The Impact of New Infrastructure on Ecological Efficiency

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Abstract. The integrated construction of a "digital China" and a "beautiful China" is a major task and a strategic initiative to open up new horizons of modernization. Based on panel data spanning from 2011 to 2021, encompassing 284 prefecture-level and above cities in China, this study employs multi-period Difference-in-Differences (DID) and spatial DID models. These models are constructed following theoretical analyses of the intrinsic mechanisms influencing the ecological efficiency of new infrastructures. Additionally, quasi-natural experiments are conducted based on the policy implementations in the demonstration city of "Broadband China". The study systematically investigates the impact of new infrastructures on China's eco-efficiency and elucidates their role within the mechanism. The study found that: new infrastructure construction has a significant effect on eco-efficiency, and this conclusion passed a sequence of robustness test; mechanism analysis shows that new infrastructure construction improves eco-efficiency through improving human capital level; heterogeneity analysis shows that new infrastructure has a more obvious effect on ecological efficiency improvement in eastern and resource cities; and the results of the analysis of the spatial effect show that new infrastructure not only improves eco-efficiency in the pilot cities, but also significantly improves ecological efficiency in the pilot neighboring cities.

Keywords: new infrastructure; ecological efficiency; broadband China; human capital; spatial effects.

1 Introduction

In order to further promote high-quality development and achieve harmonious coexistence between humans and nature, it is necessary to grasp the dialectical and unified relationship between high quality development and high-level protection. Under the goal of constructing a beautiful China by 2035, how to realize synergistic symbiosis between development and protection, and improve the eco-efficiency of urban development has become the central issue of the researchers and government decision-making departments. In recent years, the integration of new infrastructure represented by 5G, industrial Internet, AI, and cloud computing with green development has gradually deepened[1], aligning naturally with the improvement of ecological efficiency.

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Existing research indicates that new infrastructure can promote high-quality development and technological innovation in the manufacturing industry[2,3].There are also literatures has shown that new infrastructure can reduce air pollution and carbon emission[4,5].

This article primarily explores the impact of new infrastructure on ecological efficiency, and explores whether new infrastructure can improve environmental governance while promoting economic growth. This article also investigates the impact pathway and spillover effect of new infrastructure on ecological efficiency.

2 Theoretical Analysis

New infrastructures can reduce emissions of environmental pollutants while promoting economic growth, creating opportunities for increased eco-efficiency. Firstly, new infrastructures digitally empower the endogenous dynamics of the economy. Secondly, new infrastructure can curb environmental pollution by enhancing the environmental governance capabilities of enterprises, governments, and the general public. From the perspective of enterprises, the improvement of new infrastructures helps enterprises realize intelligent and digital upgrading, thereby reducing energy consumption and resource waste. From the government's perspective, the development and upgrading of new infrastructure can help the government effectively enhance its environmental regulation efforts[6]. From the perspective of publics, the government service platform built on the basis of the new infrastructure enhances the importance of environmental protection by all sectors of the society and creates a favorable social atmosphere for low-carbon green transformation[7]. Accordingly, the following hypotheses are formulated in this paper:

H1: New infrastructure can improve eco-efficiency.

High human capital accumulation can enhance eco-efficiency by facilitating the implementation of environmental policies and promoting technological change[8]. Firstly, the construction of new infrastructures will also promote the development of knowledge-intensive and technology-intensive high-end industries, which will create new and high-quality jobs, thus realizing both the "quality" and "quantity" improvements in urban human capital. Secondly, High-quality people pay more attention to long-term interests and maintain a high sensitivity to environmental quality, this environmental awareness will guide people to take practical action to participate in environmental governance activities. Thirdly, the digital talent service platform built with the help of new infrastructure can provide high-quality and efficient services for the majority of talents and attract the inflow of high-skilled entrepreneurial and innovative talents[9], which not only provides a supply of talents for the construction of the urban green industry system, but also provides talent support for the introduction and absorption of low-carbon and clean technologies[10].Therefore, this paper proposes the following hypotheses:

H2: New infrastructure improves eco-efficiency by raising the level of human capital.

Firstly, new infrastructure can realize technological spillover from outside the region

by virtue of its high proliferation and strong penetration characteristics, promoting technological progress in environmental pollution control in remote and backward areas, and boosting the eco-efficiency of neighboring cities. Secondly, the construction of new infrastructure can overcome communication barriers between cities, promote the exchange and sharing of environmental protection governance experience between neighboring cities, and contribute to the establishment of a platform for the sharing of early-warning information on ecological and environmental pollution. Thirdly, cities with perfect new infrastructures can produce market competition effect and demonstration effect, attracting neighboring cities to imitate and learn, thus forcing the neighboring areas to change from high-pollution development mode to green development mode. hypothesizes are as follows:

H3: New infrastructure improves the ecological efficiency of surrounding cities through spatial spillover.

