Complementarities in Developmental Infrastructure - Rural Roads and Access to Electricity

Namrata Chindarkar [*], Deepti Sharma [†], Rohan Gudibande [‡], Milind Gupta [§]

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Abstract

This paper investigates whether there is complementarity between two basic infrastructure investments in India: roads and grid electricity. Using household panel data from the ACCESS surveys (2015 and 2018) matched with administrative data from the Pradhan Mantri Gram Sadak Yojana (PMGSY), we examine whether the sequencing of infrastructure delivery matters. Using fixed effects regressions, we find that households in villages with early road access (before 2015) were 6.5 percentage points more likely to be connected to the electricity grid by 2018 relative to those with later road access. The complementary effect is strongest among households located within 3 km of a PMGSY road. In addition, we observe improvements in the quality of electricity supply, including reliability, duration, and voltage stability, among early road recipients. Our findings underscore the importance of sequencing and spatial proximity in the design of rural infrastructure and provide evidence that complementarities across sectors are central to achieving universal energy access.

1 Introduction

A key knowledge gap persists regarding whether the absence or inadequacy of one infrastructure limits access to another, creating bidirectional constraints. Thus, the question remains whether access to one basic infrastructure impacts the delivery of another infrastructure. In this paper, we test the "complementarity" between access to rural roads and access to grid electricity to better understand the complementary effects of distinct policies aimed at enhancing access to basic infrastructure.

Much of the literature focuses on the impact on economic outcomes (income and poverty; health and education investments; employment) of a basic infrastructure such as roads or electricity in isolation [Agarwal et al., 2023, Adukia et al., 2020, Aggarwal, 2018, 2021, Asher and Novosad, 2020]. The results of these studies are mixed depending on the scale at which infrastructure interventions are examined - large populations versus small regions. Some studies find modest or null effects on economic development in the short to

[*]Associate Professor & Chairperson, JSW School of Public Policy, Indian Institute of Management Ahmedabad
[†]Assistant Professor, Ahmedabad University
[‡]Assistant Professor, KREA University
[§]Research Associate, Indian Institute of Management Ahmedabad

medium term, while others find large positive effects on reallocation of labor, and long-term gains in sectoral productivity based on local conditions [Bansal, 2025, Lipscomb et al., 2013, Kurian, 2023].

Few studies examine the joint effects of investments in road and electricity infrastructure in developing country contexts. Burlig and Preonas [2024] find that since the implementation of the large-scale rural infrastructure development program in India - *Rajiv Gandhi Grameen Vidyutikaran Yojana* (RGGVY) - commercial electricity consumption increased by 3.8 percentage points, household electricity consumption increased by 4kwh/month and night-time brightness showed a measurable increase in rural areas between 2000 and 2011. The study posits that electrification gains were conditional upon pre-existing economic development in the villages. Another study in the Indian context that treats road and electrification as joint investments finds that households increase dry season cropping when they receive both electricity and roads but not when they receive one without the other [Eynde and Wren-Lewis, 2024]. The potential channels being access to irrigation through pumps and access to markets. Further, adequate road connectivity increases market access and consequently gains from electricity-powered production by expanding scale and profitability as noted by Ghani et al. [2016] in their examination of the effects of the Golden Quadrilateral (GQ) highway network in India. A study in Brazil finds that municipalities that had an existing highway reported significantly higher local economic outcomes compared to municipalities that only had electrification [Selod et al., 2024]. In the African context, findings suggest that joint investments roads and electrification facilitate structural and sectoral transformation, and stimulate job creation and promote growth of manufacturing sector [Abbasi et al., 2022, Moneke, 2020].

Clearly, there is a likelihood of higher economic and development gains when roads and electricity are jointly provided. However, there is very little evidence on the complementarity between access to roads and access to electrification and whether this inter-relationship can be causally established [Abbasi et al., 2022, Eynde and Wren-Lewis, 2024]. We argue that solving the following identification problems in the literature is essential in causally establishing roads and electrification as being inter-dependent. First, there exists endogeneity in the co-location of roads and electricity infrastructure. Second, complementarity is likely to depend on which comes first - roads enabling grid extensions or electrification making roads more productive. Existing studies treat the interaction as symmetric and static. And third, there is a lack of long-run (10 to 15 years) longitudinal, micro-level study on the sustained inter-dependence between roads and electrification.

