Proceedings of ICFTBA 2026 Symposium: Driving Organizational Strategic Change for Financial Gains
DOI: 10.54254/2754-1169/2026.BH38837

Digital Infrastructure and Urban Green Productivity: Reassessing the Broadband China Pilot Programme

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Abstract. Broadband expansion may support economic growth, but its green-productivity benefits remain uncertain. Establishing whether local designation delivers these benefits matters for evaluating digital investment. This paper assesses the Broadband China designation in 285 cities over 2008-2022, using cumulative green TFP and annual productivity change. A staggered difference-in-differences approach compares designation cohorts with never-designated cities. The average cumulative-productivity estimate is 0.0051 log points, or about 0.51%, with a 95% confidence interval of −0.96% to 2.00%. The annual-change estimate is also statistically indistinguishable from zero. With baseline adjustment, the cumulative estimate increases to 0.70% but remains statistically insignificant, and the joint pretreatment test no longer rejects. Non-rejection does not establish identification. Unadjusted pretreatment differences are concentrated primarily in the 2014 cohort. Removing that cohort, matching cities and excluding areas with partial treatment leave the average cumulative effect statistically insignificant. Resource-group contrasts remain exploratory because both groups exhibit pretreatment differences. The results do not establish automatic green-productivity gains from designation and emphasize the importance of outcome construction, sample selection and treatment geography.

Keywords: Broadband China, green productivity, staggered difference-in-differences, pretreatment trends

1. Introduction

Broadband diffusion can lower information costs and stimulate economic growth [1]. For example, Czernich et al. estimate that a 10-percentage-point increase in broadband penetration raised annual per capita growth by 0.9-1.5 percentage points in OECD countries over 1996-2007 [1]. However, higher output does not automatically translate into more environmentally friendly production methods. The advantages of the digital network for the coordination of activities and the diffusion of knowledge could be offset by the increased need for electricity and additional investment. Whether the positive effects of broadband outweigh its negative effects remains an empirical question.

Several studies report positive effects of Broadband China on green outcomes, although their outcome measures differ [2-4]. First, Ma and Lin [2] study green economic performance in 271 Chinese cities from 2003 to 2019 using a non-radial directional distance function. Then, Feng et al. [3] analyze green innovation in urban settings. Finally, Hu et al. [4] already investigated urban

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GTFP with positive results, incorporating industrial wastewater, sulphur dioxide and dust as undesirable outputs in the GTFP measure. These variables and their corresponding research design choices are an important starting point for this study, since it compares alternative outcome constructions and related identifying assumptions.

Recent studies also emphasize that conclusions about green benefits depend on the estimator, outcome measure and interpretation of designation [5, 6]. Zhou et al. [5] examine GTFP in 107 Yangtze River Economic Belt cities from 2010- 2022 and report different inferences under TWFE and Sun–Abraham estimation. Cao and Chen [6] audit implementation, environmental measures and baseline digital readiness, distinguishing designation from verified network improvement and cautioning against transferring conclusions between outcomes. The present study focuses on cumulative versus annual productivity measures and cohort-specific pretreatment diagnostics, while sharing these broader implementation and measurement concerns.

This study examines how results change when a city's cumulative green productivity is distinguished from its annual productivity growth rate. It also explores the results when the same sample of cities is analyzed by cohort and when the boundaries of administrative treatment are checked. This study reassesses prior research using a different assembled dataset rather than replicating the original microdata. Results are presented regardless of sign and significance. No model has been selected because it supports the expected positive effect of a policy.

2. Institutional background and theoretical expectations

The Broadband China strategy was launched in 2013 [7]. For the demonstration of Broadband China, lists of cities and other areas to be designated successively in 2014–2016 were compiled [8-10]. Designation was not randomly assigned: the official announcement describes city applications, provincial preliminary review and comprehensive expert assessment [9]. The strategy for Broadband China and the local designation therefore are to be distinguished from each other; even comparison cities can develop their own local networks and thus also benefit from nationwide broadband development and investment. The estimand is therefore the additional change associated with local designation, not the effect of introducing the internet to previously unconnected cities.