3 Methodology and Data

3.1 Staggered DID Model

The benchmark regression model is set as follows:

$$UEE_{it} = \alpha_1 + \theta_1 DID_{it} + \varphi_1 Z_{it} + \eta_i + \mu_i + \varepsilon_{it} \quad (1)$$

where UEE_{it} is the ecological efficiency of city i in year t; DID_{it} is a policy shock variable for the "Broadband China" strategy, if the city is within the scope of three "Broadband China pilot projects, the value is 1; otherwise, the value is 0; η_i and μ_i fixed effects for cities and years respectively; ε_{it} is a randomized disturbance term that affects eco-efficiency; θ_1 is impact coefficient. Z_{it} represents a set of control variables.

3.2 Variable Description

3.2.1 Explained Variable: Eco-efficiency.

This paper uses the Super-SBM model to measure the ecological efficiency of 284 cities in 2011-2021. Capital input includes fixed capital stock and year-end employment; resource input includes urban construction land area, annual water supply, and annual electricity consumption; desirable output is gross domestic product of city; undesirable output include industrial sulfur dioxide emissions, industrial smoke emissions, carbon emissions, and average annual concentration of PM2.5.

3.2.2 Core explanatory Variable.

This research uses the "Broadband China" policy (DID) as a dummy variable. If the city is selected for the pilot scope, the pilot year and subsequent years are set to 1, and other years are set to 0.

3.2.3 Mechanism Variable.

Human capital (HC) is measured by the number of college students per 10,000 registered population in a city.

3.2.4 Control Variable.

This article includes a series of control variables. Including:(1) The level of opening up to the outside world (FDI). (2)The level of financial development(FIN). (3) The industrial structure (4) The level of economic development (PGDP) (5) Urbanization rate(Urban).

3.3 Data Sources

The above city data are from China Statistical Yearbook, China Urban Statistical Yearbook, and each city's statistical bulletin.

4 Analysis of Empirical Results

4.1 Benchmark Regression Results

The second column of Table 1 reports the direct impact of the "Broadband China" dummy variable on urban ecological efficiency after adding control variables, with a coefficient of 0.017 and passing the significance test. The H1 of this article is established.

Table 1. Baseline regression results

Variables	(1) UEE	(2) UEE	(3) DID
DID	0.012*** (-0.003)	0.017*** (-0.003)	
HC			0.047** (-0.020)
Control Variables		control	control
cons	0.421*** (-0.003)	-1.246*** (-0.086)	9.747*** (-0.793)
City FE	YES	YES	YES
Year FE	YES	YES	YES
N	3,124	3,124	3124
R^2	0.376	0.556	0.403

Note: ***, **, and * represent significant at the 1%, 5%, and 10% levels, respectively, with robust standard errors in parentheses. The following table is the same.

4.2 Parallel Trend Test and Placebo Test

The key premise for unbiased DID results is to satisfy the parallel trends assumption, which means that before the impact of policy, there is a similar trend in the changes of ecological efficiency between the pilot cities and non-pilot cities. Therefore, this study employs an event analysis method to investigate the dynamic impact. The results of the parallel trends test shown in Figure 1 indicate that before the implementation of the policy, there is no significant difference in the level of ecological efficiency between pilot cities and non-pilot cities, satisfying the parallel trends assumption.

Randomly select cities and times implementing the "Broadband China" policy to form a pseudo experimental group and the regression is re-run to obtain a simulated estimated coefficient. The above process is repeated 1000 times to obtain 1000 simulated estimated coefficients and the distribution of the coefficients is plotted. As can be seen in Fig 2, the randomly generated coefficients are normally distributed and have a mean value close to 0, which is far from the true DID coefficient value. This indicates the robustness of the benchmark regression results.

