 2023). By enabling firms to quickly analyze market conditions and industry trends, these technologies allow for more timely and informed investment decisions, ultimately enhancing overall investment efficiency.

Beyond theoretical foundations, recent empirical studies emphasize that the expansion of broadband and high-speed internet constitutes a key determinant of corporate investment efficiency. Autor (2019) highlights that broadband diffusion not only increases the speed of information exchange but also enhances information transparency and accessibility. Since corporate investment decisions rely heavily on the completeness and reliability of information, improvements in digital infrastructure substantially enhance information quality and flow (Liu et al., 2024), thereby strengthening firms' capacity to identify and respond to changes in the external environment. These benefits are particularly significant for small and medium-sized enterprises (SMEs), as improved digital infrastructure helps them overcome informational disadvantages, enhance competitiveness, and improve investment returns (Peng et al., 2024; Zhai et al., 2024). Accordingly, this study proposes the following hypothesis:

Hypothesis 1. Digital infrastructure enhances corporate investment efficiency

Digital Infrastructure, Flattened Management Structures, and Investment Efficiency

The advancement of digital infrastructure has also brought about profound changes in corporate organizational structures and management practices. Traditional management theories, such as Weber's bureaucracy theory, argue that increased hierarchical complexity within organizations leads to slower information transmission and reduced decision-making efficiency (Li et al., 2024). However, the diffusion

of digital technologies has enabled firms to streamline organizational layers and adopt flatter management structures. Digital tools, including cloud computing and big data systems, facilitate the integration and real-time sharing of information, reducing reliance on multiple layers of middle management and minimizing information distortion (Otarbayeva et al., 2024). As a result, firms operating under flatter organizational structures can respond more rapidly to market signals and improve the efficiency of their investment decisions (Cao, Dong, et al., 2020).

Recent studies further corroborate this view. Brynjolfsson and McAfee (2014) argue that advancements in digital infrastructure—particularly in information processing and decision-support systems—are closely associated with transformations in corporate organizational structures (Gu et al., 2024; Jin et al., 2023). These changes significantly enhance operational efficiency and the quality of investment decisions. Additionally, digital infrastructure promotes the integration of internal and external information flows, enabling managers to gain a more comprehensive understanding of firm operations and make more informed investment choices. Such improvements not only increase short-term investment efficiency but also support firms' long-term sustainable development (Jin et al., 2024; Song et al., 2024). Based on this reasoning, the following hypothesis is proposed:

Hypothesis 2. Digital infrastructure facilitates the flattening of corporate management structures, thereby improving management efficiency and enhancing corporate investment efficiency.

3. Methodology

This study adopts a quasi-experimental design centered on China's Broadband China pilot rollout as an exogenous shock to local digital infrastructure. Using an unbalanced panel of Chinese A-share listed firms from 2007–2021, firm-level financial and governance data are merged with city-level policy implementation information to identify treated and control firms based on whether their city was selected as a pilot in a given year. Corporate investment efficiency is measured by estimating expected (normal) investment from standard determinants (e.g., growth opportunities, cash flow, leverage, size, and past investment) and defining inefficient investment as the deviation from predicted investment; positive residuals indicate overinvestment, while negative residuals indicate underinvestment. The baseline model applies a difference-in-differences (DID) specification with firm and year fixed effects (and, where appropriate, industry-by-year or city-by-year controls) to isolate the policy's impact, while clustering standard errors at the city level to account for within-region correlation over time. A series of validity checks—such as pre-trend (event-study) tests, alternative investment-efficiency measures, and placebo assignments—are used to support the parallel-trends assumption and the robustness of the estimated effects.

To strengthen causal inference and address selection concerns, the analysis integrates propensity score matching (PSM-DID) by matching treated firms to observationally similar control firms using pre-policy firm characteristics (e.g., size, profitability, leverage, growth, cash holdings, ownership, and governance) and re-estimating DID on the matched sample. Potential endogeneity from non-random pilot placement is further mitigated using an instrumental variable (IV) strategy, where the instrument captures predetermined factors that shape broadband deployment feasibility or intensity but are plausibly unrelated to contemporaneous firm investment inefficiency (except through digital infrastructure). Heterogeneity is examined via sub-sample regressions and interaction terms, comparing effects across regions with different baseline infrastructure levels and across provincial capital vs. non-capital cities. Finally, mechanism analysis tests whether managerial efficiency mediates the policy effect by estimating (i) the impact of broadband policy on managerial efficiency, (ii) the association between managerial efficiency and inefficient investment, and (iii) the attenuation of the policy coefficient after introducing the mediator, complemented by bootstrap tests for indirect effects.

Data Sample

This study employs financial data from Chinese A-share listed firms covering the period 2007–2021, obtained from the CSMAR database, corporate announcements, and annual reports. To ensure data integrity and enhance the reliability of empirical results, the sample is processed according to the following criteria. First, financial institutions are excluded due to their distinctive capital structures and leverage characteristics, which may bias investment behavior estimates. Second, firms labeled as ST or *ST are removed, as these companies typically face severe financial distress that could distort measurements of investment efficiency. Third, observations with missing values are eliminated to guarantee data completeness. Finally, all continuous variables are winsorized at the 1% level at both tails to mitigate the influence of extreme values and reduce potential estimation bias.

The resulting dataset includes listed firms from a wide range of regions and industries across China, providing a comprehensive empirical foundation for evaluating the impact of the Broadband China policy on corporate investment efficiency. The credibility of the dataset is further strengthened by the authoritative nature of the CSMAR database, which has undergone multiple verification procedures and is widely used in academic research. The rigorous data-cleaning process ensures that the sample is representative and that the empirical findings are robust and reliable.

Corporate Investment Efficiency

The dependent variable is corporate investment efficiency (INV), with particular attention paid to distinguishing overinvestment from underinvestment. Investment efficiency reflects the extent to which firms allocate capital in line with optimal returns. Following Richardson (2006), investment efficiency is measured using a regression framework that incorporates firm-level financial and market characteristics:

$$INV_{i,t} = \alpha 0 + \alpha 1 Growth_{i,t} + \alpha 2 Lev_{i,t-1} + \alpha 3 Cash_{i,t-1} + \alpha 4 Age_{i,t-1} + \alpha 5 Size_{i,t-1} + \alpha 6 Return_{i,t-1} + \alpha 7 INV_{i,t-1} + \sum Industry + \sum Year + \varepsilon_{i,t} \quad (1)$$

Here, INV represents total investment, defined as cash payments for fixed assets, intangible assets, and other long-term assets minus cash recovered from disposals. Growth is measured by Tobin's Q to capture growth opportunities. Lev denotes financial leverage, calculated as the debt-to-asset ratio. Cash reflects operating cash flow scaled by beginning-of-period total assets. Age measures the number of years since listing, Size is the natural logarithm of total assets, and Return represents annual stock returns including dividend reinvestment.