Given a lack of evidence on the sequencing between roads and electrification that potentially generates complementarity, our paper asks - *Does sequencing of infrastructure result in complementarity? Further, conditional on complementarity being detected, what drives the direction of complementarity?*. As discussed above, the literature identifies the scale of implementation and related costs of road or electrification being consequential for any subsequent effect on long-term economic and development outcomes. On further examination it can be conceived that say suppose road affects electrification, then it is likely that road reduces costs for electrification. For instance, in India, the *Pradhan Mantri Sahaj Bijli Har Ghar Yojana* (Saub-

hagya) program that aims to achieve universal household electrification by providing last-mile connectivity has issued official technical guidelines. As per the guidelines, while road access is not a formal requirement under Saubhagya, the presence of roads can significantly facilitate the transportation of materials and equipment necessary for electrification projects[1]. Improved road connectivity can thus enhance the efficiency and feasibility of implementing electrification initiatives in rural areas.[2]

Against this background, our paper contributes by positing that existing road infrastructure is necessary for enhancing access to high-quality and reliable household electricity in the rural Indian context. We use two sources of data to examine this. First, geo-referenced *Pradhan Mantri Gram Sadak Yojana* (PMGSY) or rural roads program administrative data from Geosadak, which has details about the road network in terms of its commissioning year, work name, length of road, and type of construction (road/bridge). And second, we use household-level panel data from the "Access to Clean Cooking Energy and Electricity" (ACCESS) surveys conducted in 2015 and 2018. This is a unique dataset that includes indicators on multidimensional energy access at the household level in rural India [Mani et al., 2019].

We present three main findings. First, access to grid electrification is higher (6.5 percentage points [pp]) among households that have long term/early access to PMGSY roads (on or before 2015) relative to late access (after 2015) and who are observed in both waves of ACCESS survey. Second, the highest complementary effect between roads and electrification can be seen on households with early access living within 3 km distance of a PMGSY road. They are 12 pp more likely to have access to grid electricity compared to those living farther away from a PMGSY road. Third, parameters to measure electricity service level (reliability, duration, quality) improved for the households that have early access to PMGSY roads and who are observed in both waves of ACCESS survey.

Our study makes several important contributions. One major contribution is on that our paper is the first to study the long term impact of complementarity between two basic infrastructure (considered necessary for economic growth) in terms of access and usage. Studies using instruments that rely on theoretically exogenous cost factors (such as terrain or distance to grid infrastructure) often assume that these costs are uncorrelated with other development interventions [Grogan and Sadanand, 2013, Lipscomb et al., 2013]. However, this assumption is difficult to defend empirically. For instance, if land gradient influences the cost of both road and grid infrastructure, then instruments based on topographical cost may fail the exclusion restriction by capturing the effects of simultaneous road expansion. In cases where roads and electrification are rolled out in tandem, such instruments risk conflating the independent impact of electricity access with that of complementary infrastructure. Instead, we estimate panel fixed effects regressions using a matched sample and rely on rural roads program implementation guidelines to construct our instrument. Second, this paper contributes to the literature by focusing on the sequencing of infrastructure and the directionality of complementarity, specifically between rural roads and grid electrification — an issue largely overlooked

[1] https://www.saubhagya.gov.in/assets//download/Guidelines of SAUBHAGYA.pdf

[2] Of course, the inverse could also be true with electrification making road construction easier. However, we do not focus on electrification preceding road construction.

in existing identification strategies.

2 Identification strategy

Theory of change

The distinct heterogeneous contributions of infrastructure types — including highways, railways, transportation, telecommunication systems - on growth has been widely explored. However, the interplay between these infrastructures raises a pivotal question: whether these infrastructures are complementary in nature? This study empirically investigates this dynamic, with a focus on rural roads being treated as a pre-requisite to achieve last mile delivery of high-quality and reliable rural electrification.

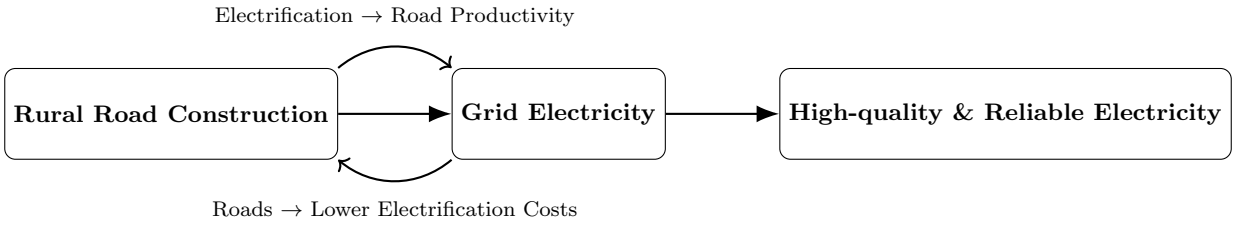


Figure 1: Theory of Change: Road Infrastructure as a Complementary Driver of Grid Electricity.