Of course, better information and better coordination may raise not just innovation activity, but also cumulative green productivity. Moreover, a sustained acceleration would appear in annual productivity growth, whereas a temporary spurt could still generate a lasting cumulative gain. The fact that there are some costs of adjustment, and increased demand for electricity, as well as limited complementary capabilities, does not mean that there will be no improvements at all, but rather that the analysis should not impose any sign on the expected effects or treat innovation activity as evidence of productivity improvements.

Accordingly, the analysis tests two null hypotheses separately: H0C, the average designation effect on log cumulative green TFP is zero, and H0A, the average designation effect on log annual GML is zero. Each is tested against a two-sided alternative. These are statistical null hypotheses, not theoretical predictions of insignificance; failure to reject either does not establish the absence of an effect.

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3. Data and econometric design

3.1. Sample and outcome construction

The sample consists of all 285 cities from the supplied productivity workbook [11], with each city matched to the policy panel [12] and with complete main outcomes and baseline covariates. The sample includes 4,275 balanced annual observations from 2008 through 2022. The city designation policy has three cohorts: 37 cities in 2014, 36 in 2015, and 35 in 2016. In total, 177 cities were never designated at the city level. The earlier panel for the city designation policy, 2010–2022, is maintained as a reference sample, with 3,705 unchanged observations. The new starting date of 2008 adds information on the years preceding the implementation of the city designation policy and excludes the mechanically normalized 2007 outcome year.

Productivity measures come from the Chinese City Environmental Performance, 2007–2023 workbook distributed by Zhongli Data [11]. The Chinese City Database, 2000–2024, version 202603, supplied by Mark Data [13], is used for additional covariates and for Internet-user counts. The raw-data worksheet is used. References [11-13] identify the delivered workbooks and supplier websites; these identify the data distributors rather than independently verified frontier calculations. A source manifest and variable dictionary are supplied which contain information about the filenames, hashes and variable mappings for the data sources. Associated productivity variables include capital, employment, electricity, real GDP, CO_2 and SO_2. Annual Global Malmquist–Luenberger index(GML) values are supplied for individual years and interpreted as annual productivity change within the framework discussed by Oh [14]. The supplied cumulative index value satisfies:

$$\mathrm{GTFP}_{it} = \mathrm{GTFP}_{i,t-1} \times \mathrm{GML}_{it}, \quad \mathrm{GTFP}_{i,2007} = 1 \tag{1}$$

For each city, this identity has been verified within rounding tolerance, and all 2007 cumulative index values equal one. The first outcome is ln(GTFP), and the second one is ln(GML), which approximates annual productivity growth. The cumulative index for a city measures the change relative to its own 2007 productivity level, i.e., it does not measure a city's position in an absolute ranking of cities' productivity. The verification of the above identity does not enable the verification of the supplier's production frontier in full.

The analysis adds no interpolation, zero filling, or winsorization. Upstream supplier processing may still have occurred. All observations for the two productivity measures and the four baseline covariates are complete for the main sample. The four baseline covariates used are 2013 log GDP per capita, log registered population, local government fiscal expenditure relative to GDP and bank loans relative to GDP. Although using fixed values for these means that the analysis does not condition on subsequent annual observations, these measures precede local designation rather than the 2013 national strategy. In addition, they may already reflect part of the response to the broader initiative and so the results need to be interpreted with caution.

3.2. Treatment geography

In the treatment audit, the analysis distinguishes whole-city designation from partial exposure. Cities within clusters such as Changsha–Zhuzhou–Xiangtan are audited as individual cities. The special case of Kunshan is not audited as an additional prefecture-level city. The special case of Yongcheng from 2015 is clearly distinguished from the special case of Shangqiu from 2016 which is audited as

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a whole city. The selected districts of Chongqing are not coded as a whole-municipality designation. For the audited dates within the definition of whole-city designation the assembled panel was correct.