Investment inefficiency is captured by the absolute value of the regression residuals (Oinv_level), which reflects deviations from optimal investment. Additionally, a binary variable (Oinv) is constructed to distinguish overinvestment (value = 1) from underinvestment (value = 0).

Broadband China Policy Variable

The key explanatory variable is the Broadband China policy, launched in 2013 through the "Broadband China Strategy and Implementation Plan," which designated broadband infrastructure as a form of strategic public infrastructure. Beginning in 2014, the policy was rolled out in multiple phases across 120 pilot cities and city clusters.

This policy is treated as a quasi-natural experiment. Two dummy variables are constructed: Time, which equals 1 for years after the policy's implementation (post-2014), and Treat, which equals 1 if a firm

is located in a Broadband China pilot city and 0 otherwise. The interaction term Time × Treat captures the differential impact of broadband infrastructure development on firms located in pilot cities relative to those in non-pilot areas.

Control Variables

To account for other determinants of investment efficiency, several control variables are included following prior literature (Kong et al., 2021; Zhang & Kong, 2022; Wang et al., 2024). Cash flow (Cflow) is measured as operating cash flow divided by total assets, reflecting internal financing capacity. Growth capability (Growth) is proxied by revenue growth rate. Ownership structure (Soe) is a dummy variable equal to 1 for state-owned enterprises and 0 otherwise.

Corporate governance is controlled for using the independent director ratio (Indiratio), defined as the number of independent directors relative to total board members. Financial leverage (FinLeverageRatio) is measured as total liabilities over total assets. Asset utilization efficiency (Rab) is calculated as revenue divided by total assets. Market competition is captured by the Herfindahl–Hirschman Index (HHI), computed as the sum of squared market shares based on firms' primary business revenues within their industries.

Descriptive Statistics

Table 1. Descriptive statistics of key variables.

Variable	Obs	Mean	Std. Dev.	Min	Max
Oinv_level	29300	0.042	0.052	0.000	0.562
Oinv	29300	0.387	0.487	0.000	1.000
Time_Treat	29300	0.448	0.497	0.000	1.000
Cflow	29300	0.045	0.038	0.002	0.255
Growth	29300	0.393	1.213	− 0.879	23.418
Soe	29300	0.441	0.497	0.000	1.000
Indiratio	29300	37.386	5.339	25.000	60.000
Ratio	29300	0.448	0.201	0.046	0.927
Rab	29300	0.638	0.439	0.062	3.058
HHI	29300	0.197	0.235	0.017	1.000

Table 1 reports descriptive statistics for the main variables. The mean values of Oinv_level and Oinv are 0.042 and 0.387, respectively, indicating that average investment inefficiency is relatively low, while approximately 40% of firms exhibit overinvestment behavior. The interaction variable Time_Treat has a mean of 0.448, suggesting a relatively balanced distribution of firms between pilot and non-pilot cities. Among the control variables, Growth exhibits substantial variation, reflecting heterogeneous growth opportunities across firms. The mean value of Soe is 0.441, indicating that state-owned enterprises account for a significant share of the sample. Financial leverage and market concentration also show notable dispersion, suggesting differences in capital structure and competitive environments across industries.

Identification Strategy and Model Specification

To identify the causal effect of the Broadband China policy on corporate investment efficiency, this study employs a staggered difference-in-differences (DID) approach. Given that the policy was implemented in multiple phases across regions and over time, a multi-period DID framework following Beck et al. (2006) is adopted:

$$Y_{i,t} = \alpha 0 + \alpha 1 Treat_{i,t} + \alpha 2 Time_{i,t} + \alpha 3 Treat_{i,t} \times Time_{i,t} + X_{i,t} + \epsilon_{i,t} \quad (2)$$

where Yi,t denotes corporate investment efficiency, Treati,t identifies firms in pilot cities, Timei,t captures the post-policy period, and the interaction term reflects the policy effect. Xi,t represents the set of control variables. To address potential endogeneity concerns, an instrumental variable (IV) approach is further employed. The historical distribution of Ming Dynasty post stations is used as an exogenous proxy for modern infrastructure development, interacted with national broadband user penetration to enhance identification robustness.

4. Result and Discussion

Time-Trend Analysis of Corporate Investment Efficiency

Figures 1–3 present the time-series evolution of inefficient investment, overinvestment, and underinvestment among firms affected by the Broadband China policy. In each figure, the horizontal axis denotes the sample period from 2007 to 2021, while the vertical axis represents the investment inefficiency indicator (Oinv_level). Firms located in Broadband China pilot cities are depicted by solid lines, whereas those in non-pilot cities are shown by dashed lines. These figures illustrate changes in corporate investment behavior before and after the policy's implementation in 2014, highlighting differences across regions and investment dimensions.

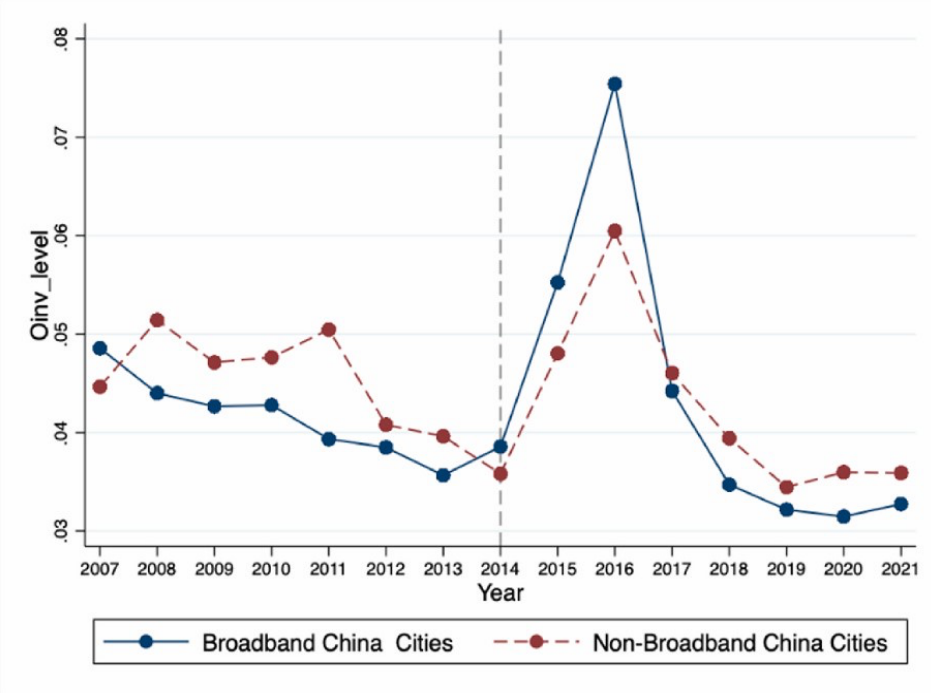

Figure 1. Trends in inefficient investment.

