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CARBON EMISSION REDUCTION EFFECT OF DIGITAL INFRASTRUCTURE: FROM THE "BROADBAND CHINA" STRATEGY

Abstract: The establishment of digital infrastructure embodies a pivotal instrument in propelling developmental metamorphosis, whilst fostering energy preservation and emission abatement. By employing municipal-level data spanning the period from 2009 to 2019, this research establishes a quasi-natural experiment anchored upon the "Broadband China" strategy. Employing the Difference-in-Differences (DID) methodology, this inquiry thoroughly examines the influence of digital infrastructure construction on the alleviation of carbon emissions. The findings indicate that the implementation of digital infrastructure exerts a notable impact on the reduction of carbon emissions. Moreover, carbon emission reduction resulting from digital infrastructure construction exhibits distinctive characteristics of heterogeneity. The empirical evidence presented within this study serves as a fundamental cornerstone for attaining the objectives of carbon peaking and carbon neutrality.

Keywords: digital infrastructure, "Broadband China" strategy, carbon emission reduction, DID method

Introduction

Attaining the pinnacle target and realising the vision of carbon neutrality have become intrinsic imperatives and significant facets in accomplishing high-quality development. With the expeditious advancement and application of digital technology within the realm of energy conservation and emission reduction, digital transformation is poised to assume a more paramount role in addressing the challenges posed by climate change. Extensive research has focused on these issues. However, the existing body of literature predominantly concentrates on the impact of conventional infrastructure on carbon emissions, encompassing the role of transportation infrastructure in carbon emissions [1, 2], as well as the correlation between energy infrastructure and carbon emissions. As a vital means to reshape the competitiveness of Chinese cities, the progress of digital transformation has garnered extensive scholarly attention. Among them, Xu et al. [3] discovered that the digital economy fosters a decline in the emission of urban environmental pollutants, while the research conducted by Lin and Zhou [4] established

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that the internet progression fosters the improvement of energy efficiency and the reduction of emissions.

Digital infrastructure embodies a plethora of distinct characteristics in comparison to traditional infrastructure. It not only possesses a broader and swifter capacity to disseminate information across temporal and spatial dimensions but also exhibits advantages in terms of network effects and spillover effects [5]. Currently, the network infrastructure of model cities has witnessed noticeable enhancements, thereby effectively propelling the "leap-forward" progress of broadband connectivity in China. Consequently, it becomes imperative for us to explore whether the digital infrastructure, exemplified by the "Broadband China" strategic initiative, engenders a reduction in carbon emissions. Zhou et al. [6] uncovered that the "Broadband China" strategy not only fosters the diffusion of technical knowledge among enterprises but also facilitates the dissemination of technical knowledge across companies. Diverging from the aforementioned literature that primarily focuses on economic indicators, Brinkley and Visser [7] directed their attention towards environmental indicators, such as sulphur dioxide, and ascertained that it substantially diminishes sulphur dioxide emissions.

With the expeditious advancement and widespread implementation of digital technologies within the realm of energy conservation and emission reduction, digital transformation is poised to assume a more prominent role in addressing the challenges posed by climate change. The enhancement of digital infrastructure not only mitigates information asymmetry, but also enhances the efficiency of government regulation and reduces regulatory costs. Additionally, it optimises industrial structures and expedites green technology innovation among enterprises, thereby fostering a reduction in carbon emissions. The innovations presented in this paper primarily revolve around the following facets: Firstly, this study expands the scope of research on digital infrastructure to encompass the environmental domain, paying meticulous attention to its effect on carbon emission reduction. It further enriches the repertoire of viable pathways for achieving carbon peaking and carbon neutrality. In addition, owing to the delayed inception of digital infrastructure construction and limited data availability, there exists a scarcity of literature that examines the impact mentioned above while effectively addressing endogeneity issues.

Literature review

The establishment of exemplar cities fosters the enhancement and modernisation of the industrial structure by facilitating infrastructure development. Firstly, as digital infrastructure improves, the application of the Internet has transcended the realm of consumers and permeated the production side, achieving a profound integration with traditional industries. Secondly, enhanced digital infrastructure facilitates the rational allocation of resource elements, promotes coordinated division of labour among industries, and engenders a more harmonious and rational transformation of the industrial structure. Thirdly, the establishment of digital infrastructure has catalysed the expansion of burgeoning sectors, progressively displacing antiquated traditional industries and bolstering the refinement and revitalisation of the industrial framework. Furthermore, multiple studies have corroborated the correlation between industrial structure optimisation and the reduction of carbon emissions [8, 9]. Wu [10] and Wu et al. [11] put forth the notion of sustainable green development and green university, drawing pertinent conclusions from their research.

Digital infrastructure serves as a conduit for information exchange and plays a crucial role in regional innovation. For instance, the development of digital service platforms promotes the diffusion of green technology. Additionally, existing literature demonstrates that the construction of demonstration cities fosters the advancement of green technology innovation [5, 6]. Technological innovation is widely acknowledged as a pivotal factor in achieving low-carbon development. Innovations in energy conservation and alternative energy technologies aid in reducing energy consumption and promoting the utilisation of clean energy sources, consequently leading to a decrease in carbon emissions.