However, uncertainty remains about how much partial exposure has affected the results, including both individual-city results and cross-city comparisons. The results in Table 2 present a boundary check. The analysis was therefore repeated after excluding Shangqiu and Chongqing for the entire period to check for possible influence from partial treatment and network spillovers. The results, for 283 cities, are presented in Table 2. Importantly, partial treatment and network spillovers need not bias the estimates in any particular direction.

3.3. Estimation and diagnostics

Two-way fixed effects (TWFE) provides a benchmark:

$$Y_{it} = \mu_i + \lambda_t + \beta D_{it} + \varepsilon_{it} \tag{2}$$

Here Y is either logged productivity outcome and D indicates designation from its first year onward. City and year effects absorb time-invariant city characteristics and common annual shocks. An adjusted version interacts the four baseline covariates with year indicators. With staggered adoption, TWFE can combine comparisons whose interpretation becomes problematic under heterogeneous effects [15].

The main comparisons use Callaway–Sant'Anna (CS) group-time effects [16]:

$$ATT(g,t) = E[Y_{it}(g) - Y_{it}(\infty) \mid G_i = g] \tag{3}$$

The analysis first compares each cohort of cities with never-designated cities. The year before designation serves as the universal reference year for each cohort. The average post-designation cohort-year effect is computed with weights proportional to cohort size. To target observed post-designation city-years, earlier cohorts receive more years of exposure. Both the unadjusted analysis and the doubly robust covariate-adjusted analysis are reported [17]. The latter combines a propensity-score model with an outcome-regression model. These estimates require, in addition to conditional parallel trends, sufficient overlap and no anticipation. City-level influence functions are used to compute standard errors and joint pretreatment Wald tests. Pointwise confidence intervals are reported.

These diagnostics include: (1) estimates for each cohort individually; (2) results without the 2014 cohort; (3) results for the original matched sample; and (4) results with territorial exclusions imposed. These revisions followed inspection of the original results and were not prospectively preregistered. All specified comparisons are retained, while pretreatment tests are used as diagnostics rather than selection criteria. The tests may not have sufficient power to reject, and subsequent selection of a 'significant' model could further distort the results [18].

4. Results

4.1. Average cumulative and annual effects

As shown in Table 1, the full-sample estimate suggests an average cumulative green-productivity increase of about 0.51% following the Broadband China designation, but this estimate is not statistically significant. The unadjusted cumulative-productivity estimate is 0.0051 with an

DOI: 10.54254/2754-1169/2026.BH38837

associated 95% interval of -0.96% to 2.00% after transformation to percentage change. The corresponding baseline-adjusted estimate is 0.0070, with a p-value of 0.367 and a 95% CI of -0.0082 to 0.0221 log points, or approximately -0.81% to 2.23% after transformation to percentage change. Thus, although these intervals include effects in either direction, they provide no statistically clear evidence of an average policy effect.

Table 1. Average effects and pretreatment diagnostics

Outcome	Specification	Estimate	SE	p-value	Pretrend p
Cumulative	TWFE	0.0115	0.0076	0.129	—
Cumulative	TWFE + X × year	0.0028	0.0067	0.670	—
Cumulative	CS	0.0051	0.0075	0.497	0.012
Cumulative	CS + baseline X	0.0070	0.0077	0.367	0.487
Annual change	TWFE	-0.0008	0.0024	0.750	—
Annual change	TWFE + X × year	0.0031	0.0019	0.102	—
Annual change	CS	-0.0002	0.0032	0.956	0.602
Annual change	CS + baseline X	0.0011	0.0031	0.707	0.268

Notes: 285 cities and 4,275 observations, 2008–2022. X denotes four 2013 covariates. Inference accounts for city clustering. CS uses never-designated comparisons. Pretrend p is the joint Wald p-value for universal-base pretreatment contrasts; it is not the treatment-effect p-value. Source: author's calculations.