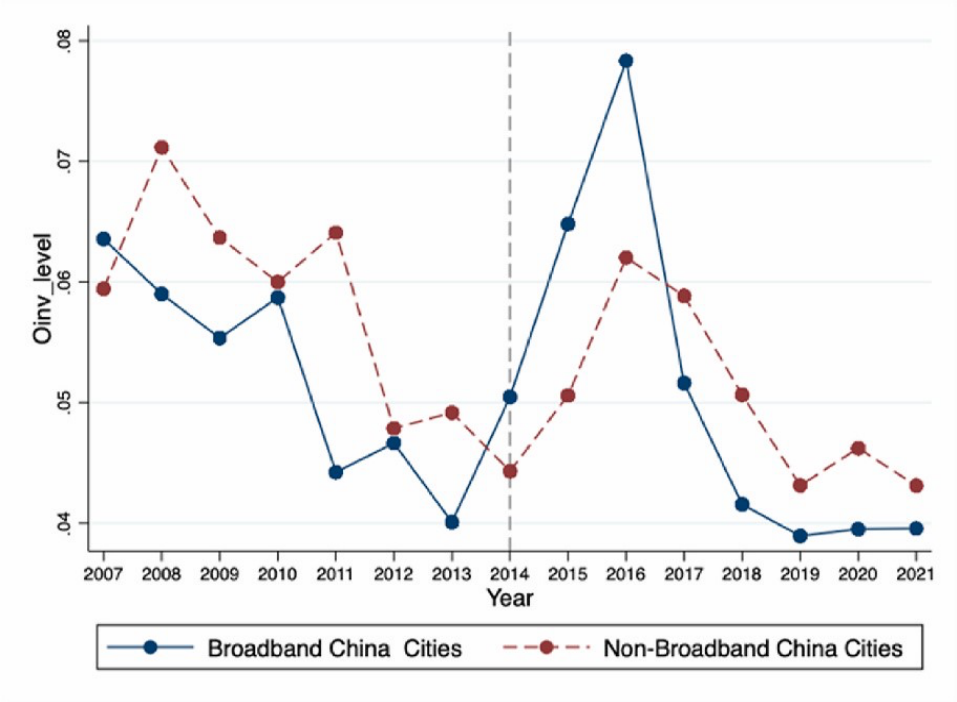

Figure 2. Trends in overinvestment.

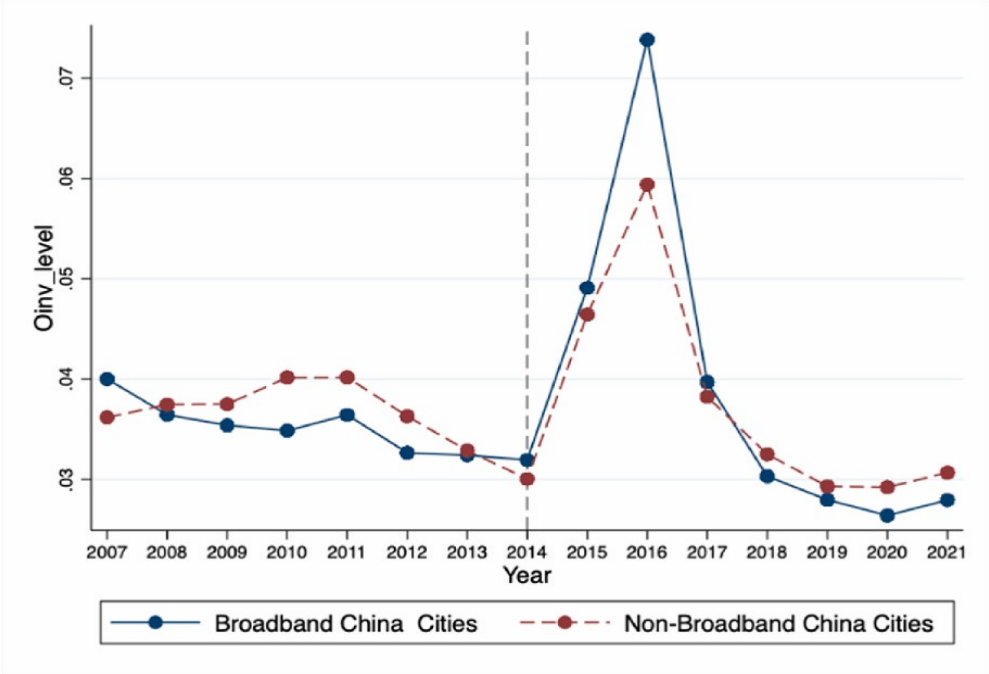

Figure 3. Trends in underinvestment.

As shown in Figure 1, prior to the implementation of the Broadband China policy, firms in pilot and non-pilot cities exhibited similar levels of inefficient investment, indicating comparable investment behavior across regions. Following the policy's introduction in 2014, inefficient investment among firms in pilot cities initially increased and reached a peak around 2016, after which it declined markedly. This pattern suggests

that the early stages of broadband infrastructure expansion may have induced temporary investment distortions, while subsequent adaptation and learning led firms toward more rational investment decisions.

Figure 2 further captures the dynamics of overinvestment. Firms in pilot cities experienced a pronounced rise in overinvestment shortly after the policy launch, with the highest level observed in 2016, followed by a gradual decline. This trend implies that rapid improvements in digital infrastructure may have initially encouraged excessive investment, but over time, firms adjusted their strategies as information quality and management practices improved. Figure 3 illustrates the evolution of underinvestment. After the implementation of the Broadband China policy, underinvestment among firms in pilot cities declined significantly, indicating that enhanced digital infrastructure reduced information asymmetry and financing constraints. As a result, firms were better able to undertake appropriate investment projects and avoid insufficient capital allocation.

Overall, the time-trend evidence suggests that the Broadband China policy has contributed to improvements in corporate investment efficiency. Although short-term overinvestment occurred during the early phase of policy implementation, firms gradually optimized their investment behavior as digital infrastructure development matured. These findings are consistent with the hypothesis that improved digital infrastructure enhances management efficiency, alleviates information asymmetry, and promotes more efficient corporate investment decisions.