Specification-1: Early vs. late access to PMGSY on access to grid electricity

To estimate the effect of early road access on household access to grid electricity, we implement the following estimation design using a matched sample. Since households that received roads before 2015 (early access) may differ systematically from those that received roads later (after 2015), we restrict the analysis to a matched sample to ensure balance on observed pre-treatment covariates.

We estimate the following specification:

$$GridAccess_{ivt} = \alpha + \beta_1 Post_t + \beta_2 EarlyAccess_{iv} + \beta_3 (Post_t \times EarlyAccess_{iv}) + \gamma \mathbf{X}'_{it} + \lambda_t + \phi_v + \epsilon_{ivt} \quad (1)$$

$GridAccess_{ivt}$ is a binary indicator equal to 1 if household i residing in village v in period t receives electricity through the grid, and 0 otherwise. $EarlyAccess_{iv}$ is a treatment indicator equal to 1 if the household's village received early access to road on or before 2015, and 0 if it received a road after 2015. This is based on the IMS road completion year (from administrative data of PMGSY). $Post_t$ is a time dummy equal to 1 for wave-2 of ACCESS conducted in 2018 and 0 for the wave-1 in 2015. The main variable of interest is β_3 that captures the likelihood of grid access for early road recipients relative to late recipients, after the road construction period. $\mathbf{X}_{it}$ is a vector of household-level covariates (e.g., demographic characteristics, baseline amenities) and λ_t survey year fixed effects and ϕ_v considers village fixed effect. ϵ_{ivt} is the error term, clustered at the appropriate village level.

Specification-2: Effect of distance to PMGSY road on access to grid electricity

Extending the above specification, we also expect the distance between the PMGSY road and the village to have an effect on the likelihood of getting grid connectivity. To estimate the impact of heterogeneous distance, we estimate the following specification:

$$GridAccess_{ivt} = \alpha + \sum_{d} \eta_d (Dist_{iv} \times Post_t \times EarlyAccess_{iv}) + \gamma \mathbf{X}_{it} + \lambda_t + \phi_v + \epsilon_{ivt} \tag{2}$$

where $\sum_d$ denotes the summation over the three distance categories (0–3 km, 3–7 km, and $>$ 7 km). Here $GridAccess_{ivt}$ is a binary variable equal to 1 if household i in village v is connected to the electricity grid at time period t. $Distance_{iv}$ is a dummy variable for each distance category. The coefficient on η_d gives us likelihood of grid access for early road recipients relative to late recipients under different distance categories. Other controls and fixed effects are same as mentioned in equation 1.

Since road placement may be endogenous to development priorities or local demand, we instrument for road placement (either early or late) using the regression discontinuity design (RDD) suggested in Asher and Novosad [2020]. More on this in section 6.

Specification 3: Early vs. late access to PMGSY on multi-tier electricity access

We run the above specifications on the sample of households with access to grid electricity using World Bank's Multi-Tier Framework (MTF) indicators for quality and reliability of electricity access as outcome variables [Bhatia and Angelou, 2015]. The World Bank's MTF considers five aspects of electricity service such as capacity (ability to power appliances), duration (number of hours of grid electricity), reliability (frequency and duration of outages), quality (number of days low/high voltage), affordability (basic service less than 5% of a household income) and legality (having a legal electricity connection). Several studies have used the ACCESS survey to capture multi-dimensionality of electricity access rather than mere connectivity [Akter et al., 2023, Sedai et al., 2021].

Let MTF_{ivt} be an MTF indicator for a household i in village v, surveyed in year t, and connected to the grid ($hasgrid_i = 1$). Using equation 1, we estimate the following specification:

$$MTF_{ivt} = \alpha + \beta_1 Post_t + \beta_2 EarlyAccess_{iv} + \beta_3 (Post_t \times EarlyAccess_{iv}) + \gamma \mathbf{X}'_{it} + \lambda_t + \phi_v + \epsilon_{ivt} \tag{3}$$

3 Data Description

3.1 PMGSY

Pradhan Mantri Gram Sadak Yojana (PMGSY) is an initiative undertaken by the Government of India starting in the year 2000 to enhance the rural road connectivity. At the time of its implementation, there

were several habitations (smaller, localized cluster of residents within a village) across the country that did not have road connectivity. Even when habitations had connectivity, the roads were of sub-par quality and not "all-weather", making them inaccessible during parts of the year. Thus, the aim of PMGSY is to provide every such habitation in the country connectivity with all-weather roads. The eligible habitations for the program are determined based on habitation-level population. Habitations that have a population of 500 or more if they live in the plains and those with a population of 250 or more if they are in the hills are eligible. As of 2024, about 1.67 lakh habitations are eligible to be covered under this scheme and thereby get access to an all-weather road connectivity network.