Annual changes in productivity are estimated at −0.0002 (with no adjustment) or 0.0011 (with adjustment), with intervals around these estimates that include zero. These estimates address changes in annual productivity growth and should not be confused with alternative measures of the same cumulative effect. Estimates of TWFE are also subject to considerable uncertainty, even with a baseline-by-year adjustment.

The extension of the sample period back in time does not change the post-treatment point estimates for CS, as the set of cities, the cohort-specific reference years, and the post-treatment observations stay the same. The extension mainly lengthens the pretreatment period. Identical post-treatment estimates therefore do not provide independent confirmation of robustness.

4.2. Pretreatment differences and cohort composition

The unadjusted joint pretreatment p-value for cumulative productivity decreased from 0.042 for the 2010–2022 sample to 0.012 for the 2008–2022 sample. The clearest pretreatment differences for the first cohort are shown in Figure 1. The joint p-value was 0.001 for the 2014 cohort, compared with 0.782 for 2015 and 0.520 for 2016. For the 2014 cohort, the post-treatment estimate was 0.0226 ($p = 0.069$). The fact that this cohort also shows the strongest pretreatment differences means that its comparatively positive post-treatment estimate cannot be viewed as providing convincing evidence of positive impact.

DOI: 10.54254/2754-1169/2026.BH38837

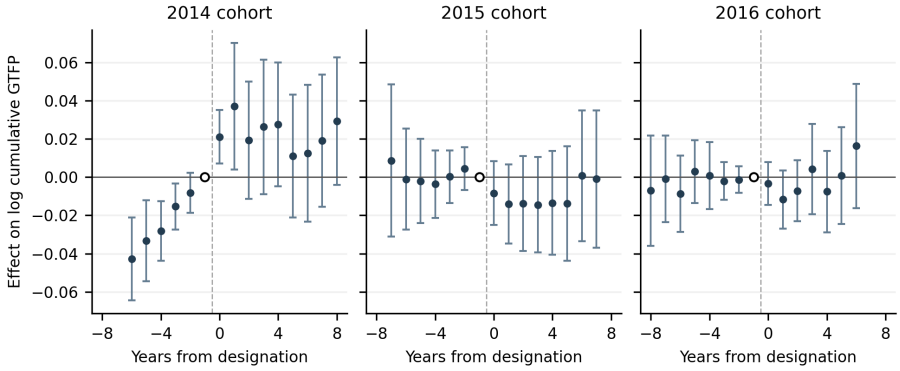


Figure 1. Cohort-specific cumulative-productivity contrasts

Notes: Unadjusted cohort–year CS estimates against never-designated cities. Bars show pointwise 95% confidence intervals; hollow points mark the normalized year before designation. The horizontal axis differs from calendar time. Source: author's calculations.

Baseline-adjusted cumulative estimates produce a different diagnostic: the extended-sample joint p-value is 0.487, compared with 0.901 in the reference sample. Thus, it would be inaccurate to claim that every specification rejects parallel trends. Adjustment conditions on the four observed baseline covariates, but non-rejection cannot rule out unobserved selection or anticipation. The adjusted average itself remains imprecise.

The annual-growth outcome does not reject joint pretreatment restrictions either without adjustment ($p = 0.602$) or with it ($p = 0.268$). This is informative about that outcome's identifying restrictions, not a reason to discard cumulative productivity. Differencing removes persistent cumulative differences and changes the economic question.