DID Results: Broadband China Policy and Corporate Investment Efficiency

Table 2 "Broadband China" and Corporate Investment Efficiency: DID Model Regression Results

Variables	**Inefficient Investment**		**Overinvestment**		**Underinvestment**	
	(1)	(2)	(3)	(4)	(5)	(6)
	Oinv_level	Oinv_level	Oinv_level	Oinv_level	Oinv_level	Oinv_level
Time_Treat	−0.0027***	−0.0035***	−0.0063***	−0.0085***	0.0004	0.0005
	(0.0010)	(0.0010)	(0.0019)	(0.0019)	(0.0011)	(0.0011)
Cflow		0.0866***		0.0862***		0.0732***
		(0.0147)		(0.0274)		(0.0172)
Growth		0.0025***		0.0051***		0.0004
		(0.0005)		(0.0011)		(0.0004)
Soe		−0.0117***		−0.0129**		−0.0104***
		(0.0027)		(0.0051)		(0.0027)
Indiratio		−0.0003***		−0.0003*		−0.0002*
		(0.0001)		(0.0002)		(0.0001)
Ratio		0.0018		0.0213**		−0.0100**
		(0.0045)		(0.0084)		(0.0049)
Rab		−0.0182***		−0.0354***		−0.0058***
		(0.0021)		(0.0041)		(0.0022)
HHI		0.0005		−0.0037		0.0034**
		(0.0015)		(0.0032)		(0.0017)
Constant	0.0427***	0.0653***	0.0521***	0.0788***	0.0360***	0.0529***
	(0.0005)	(0.0048)	(0.0008)	(0.0094)	(0.0005)	(0.0051)
N	29,087	29,087	10,658	10,658	17,594	17,594
Adj. R^2	0.107	0.119	0.115	0.139	0.083	0.089

Table 2 reports the difference-in-differences (DID) estimation results examining the impact of the Broadband China policy on corporate investment efficiency across three dimensions: inefficient investment, overinvestment, and underinvestment. The dependent variable is *Oinv_level*, while the key explanatory variable, *Time_Treat*, captures the effect of the policy on firms' investment behavior. Columns (1) and (2) present the results for inefficient investment, Columns (3) and (4) for overinvestment, and Columns (5) and (6) for underinvestment.

The results indicate that *Time_Treat* exhibits a significantly negative effect on both inefficient investment and overinvestment across all model specifications. This finding suggests that the Broadband China policy effectively curtails inefficient investment behaviors, particularly excessive investment. In the models examining inefficient investment (Columns (1) and (2)), the estimated coefficients of *Time_Treat* are −0.0027 and −0.0035, respectively, both statistically significant at the 1% level. These results confirm that the policy implementation substantially reduces inefficient investment, supporting the hypothesis that improvements in digital infrastructure enhance corporate investment efficiency by facilitating information flow and improving managerial decision-making. Similarly, in the overinvestment regressions (Columns (3) and (4)), the coefficients of *Time_Treat* are −0.0063 and −0.0085, both statistically significant, indicating that the expansion of broadband infrastructure contributes to more rational investment decisions by firms and effectively suppresses overinvestment tendencies.

In contrast, the results for underinvestment (Columns (5) and (6)) show that the coefficients of *Time_Treat* (−0.0004 and −0.0005) are not statistically significant. This suggests that the Broadband China policy does not exert a meaningful effect on alleviating underinvestment. A possible explanation is that the policy primarily addresses overinvestment by reducing information asymmetry and enhancing management efficiency, whereas underinvestment may be driven by deeper structural issues, such as market imperfections and resource constraints, which cannot be fully resolved through digital infrastructure development alone.

Table 3.Parallel Trend Test (Dynamic Effects Test)

Variables	**Inefficient Investment**		**Overinvestment**		**Underinvestment**	
	(1)	(2)	(3)	(4)	(5)	(6)
	Oinv_level	Oinv_level	Oinv_level	Oinv_level	Oinv_level	Oinv_level
pre7	0.0074	0.0079	0.0159**	0.0158**	0.0034	0.0037
	(0.0052)	(0.0051)	(0.0069)	(0.0068)	(0.0037)	(0.0036)
pre6	0.0078	0.0087	0.0175*	0.0168*	0.0028	0.0032
	(0.0058)	(0.0050)	(0.0085)	(0.0083)	(0.0041)	(0.0040)
pre5	0.0021	0.0020	0.0051	0.0050	0.0004	0.0003
	(0.0050)	(0.0055)	(0.0070)	(0.0069)	(0.0044)	(0.0044)
pre4	0.0032	0.0035	0.0093	0.0089	−0.0011	−0.0012
	(0.0058)	(0.0057)	(0.0076)	(0.0072)	(0.0049)	(0.0049)
pre3	−0.0004	0.0004	−0.0014	0.0001	0.0003	0.0003
	(0.0050)	(0.0048)	(0.0077)	(0.0082)	(0.0033)	(0.0033)
pre2	−0.0029	−0.0027	−0.0055	−0.0042	−0.0024	−0.0027
	(0.0050)	(0.0054)	(0.0074)	(0.0072)	(0.0041)	(0.0040)
current	0.0044	0.0038	0.0039	0.0025	0.0040	0.0039
	(0.0103)	(0.0099)	(0.0097)	(0.0090)	(0.0119)	(0.0110)
post1	0.0127**	0.0110*	0.0108	0.0083	0.0115*	0.0113*
	(0.0059)	(0.0057)	(0.0084)	(0.0083)	(0.0055)	(0.0054)
post2	0.0211**	0.0199	0.0107	0.0139	0.0245**	0.0242**
	(0.0119)	(0.0113)	(0.0114)	(0.0100)	(0.0115)	(0.0112)

Variables	Inefficient Investment		Overinvestment		Underinvestment	
post3	−0.0040	−0.0047	−0.0047	−0.0003	−0.0026	−0.0027
	(0.0002)	(0.0059)	(0.0078)	(0.0075)	(0.0043)	(0.0042)
post4	−0.0113*	−0.0115*	−0.0131*	−0.0140*	−0.0093**	−0.0094**
	(0.0056)	(0.0054)	(0.0074)	(0.0070)	(0.0039)	(0.0039)
post5	−0.0143**	−0.0143**	−0.0158**	−0.0172**	−0.0121**	−0.0119**
	(0.0057)	(0.0058)	(0.0072)	(0.0070)	(0.0042)	(0.0041)
post6	−0.0149**	−0.0154**	−0.0151*	−0.0168**	−0.0136**	−0.0134**
	(0.0061)	(0.0061)	(0.0073)	(0.0075)	(0.0040)	(0.0040)
post7	−0.0179***	−0.0180***	−0.0179**	−0.0202**	−0.0162***	−0.0164***
	(0.0058)	(0.0057)	(0.0076)	(0.0077)	(0.0043)	(0.0044)
Controls	No	Yes	No	Yes	No	Yes
Constant	0.0429***	0.0578***	0.0509***	0.0699***	0.0372***	0.0476***
	(0.0000)	(0.0071)	(0.0099)	(0.0093)	(0.0028)	(0.0067)
N	29,087	29,087	10,658	10,658	17,594	17,594
Adj. R^2	0.144	0.154	0.161	0.182	0.142	0.140

Notes: *, **, *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively. Clustered standard errors at the firm level are reported in parentheses.