Research design

Benchmark regression model

In this study, the processing group and control group are established based on the list of model cities. Specifically, the treatment group comprises 109 "Broadband China" demonstration cities, while the control group consists of the remaining cities that have not received approval for construction.

$$Y_{it} = \alpha_0 + \beta p_{it} + \delta X_{it} + v_t + u_i + \varepsilon_{it} \tag{1}$$

where Y_{it} represents the dependent variable, v_t and u_i represent the time and individual fixed effects, respectively. ε_{it} is the random error term. X_{it} is a set of variables that may have an impact on carbon emission levels. β and δ are the conditioning coefficients of the model. p_{it} is the core explanatory variable of this study that measures the impact of the construction of the "Broadband China" demonstration city on carbon emissions.

Data source and variable description

The research sample consists of panel data collected from 287 cities in China spanning the period from 2009 to 2019. The carbon emission data utilised in the study is sourced from the China Carbon Accounting Database, while other relevant data is obtained from the statistical yearbooks of various provinces throughout the years.

Policy variable

A value of 1 is assigned to the current year and subsequent years when the construction of "Broadband China" demonstration cities takes place, and a value of 0 is assigned otherwise. As the list of the three batches of demonstration cities is typically announced in the second half of the year, the year following the release of the list is defined as the policy implementation year.

Control variables

To control for potential confounding factors that may influence carbon emission levels, a series of control variables are incorporated following the approach outlined in [12].

Economic development (*pgdp*): Economic growth serves as a significant driver of carbon emissions. The logarithm of Gross Domestic Product (GDP) per capita is utilised to examine the level of economic development.

Population agglomeration (*pop*): population agglomeration directly contributes to expanded production activities, leading to increased carbon emissions. Therefore, this paper calculates population density by using the logarithm of the total population per unit area.

Foreign investment (*fdi*): Foreign investment can lead to pollution transfer and increased carbon emissions in the host country. Conversely, other research indicates that foreign investment can generate positive effects through technology transfer, resulting in reduced carbon emissions. To capture this variable, the proportion of *fdi* to regional GDP is employed as a measure.

Financial development (*fia*): Financial development serves as a crucial aspect in initiating carbon emission reduction efforts. Therefore, this paper employs the ratio of financial institution loans to regional GDP as a proxy variable for financial development.

R&D investment (*rd*): Increased investment in research and development (R&D) is an effective means to reduce carbon emissions. Consequently, the proportion of fiscal expenditure on technology to total fiscal expenditure is used as a measure of R&D investment.

Results and analysis

Benchmark regression analysis

In Table 1, columns (1) and (2) display the estimation outcomes with the inclusion of city fixed effects and year fixed effects, while columns (3) and (4) showcase the estimation results with the addition of control variables. Based on the estimated coefficients in columns (3) and (4), demonstration cities construction leads to a reduction in carbon emissions by 3.3 % and 5.0 % respectively, in comparison to non-pilot cities. Furthermore, this paper conducts an analysis of the economic significance of the estimated coefficients from the perspective of the sample mean.

The results from column (3) of Table 1 are considered as the benchmark for interpretation. The estimated coefficient of *pgdp* is positive, indicating that higher levels of local economic development contribute to increased carbon emissions. The estimated coefficient of *pop* is also positive, suggesting that greater population agglomeration is associated with higher levels of urban carbon emissions.

Table 1

Benchmark regression analysis

Variable	Model 1	Model 2	Model 3	Model 4
	Y1	**Y2**	**Y1**	**Y2**
policy	-0.023^{**} (0.019)	-0.055^{**} (0.020)	-0.033^{**} (0.015)	-0.057^{***} (0.012)
pgdp			0.435^{***} (0.105)	0.186^{***} (0.013)
pop			0.412^{**} (0.156)	0.200 (0.142)
fdi			0.006^{*} (0.004)	0.015 (0.003)
fia			–0.001 (0.012)	–0.048 (0.005)
rd			0.002 (0.004)	-0.009^{***} (0.133)
Observations	3157	3157	3157	3157
R^2	0.960	0.742	0.967	0.884

Note: Robust standard errors clustered to the city level in parentheses; *, **, and *** denote the significance level of 10 %, 5 %, and 1 %, and R^2 represents the fitting coefficient. The number in brackets indicate the statistical test value

Parallel trend test

A crucial prerequisite for conducting policy impact assessment using DID method is that the control group and the treatment group demonstrate a shared trajectory in carbon emission levels in the absence of policy intervention. To verify this hypothesis, the present study employs the dynamic difference method, employing the methodology outlined in [13], to perform a parallel trend analysis. The following formula is employed for this purpose:

$$Y_{it} = \alpha_0 \sum_{k=-3}^{k=3} \beta p_{i,t+k} + \delta \mathrm{X}_{\mathrm{it}} + v_t + u_i + \varepsilon_{it} \qquad (2)$$

where $p_{i,t+k}$ represents the k year of the establishment of the demonstration city. In this paper, the focus of argument is β_k, which reflects the "Broadband China" model cities set up before and after the establishment of the influence of the level of carbon emissions. The interpretation of the remaining parameters is the same as in formular (1). The regression findings are presented in Table 2.