4.3. Sample sensitivity and exploratory heterogeneity

The specified cumulative-outcome checks are reported in Table 2. The sensitivity analysis excluding the 2014 cohort yields an estimate of −0.0058 ($p = 0.478$). The joint pretreatment restrictions were not rejected after excluding the 2014 cohort. However, because this exclusion was motivated by the observed diagnostic results, it remains a sensitivity analysis rather than a replacement for the primary sample. The original matched sample yields an estimate near zero while still rejecting the joint pretreatment restrictions. Therefore, balancing the observed covariates did not establish balanced outcome trends for the analysis. The results for the sample with territorial exclusions did not change the results of the prior analysis and left the previously identified substantive uncertainty unchanged.

Table 2. Cumulative-productivity sensitivity checks

Sample	Cities	Estimate	SE	p-value	Pretrend p
Full sample	285	0.0051	0.0075	0.497	0.012
Exclude 2014 cohort	248	-0.0058	0.0082	0.478	0.471
Original matched cities	160	-0.0008	0.0081	0.919	0.011
Territorial exclusions	283	0.0051	0.0076	0.497	0.013

Notes: Unadjusted CS, 2008–2022. The matched sample fixes the original 80 treated and 80 comparison cities. Territorial exclusions remove Chongqing and Shangqiu for the entire period. All specifications retain their eligible never-designated comparisons. Source:

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author's calculations.

For non-resource and resource cities, the resource-group estimates have opposite signs (0.0237 and -0.0308). Although both groups reject the joint pretreatment restrictions ($p < 0.001$ and $p = 0.039$), 32 of 73 designated non-resource cities belong to the 2014 cohort, compared with 5 of 35 resource cities. Composition therefore can complicate the between-group comparison, although it does not mechanically explain the opposite point-estimate signs. Equal weighting across cohorts within each of these groups over a common horizon of zero to six years preserves the opposite signs of the two estimates. This descriptive check, however, does not provide a formal test of group differences or valid subgroup identification.

5. Discussion

The auxiliary network-use check uses the supplied "international internet users" field, recorded in accounts, which does not automatically equal the number of fixed-broadband subscriptions or unique individuals. Covering 2008–2019 completely for 264 cities and 3,168 observations, the log-account estimate equals -0.0032 ($p = 0.920$), whereas the pretreatment restrictions are strongly rejected ($p < 0.001$). Some counts show large changes, but these do not establish whether designation increased connectivity. The proposed chain from designation through connectivity to greener production therefore remains unverified.

Although the current results differ from previous studies that found positive effects of Broadband China on green outcomes [2-4], it is difficult to pinpoint the reasons for these differences. Possible differences include the set of frontier inputs, undesirable outputs, sample period, city sample, and corresponding estimands. Constructing alternative frontiers from the same harmonized raw data would be an important step toward isolating measurement effects, while also holding the sample, treatment coding and estimator fixed. Additional mechanism regressions and tests cannot replace this analysis and also cannot repair violations of the parallel-trends assumption.

Note, however, that concurrent policies, possible spillovers, and specification choices, including the choice of the 2013 baseline, remain limitations. Joint pretreatment tests do not bound the possible bias from departures from parallel trends. Therefore, the current evidence only allows for a qualified reassessment of the green benefits of broadband investment rather than a refutation.

6. Conclusion

Using a sample of 285 cities over the 2008–2022 period, this study finds no statistically significant average increase in either cumulative or annual green productivity associated with Broadband China designation. Unadjusted cumulative green-productivity estimates show pretreatment differences that are largest for the 2014 cohort; however, baseline adjustment and the annual-growth outcome produce less adverse diagnostics without revealing significant average gains. Matching, dropping the 2014 cohort, and territorial exclusions do not alter the basic message of uncertainty regarding the effects associated with Broadband China designation on environmental productivity. These conclusions concern average designation effects for the sampled cities over 2008–2022 and cannot be directly generalized to individual firms. They do not rule out gains in particular cities, but the present analysis does not establish city-specific causal effects. Future research could reconstruct alternative frontiers from harmonized inputs and improve measures of actual network exposure, while holding the sample, treatment coding and estimator fixed where possible.

DOI: 10.54254/2754-1169/2026.BH38837

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