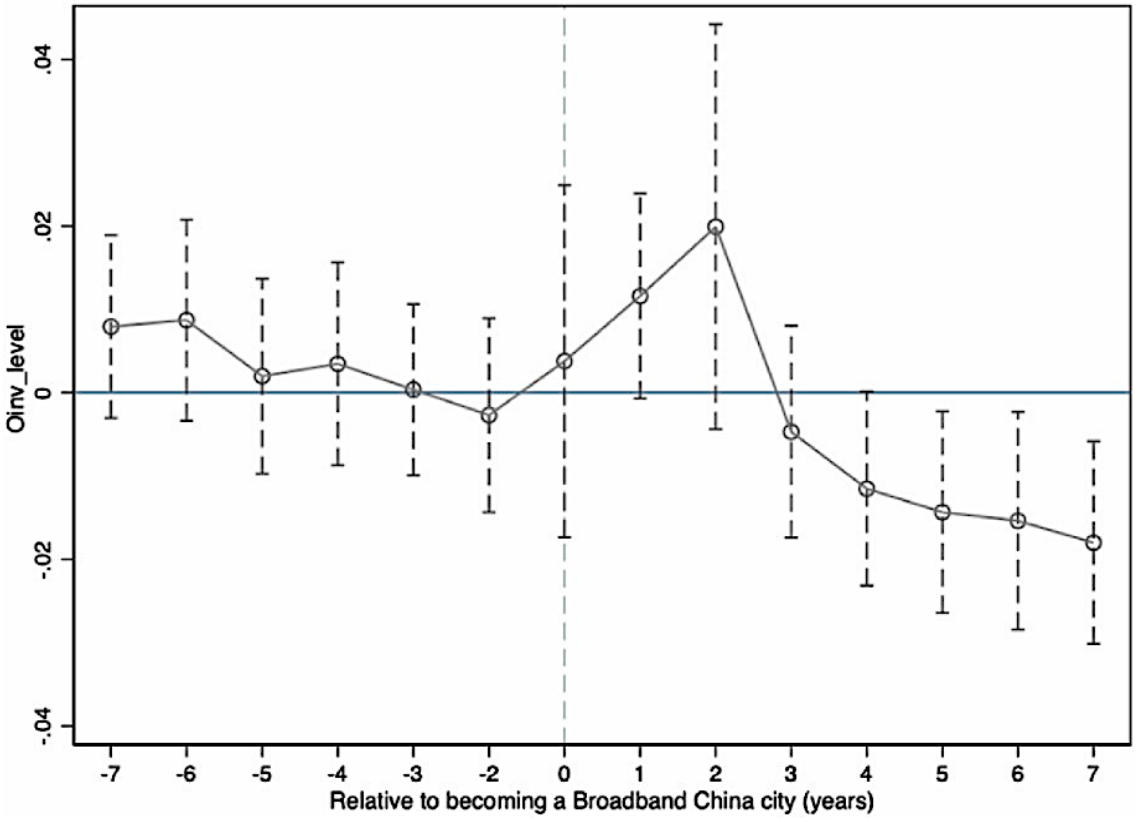

Figure 4. Dynamic effects test.

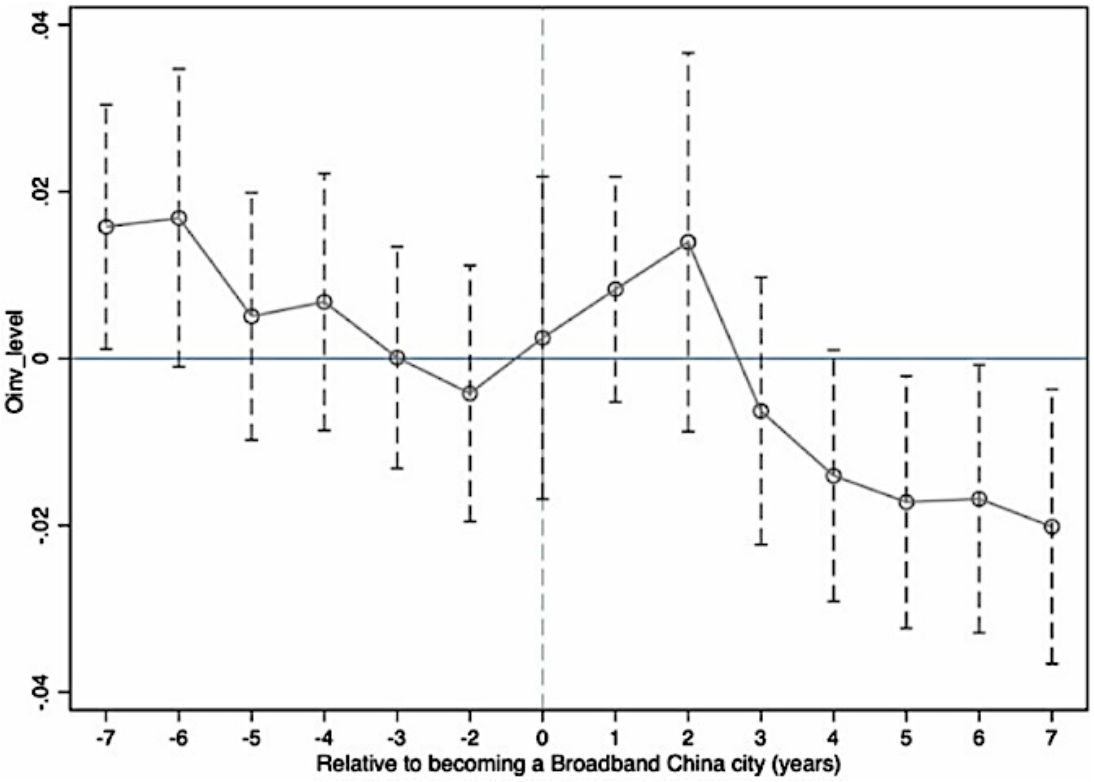

Figure 5. Dynamic effects test – overinvestment.