3.2 ACCESS

We use data on energy access from the ACCESS data set, India's largest energy access. The survey covers six Indian states: Bihar, Jharkhand, Madhya Pradesh, Odisha, Uttar Pradesh, and West Bengal. These states are among the most populous and and among the most energy deprived states of India. The first wave conducted in 2014–2015 and surveyed 8,563 households covering 714 villages across 51 districts. The second wave was conducted in 2018 and surveyed 9,072 households covering 754 villages across 54 districts. The increase in households in 2018 is owing to both sample attrition as well as addition. Sample retention rate was 86% [Mani et al., 2019]. Apart from rich information on household's access to and use of energy, the survey provides information on demographic and household characteristics, lighting and cooking satisfaction, and so on. While there are a total of 17,635 households in the panel data, our sample for analysis includes 15,594 observations after matching on observed covariates.Propensity score matching has been done on the cross-sectional data from 2015 survey year using nearest neighbour and caliper techniques. Further for analysis, the matched sample has been extended to a full panel, including data from 2018 survey (the quality of matching and balance in covariates is shown in table A1 and figure A1.)

We merge the geo-referenced PMGSY road network data with the ACCESS survey using village-level geographical coordinates available for each village included in the ACCESS dataset.[3] This merging exercise enabled us to generate two important variables for our analysis - (i) years since an ACCESS village has a PMGSY road and (ii) distance of an ACCESS village to the nearest PMGSY road.

4 Descriptive Statistics

Table 1 presents summary statistics from the pooled ACCESS survey waves (2015 and 2018) merged with PMGSY administrative data. Majority of our sampled households (74.7 percent) report having grid electricity, and 87.2 percent reside in villages connected by a PMGSY road. Nearly three-quarters of the sample (74 percent) reside in villages that received early road access (on or before 2015). It is important to note that the ACCESS survey follows a balanced panel of households across the two survey waves (2015 and 2018).

[3]To protect the identity of the respondents, the geographical coordinates in ACCESS were collected only at the village level. These are proprietary data and not available in the public-use ACCESS data files.

Consequently, the post-period indicator simply reflects survey timing, with households observed once before and once after, rather than changes in sample composition.

In terms of spatial distribution, 59.5 percent of households are within 3 km of the nearest PMGSY road, 18.9 percent fall in the > 3 *to* ≤ 7 km range, and 21.6 percent live more than 7 km away. Among households with electricity spending data, average monthly expenditures are about 247 INR, representing roughly 5 percent of annual household expenditures.

Turning to the Multi-Tier Framework (MTF) indicators, households report mean scores around 1.6 for capacity, duration, and quality, while reliability is slightly lower (1.26). Affordability averages 1.32, and legality is higher at 2.24, reflecting widespread regularization of electricity connections. The overall tier index is relatively low, averaging 0.29, suggesting substantial scope for improvement in multidimensional electricity access.

Table 1: Sample Description from ACCESS (wave-1 and 2) and PMGSY administrative data

	N	Mean	SD
Has Grid Electricity (1= Yes, 0= No)	15646	0.747	0.435
Has a PMGSY Road (1= Yes, 0= No)	15646	0.872	0.335
Post (1= ACCESS Wave 2018, 0=2015)	15646	0.500	0.500
Early Access to a PMGSY Road (by 2015)	15646	0.743	0.437
Dummy for Distance ≤ 3 km	15646	0.595	0.491
Dummy for Distance > 3 *to* ≤ 7 km	15646	0.189	0.391
Dummy for Distance > 7 km	15646	0.216	0.411
Monthly Electricity Spending	11012	247.435	368.297
Share of Electricity Spending in Yearly Expenditures	10963	0.051	0.074
Capacity Tier (0–3)	15636	1.669	1.072
Duration Tier (0–3)	15646	1.559	1.058
Reliability Tier (0–3)	15646	1.260	1.271
Quality Tier (0–3)	15646	1.568	1.348
Affordability Tier (0/3)	15646	1.323	1.490
Legality Tier (0/3)	11494	2.244	1.303
Overall Tier (0–3)	15646	0.287	0.643

Source: Author's calculations based on PMGSY administrative data and ACCESS household survey.