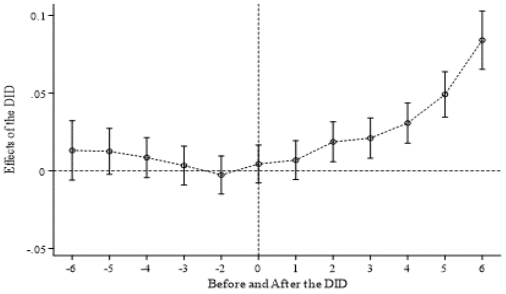

Fig. 1. Parallel Trend Test

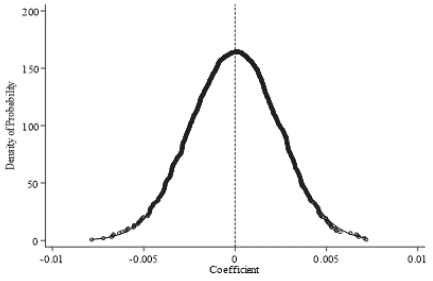

Fig. 2. Placebo Test

4.3 Heterogeneity Analysis

As shown in column (1) of Table 2, The pilot policy of "Broadband China" has a greater impact on the ecological efficiency of cities in eastern China. This may be due to the fact that cities in the east started to build new infrastructures earlier, and the new infrastructures are already more complete, thus enjoying the digital dividend earlier, and

therefore the eco-efficiency improvement is obvious. As shown in column (3) of Table 2, the stimulating effect of policies has a more significant impact on the ecological efficiency of resource-based cities. This may be due to the fact that compared with non-resource cities, the industries of resource cities are mostly based on heavy industry, and in the process of development, they are faced with the double pressure of economic transformation and environmental protection, and the construction of new infrastructures provides a strong support for the transformation and upgrading of resource cities.

Table 2. Heterogeneity test results

Variables	(1) Eastern	(2) Midwestern	(3) Resource-based	(4) Non-resource-based
DID	0.028***	0.004	0.035***	-0.004
	(-0.006)	(-0.005)	(-0.005)	(-0.004)
Control Variables	YES	YES	YES	YES
cons	0.459***	0.403***	0.421***	0.422***
	(-0.005)	(-0.004)	(-0.005)	(-0.004)
City FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
N	1100	2024	1265	1848
R^2	0.358	0.399	0.378	0.385

4.4 Analysis of Impact Mechanisms

This paper explores the mechanistic role of human capital in the impact of new infrastructure on ecological efficiency in a theoretical analysis.

$$HC_{it} = \alpha_2 + \theta_2 DID_{it} + \varphi_2 Z_{it} + \eta_i + \mu_i + \varepsilon_{it} \quad (2)$$

From the results in column (3) of Table 1, the regression coefficient of the core explanatory variable DID on human capital is significantly positive at the 5% level, i.e., perfect new infrastructure promote the continuous accumulation of human capital. Dong et al.[8] (2022) found that high quality human resources will promote the effective implementation of environmental protection policies to enhance eco-efficiency. This proves that new infrastructure drives urban eco-efficiency by enhancing human capital, i.e., H3 holds.

4.5 Spatial Difference in Difference Model

Firstly, by calculating the annual Moran index, it is demonstrated that there is spatial autocorrelation between urban ecological efficiency. Secondly, through LM, LR, Wald, and Hausman tests, a fixed individual effect and time effect spatial Durbin model was ultimately chosen. In this article, we used an economically geographically nested spatial weight matrix, and Table 3 shows the results. The indirect effect in column (3)

indicates that the "Broadband China" demonstration city policy also helps to improve the ecological efficiency of neighboring non pilot cities.

Table 3. Spatial durbin model regression results

Variables	(1) UEE	(2) direct effect	(3) indirect effect	(4) aggregate effect
DID	0.012*** (-0.003)	0.013*** (-0.003)	0.036*** (-0.011)	0.049*** (-0.011)
W×DID	0.021*** (-0.007)			
rho	0.332*** (-0.028)			
City FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
N	3124	3124	3124	3124
R^2	0.011	0.011	0.011	0.011

5 Conclusions

The conclusions are as follows:(1)The results indicate that the implementation of the "Broadband China" pilot policy can significantly improve urban ecological efficiency, that is, the construction of new infrastructure has a positive impact on ecological efficiency. (2) In eastern cities and resource-based cities, the improvement of urban ecological efficiency by new infrastructure is more significant. (3) The construction of new infrastructure can activate the effect of urban human capital and promote the improvement of ecological efficiency. (4) Under the spatial perspective, the cities with relatively well-developed new infrastructures can also play a demonstration role in driving the eco-efficiency of neighboring cities.

Based on the above conclusions, the following policy suggestions are put forward:(1) Promote the empowerment of traditional industries with new infrastructure, attract digital talents, and provide talent support for the research and promotion of clean environmental protection technologies. (2) By leveraging new infrastructure, we can break through data sharing barriers, eliminate data silos, strengthen exchanges and cooperation in ecological governance among neighboring cities, and continuously improve regional ecological efficiency.

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