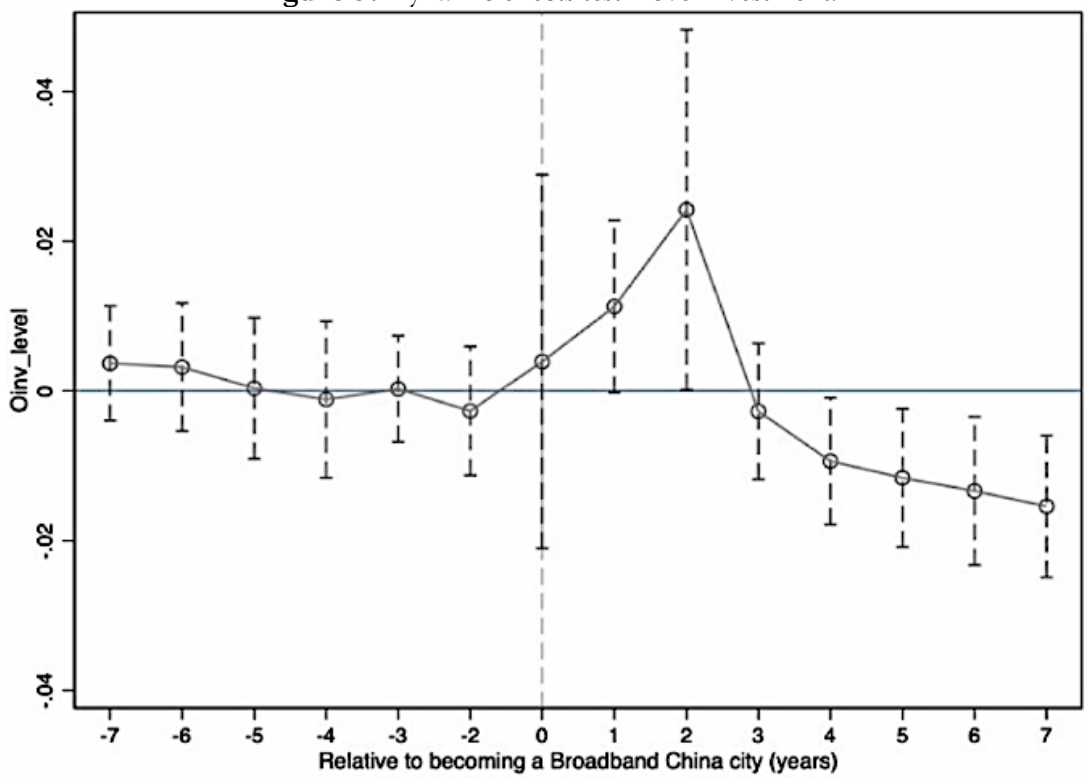

Figure 6. Dynamic effects test – underinvestment.

Addressing Endogeneity: Instrumental Variable Approach

Table 4.Instrumental Variable Estimates

Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
	First stage	Second stage	First stage	Second stage	First stage	Second stage
	Time_Treat	Oinv_level	Time_Treat	Oinv_level	Time_Treat	Oinv_level
Stage_Invet	0.4265***		0.4350***		0.0460***	
	(0.0075)		(0.0124)		(0.0019)	
Time_Treat		−0.0167***		−0.0204***		0.0023
		(0.0023)		(0.0060)		(0.0037)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Constant	−2.0525***	0.0487***	−2.7460***	0.0643***	0.0977***	0.0385***
	(0.0515)	(0.0041)	(0.0837)	(0.0082)	(0.0370)	(0.0033)
Kleibergen–Paap rk LM statistic	2559.257		990.083		532.294	
p-value	[0.000]		[0.000]		[0.000]	
Kleibergen–Paap Wald F statistic	3207.500		1237.754		589.568	
Observations	13,479	13,479	5,120	5,120	8,360	8,360
R-squared	—	0.039	—	0.074	—	0.023

Table 4 reports the instrumental variable (IV) estimation results, which are employed to mitigate potential endogeneity concerns between the *Time_Treat* variable and corporate investment behavior. To identify the exogenous impact of the Broadband China policy, this study adopts the historical distribution of Ming Dynasty post stations as an instrumental variable, interacted with national broadband user penetration to enhance relevance. This approach follows a two-stage estimation procedure: the first stage evaluates the association between the instrumental variable and policy implementation, while the second stage estimates the causal effect of the policy on corporate investment efficiency.

The Kleibergen–Paap rk statistics and their corresponding p-values indicate strong identification, suggesting that the instrumental variable is both relevant and valid. To further ensure robustness, separate IV regressions are conducted for inefficient investment, overinvestment, and underinvestment.

The second-stage results demonstrate that *Time_Treat* has significantly negative effects on inefficient investment and overinvestment, with estimated coefficients of −0.0167 and −0.0264, respectively, both statistically significant at the 1% level. These findings indicate that the Broadband China policy effectively curbs inefficient and excessive investment behavior, consistent with the baseline DID estimates and reinforcing the robustness of the main conclusions. Moreover, the Kleibergen–Paap Wald F statistics in all specifications exceed the conventional threshold of 10, confirming that the instrument does not suffer from weak identification problems.

Overall, the IV estimation results corroborate the baseline findings, providing strong evidence that the Broadband China policy exerts a positive and causal effect on corporate investment efficiency by reducing inefficient and overinvestment behavior.

Table 5.Robustness Test Results: PSM–DID

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Inefficient Investment		Overinvestment		Underinvestment	
Time_Treat	−0.0028***	−0.0036***	−0.0065***	−0.0088***	0.0003	0.0005
	(0.0010)	(0.0010)	(0.0019)	(0.0019)	(0.0011)	(0.0011)
Controls	No	Yes	No	Yes	No	Yes
Constant	0.0427***	0.0603***	0.0521***	0.0793***	0.0301***	0.0511***
	(0.0005)	(0.0048)	(0.0008)	(0.0093)	(0.0005)	(0.0051)
Observations (N)	28,850	28,850	10,570	10,570	17,440	17,440
Adj. R^2	0.108	0.119	0.117	0.141	0.085	0.091

Table 5 reports the robustness check results based on the combination of propensity score matching (PSM) and the difference-in-differences (DID) approach. Separate regressions are conducted for inefficient investment, overinvestment, and underinvestment to further assess the robustness of the estimated effects of the Broadband China policy on corporate investment efficiency. By matching firms in the treatment and control groups with similar observable characteristics, the PSM-DID method effectively alleviates potential selection bias and enhances the credibility of the causal inference.