Table 2

Parallel trend test results

Variable	Y1	Y2
Before(3)	0.016 (0.006)	0.047 (0.009)
Before(2)	0.021 (0.073)	–0.072 (0.030)
Before(1)	–0.030 (0.028)	–0.070 (0.008)
After(1)	-0.014^{**} (0.014)	-0.038^{**} (0.011)
After(2)	-0.020^{**} (0.036)	-0.052^{**} (0.045)
After(3)	-0.030^{***} (0.015)	-0.064^{**} (0.008)

Randomness problem

The underlying assumption behind employing the difference method to accurately discern the policy impact is the random selection of pilot cities. However, in reality, the selection process of these demonstration cities typically involves considerations such as economic development level, geographical location, and resource endowment of each city. These variations may have distinct effects on the long-term quality of economic development in cities, thereby potentially interfering with the estimation outcomes.

To mitigate the influence of these factors, the current study incorporates a cross-term between these prerequisite factors and the linear trend of time into the regression analysis.

Robustness test

In order to further substantiate the credibility of these findings, this study conducted rigorous tests to ensure their robustness. Apart from the policy change associated with the establishment of "Broadband China" demonstration cities, other policies or random factors could also result in regional disparities in carbon emission levels. To mitigate the influence of such factors, a counterfactual test was performed by altering the timing of policy implementation. Columns (1) and (2) in Table 3 present the implementation of a hypothetical "Broadband China" demonstration city three years ahead of schedule. Notably, the estimated coefficient of the hypothetical "Broadband China" demonstration city is not statistically significant, thereby indicating that its impact is not attributable to other factors.

In the baseline regression, outliers can potentially impact the regression outcomes. For instance, certain regions may exhibit significantly higher carbon emissions compared to other cities due to abundant coal resources or heavy industries. Conversely, some cities may have lower carbon emission levels due to favourable natural geographic conditions or specific economic growth patterns. Including these samples in the regression analysis can skew the results.

To mitigate the impact of outliers on the regression outcomes, this study employed a 5% tail reduction approach on the dependent variables and re-conducted the regression.

It is observed that even after the tail reduction treatment, the estimated coefficient for the "Broadband China" demonstration city remains significantly positive at the 5 % significance level. Additionally, the coefficient value is nearly identical to the benchmark, further substantiating the reliability of the benchmark results to a certain extent.

Table 3

Robustness test results

Variable	**Change the timing of policy implementation**		**Exclude the influence of extreme values**	
	Y1	**Y2**	**Y1**	**Y2**
policy	–0.014 (0.002)	–0.107 (0.011)	–0.028** (0.013)	–0.061** (0.018)
Observations	3157	3157	3016	3016
R^2	0.653	0.560	0.944	0.839

Heterogeneity analysis

Due to substantial variations in geographical location, economic development stages, and levels of energy conservation and environmental awareness among different cities, these divergent urban characteristics can lead to varying responses. In light of this, this study further examines whether policy changes exhibit heterogeneity, as shown in Table 4.

Table 4

Heterogeneity analysis results

Variable	**Eastern regions**		**Central and western regions**	
	Y1	**Y2**	**Y1**	**Y2**
policy	–0.073*** (0.019)	–0.079*** (0.005)	–0.010 (0.020)	–0.022 (0.018)
Observations	1110	1110	1906	1906
R^2	0.984	0.862	0.948	0.733

The findings unveil that the establishment of "Broadband China" exemplar cities has considerably mitigated carbon emissions in the eastern realm. However, the impact on carbon emission levels in midland lacks statistical significance. In contrast to the eastern region, midland possess comparative advantages in terms of energy and resources. Nevertheless, they also encounter challenges such as industrial entrenchment and route dependency during the course of industrial advancement. Furthermore, midland regions have undergone the transference of industries from the eastern regions, and the relocation of high-energy-consuming enterprises has impeded the promotion of carbon emission reduction.

Conclusion

Grounded in the fundamental fact that digital infrastructure construction exerts a profound impact on China’s economy and society, DID method is employed to scrutinise the underlying mechanisms of digital infrastructure construction on the reduction of carbon emissions. The findings of this study reveal that the "Broadband China" policy has yielded a significant reduction in urban carbon emissions, and this positive effect demonstrates sustainability. These results have been further validated through robustness tests. Additionally, heterogeneity analysis demonstrates that regional disparities exist in the impact of exemplar city construction on carbon emissions, and the eastern region experiences greater dividends from digital infrastructure construction, surpassing those observed in midland.

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