Although the sample size decreases slightly after matching, the adjusted R-squared values remain relatively high, indicating that the models retain strong explanatory power. All specifications control for key firm-level characteristics, including cash flow, growth capability, and ownership structure.

The estimation results show that the core explanatory variable, *Time_Treat*, continues to exhibit significantly negative coefficients in the inefficient investment and overinvestment models, with estimated values of −0.0028 and −0.0065, respectively, both significant at the 1% level. These findings suggest that the Broadband China policy persistently reduces inefficient investment and overinvestment behavior, consistent with the baseline DID results and reinforcing their robustness. In contrast, the coefficients of *Time_Treat* in the underinvestment models are −0.0003 and −0.0005 and fail to reach statistical significance, indicating that the policy does not exert a discernible effect on alleviating underinvestment.

Overall, the PSM-DID robustness tests confirm the stability and reliability of the baseline findings, demonstrating that the Broadband China policy significantly enhances corporate investment efficiency, primarily through mitigating overinvestment behavior. These results provide strong support for the study's main conclusions.

Table 6.Mechanism Test Results: Managerial Efficiency

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Inefficient Investment		Overinvestment		Underinvestment	
Time_Treat	0.0031***	0.0020	−0.0013	−0.0040*	0.0057***	0.0081***
	(0.0015)	(0.0013)	(0.0027)	(0.0027)	(0.0010)	(0.0010)
Manage	−0.0002***	−0.0001	−0.0001	−0.0001	−0.0002***	−0.0002***
	(0.0000)	(0.0000)	(0.0001)	(0.0001)	(0.0000)	(0.0000)
Time_Treat × Manage	−0.0003***	−0.0002***	−0.0002*	−0.0002*	−0.0003***	−0.0003***
	(0.0000)	(0.0000)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Controls	No	Yes	No	Yes	No	Yes
Constant	0.0458***	0.0630***	0.0548***	0.0772***	0.0398***	0.0499***
	(0.0009)	(0.0048)	(0.0018)	(0.0094)	(0.0009)	(0.0050)
Regional FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes

Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations (N)	29,017	29,017	10,635	10,635	17,552	17,552
Adj. R^2	0.112	0.121	0.110	0.139	0.095	0.099

Notes: *, **, *** indicate significance at the 10%, 5%, and 1% levels, respectively. Clustered standard errors at the firm level are reported in parentheses.

Table 6 reports the results of the mechanism analysis examining whether the Broadband China policy enhances corporate investment efficiency through improvements in management efficiency. The key explanatory variable in this test is *Time_Treat_Manage*, which captures the interaction between policy implementation and firm-level management efficiency. This interaction term is introduced to assess whether management efficiency acts as a mediating channel linking the Broadband China policy to corporate investment efficiency. The regressions control for major firm characteristics—including cash flow, growth capability, and ownership structure—and incorporate regional, industry, and firm fixed effects to ensure the robustness of the estimates.

The empirical results indicate that the interaction term *Time_Treat_Manage* is significantly negative across all model specifications, suggesting that management efficiency plays a meaningful mediating role in the relationship between the Broadband China policy and corporate investment efficiency. Specifically, the coefficients in Models (1) through (6) are statistically significant at the 1% or 5% levels, demonstrating that improvements in management efficiency effectively reduce inefficient investment and overinvestment while contributing to overall investment rationalization. The results from Models (1), (3), and (5), in particular, show that enhanced management efficiency substantially mitigates inefficient and excessive investment, while also exerting a positive moderating influence in the underinvestment specifications.

Overall, the findings confirm that management efficiency constitutes a critical transmission mechanism through which the Broadband China policy affects corporate investment efficiency. By streamlining internal decision-making processes and improving information flow and transparency, higher management efficiency helps firms curb irrational investment behavior. These results are consistent with Hypothesis 2, which posits that digital infrastructure development influences corporate investment decisions indirectly by improving management efficiency.

The mechanism test further underscores the economic significance of management efficiency in explaining the policy's effectiveness. The expansion of digital infrastructure—particularly the widespread deployment of broadband networks—enables firms to access market information more quickly and enhances internal coordination and managerial processes. Through the extensive application of information technologies, firms are better able to integrate resources and analyze market signals, leading to more rational investment decisions (Cao et al., 2020; Kong et al., 2024). This mechanism helps explain why improvements in management efficiency significantly reduce inefficient and overinvestment behavior. Moreover, the moderating role of management efficiency appears more pronounced among state-owned enterprises, likely due to their more complex organizational hierarchies, which allow greater scope for managerial optimization under policy incentives. Taken together, these findings provide strong empirical support for the view that the Broadband China policy improves corporate investment efficiency primarily by enhancing management efficiency.

Table 7. Heterogeneity Test of New Infrastructure Levels

Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Time_Treat	−0.0031**	−0.0095***	0.0000	−0.0037**	−0.0080***	0.0002
	(0.0014)	(0.0027)	(0.0010)	(0.0015)	(0.0028)	(0.0015)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.0500***	0.0560***	0.0518***	0.0718***	0.0940***	0.0533***
	(0.0072)	(0.0148)	(0.0073)	(0.0068)	(0.0141)	(0.0071)
Regional FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations (N)	12,000	4,301	7,544	10,003	5,735	9,552
Adj. R^2	0.126	0.124	0.076	0.125	0.140	0.099

Table 7 reports the heterogeneity test results examining whether the impact of the Broadband China policy on corporate investment efficiency differs across regions with varying levels of new infrastructure development. This analysis distinguishes between areas with relatively high and low infrastructure levels and evaluates the policy's effects on inefficient investment, overinvestment, and underinvestment. Given the substantial regional disparities in infrastructure—particularly digital infrastructure—conducting separate regressions for these two groups is essential to capture heterogeneous policy effects and to better assess the contextual effectiveness of the policy.

The empirical results indicate that the coefficient of *Time_Treat* is significantly negative for both inefficient investment and overinvestment in regions with higher levels of new infrastructure. Specifically, the estimated coefficients are −0.0031 for inefficient investment and −0.0095 for overinvestment, significant at the 5% and 1% levels, respectively. These findings suggest that in regions with more advanced infrastructure, the Broadband China policy effectively improves corporate investment efficiency by substantially reducing inefficient and excessive investment behavior.

In contrast, in regions characterized by lower levels of infrastructure development, the negative effect of *Time_Treat* on inefficient investment does not reach statistical significance. Only in the overinvestment specification does the coefficient (−0.0080) remain significant at the 1% level, indicating that while the policy still helps curb overinvestment in infrastructure-constrained regions, its overall effectiveness is weaker than in more developed areas. For underinvestment, *Time_Treat* does not exhibit a significant effect in either group, implying that the policy's influence on alleviating underinvestment is relatively insensitive to regional infrastructure conditions.

Overall, the heterogeneity analysis highlights new infrastructure level as an important moderating factor in determining the effectiveness of the Broadband China policy. Regions with more developed infrastructure benefit more strongly from the policy, particularly in terms of reducing inefficient investment and overinvestment, underscoring the complementary role of infrastructure readiness in enhancing policy outcomes.

Table 8 reports the heterogeneity analysis examining the effects of the Broadband China policy on corporate investment efficiency across provincial capital cities and non-provincial capital cities. Provincial capitals typically enjoy advantages in terms of resource allocation, policy support, and infrastructure development, whereas non-provincial cities tend to face relatively weaker institutional and infrastructural conditions. Accordingly, it is important to investigate whether the policy exerts differentiated effects on inefficient investment, overinvestment, and underinvestment across these two city tiers. This analysis

provides further insights into the channels through which the policy operates and highlights variations in policy effectiveness across urban contexts.

The results indicate that Time_Treat has a significantly negative effect on inefficient investment and overinvestment in provincial capital cities. Specifically, in Models (1) and (2), the coefficients are −0.0031 and −0.0088, respectively, both statistically significant at the 5% and 1% levels. These findings suggest that the Broadband China policy effectively reduces inefficient investment and curbs overinvestment in provincial capital cities, thereby enhancing corporate investment efficiency in these locations.

In contrast, the policy's impact is notably weaker in non-provincial capital cities. Although Time_Treat exhibits a significantly negative coefficient of −0.0083 in the overinvestment specification (Model 4), significant at the 1% level, its effects on inefficient investment and underinvestment in non-provincial capital cities are not statistically significant. This implies that while the policy can still restrain excessive investment behavior in non-capital cities, its overall effectiveness in improving investment efficiency is more limited compared to provincial capitals.

Overall, the heterogeneity analysis suggests that the Broadband China policy yields stronger investment-efficiency-enhancing effects in provincial capital cities, particularly by reducing overinvestment. These findings highlight the importance of city-level development conditions in shaping the effectiveness of digital infrastructure policies and underscore the role of urban hierarchy in mediating policy outcomes.

Table 8 Heterogeneity Test – Provincial Capitals vs. Non-Provincial Cities

Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
	Provincial Capital Cities			Non-provincial capital city		
	Oinv_level	Oinv_level	Oinv_level	Oinv_level	Oinv_level	Oinv_level
Time_Treat	−0.0031**	−0.0088***	0.0021	−0.0035**	−0.0083***	−0.0012
	(0.0013)	(0.0024)	(0.0015)	(0.0015)	(0.0028)	(0.0016)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Constant	0.0645***	0.0743***	0.0528***	0.0895***	0.0832***	0.0553***
	(0.0070)	(0.0138)	(0.0084)	(0.0066)	(0.0141)	(0.0002)
Regional FE	Yes	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations (N)	13,784	4,954	8,442	13,090	5,071	8,190
Adj. R^2	0.117	0.104	0.098	0.125	0.133	0.091

5. Conclusion

This study utilizes the Broadband China policy as a natural experiment to examine how digital infrastructure development influences corporate investment efficiency. Amid accelerating global digitalization, the expansion of broadband networks and other forms of new infrastructure has become increasingly important in improving the rationality of corporate investment decisions and enhancing managerial efficiency. Nevertheless, substantial regional disparities in infrastructure development across China may lead to heterogeneous policy outcomes. To address this issue, this study systematically investigates the effects of the Broadband China policy on inefficient investment, overinvestment, and underinvestment by employing a difference-in-differences (DID) framework combined with propensity score matching (PSM) and instrumental variable (IV) approaches. In addition, heterogeneity analyses are

conducted across different infrastructure levels and city types—specifically provincial capital and non-provincial capital cities—to identify variations in policy effectiveness and uncover the mechanisms through which digital infrastructure shapes corporate investment behavior. Using panel data on Chinese listed firms from 2007 to 2021, the results confirm the positive role of digital infrastructure in improving corporate investment efficiency while revealing notable regional and city-level differences in policy impacts.

The main findings can be summarized as follows. First, the empirical evidence indicates that the Broadband China policy significantly curbs inefficient investment and overinvestment by firms. This supports the view that digital infrastructure enhances information transmission and managerial efficiency, thereby promoting more rational investment decisions. The policy effects are particularly strong in regions with more advanced infrastructure, where inefficient and excessive investment decline markedly. By contrast, although the policy also restrains overinvestment in less-developed regions, its overall effectiveness is comparatively weaker, suggesting clear regional heterogeneity. Second, policy impacts differ substantially between provincial capital cities and non-provincial capital cities. Firms located in provincial capitals—benefiting from superior resource endowments, institutional support, and infrastructure—experience more pronounced improvements in investment efficiency and larger reductions in inefficient and excessive investment following policy implementation. In non-provincial capital cities, however, these effects are more limited. Finally, the mechanism analysis demonstrates that managerial efficiency serves as a key mediating channel through which digital infrastructure influences corporate investment behavior. By improving firms' ability to process information and allocate resources effectively, digital infrastructure helps mitigate irrational investment decisions.

Based on these findings, several policy implications emerge. First, the government should continue to advance digital infrastructure development, particularly in non-provincial capital cities and less-developed or remote areas where infrastructure gaps remain significant. Expanding broadband coverage and application can help narrow regional digital divides and ensure that the benefits of digital policies are more evenly distributed. Second, policymakers should place greater emphasis on enhancing firms' managerial efficiency by encouraging digital transformation, including the optimization of management processes and improvements in firms' capabilities to acquire and utilize information. Support measures such as tax incentives and dedicated funds can be introduced to promote managerial innovation and technological upgrading, especially for small and medium-sized enterprises seeking to strengthen their digital management capacities (Gao et al., 2022). Finally, policy design should be tailored to local conditions. While provincial capital cities can further integrate digital infrastructure with traditional industries, non-provincial capital cities should prioritize improving infrastructure quality and the business environment to attract investment. Adopting differentiated and region-specific policy measures will help maximize economic benefits and promote more balanced development across cities.

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