5 Results

Early vs. late access to PMGSY

In this section we present our results from our regression analyses. Table 2 and figure A2 presents estimates from equation (1), the complementary effect is captured through the interaction term, Early × Post. It compares households in villages that received PMGSY roads before 2015 (early access) to those that received roads later, in the post-2015 survey period. The dependent variable is a binary indicator for whether the

household has access to grid electricity. On average, villages that received early access to PMGSY roads were 21 percentage points more likely to have access to grid electricity compared to those with late access to PMGSY, independent of the survey period. Similarly, the post indicator is positive and suggests that between the first (2014-15) and second (2018) ACCESS survey waves, access to grid electricity increased by about 12.6 percentage points overall. The coefficient on the interaction term indicates that early-access villages experienced an additional gain of 6.5 pp relative to late-access villages in the post-period. Relative to the baseline electrification rate, this approximately corresponds to 12% larger improvement in electrification status among the early access villages observed in wave-2.

Table 2: Effect of Early vs. Late Access to PMGSY on Access to Grid Electricity

	Has Grid
Early	0.211***
	(0.044)
Post	0.126***
	(0.017)
Early*Post	0.065***
	(0.020)
Constant	0.512***
	(0.050)
Household Characteristics	Yes
Village FE	Yes
Wave FE	Yes
R^2	0.3494
Observations	15594

Source: PMGSY administrative data and ACCESS household survey. Notes: Early Access is a treatment indicator equal to 1 if the household's village received early access to road on or before 2015, and 0 if it received a road after 2015. This is based on the IMS road completion year (from administrative data of PMGSY). Post is a time dummy equal to 1 for wave-2 of ACCESS conducted in 2018 and 0 for the wave-1 in 2015. Controls and fixed effects are same as shown in equation 1. Standard errors in brackets. * $p < 0.10, **p < 0.05, ***p < 0.01$. Standard errors are clustered at the village level.

Effect of distance to PMGSY road

The estimates from equation (2) examine whether the effect of PMGSY roads on household's access to the grid varies by distance of the village to the nearest PMGSY road are shown in table 3 and figure A3. Since our datasets are geo-referenced, we compute the nearest distance between the village and the PMGSY road. Villages are grouped into three distance categories: $\leq$3 km, $>$ 3 *to* $\leq$ 7 km, and $>$7 km. These results highlight important spatial heterogeneity in the complementarity between road connectivity and electrification.

Relative to villages farther than 3 km, early-access villages within 3 km experienced an additional 12.3 pp increase in access to grid electricity after 2015 compared to late-access villages. This implies that proximity to a road substantially influenced access to grid electricity, particularly for those with early access to a PMGSY road.

By contrast, households in villages located in > 3 *to* ≤ 7 km from the road exhibit a different pattern. For villages located > 3 *to* ≤ 7 km from a PMGSY road, the triple interaction term is negative. This suggests that by 2018, households in early-access villages at this distance were about 13.7 percentage points less likely to gain grid electrification compared to late-access village in the same distance band, relative to villages either closer than 3 km or farther than 7 km.

For the most remote villages (located more than 7 km from the road) relative to villages closer than 7 km, the likelihood of electrification is statistically insignificant. This is in line with our expectation that for most remote locations, cost of expanding gridded electrification is so high that it is not even responsive to the timing of access to the road.

Table 3: Effect of Distance to PMGSY road on Electrification

	Has Grid
Distance $\leq$ 3 km $\times$ Post $\times$ Early	0.1232*
	0.0732
Distance $\leq$ 3 km $\times$ Post	-0.2195***
	0.0725
Early $\times$ Post	0.0689*
	0.0382
Early	0.0841
	0.0759
Distance $\leq$ 3 km	0.1275**
	0.0626
Distance 3km-7 km $\times$ Post $\times$ Early	-0.1371*
	0.083
Distance 3km-7 km $\times$ Post	0.2368***
	0.0819
Early $\times$ Post	0.0558*
	0.0215
Distance 3km-7 km	-0.1342*
	0.0542
Early	0.2160***
	0.0444
Distance >7 km $\times$ Post $\times$ Early	0.0581
	0.0522
Distance >7 km $\times$ Post	-0.0184
	0.0339
Distance >7 km $\times$ Early	0.0241
	0.0297
Early	0.2806***
	0.0467
Distance >7 km	0.0722***
	0.0233
Household Characteristics	Yes
Village FE	Yes
Wave FE	Yes
Observations	15594

Source: PMGSY administrative data and ACCESS household survey. Notes: Each distance category is defined relative to the omitted category. For villages with $Dist \leq 3$ km, the omitted category is $Dist > 3$ km. For villages with $3 < Dist \leq 7$ km, the omitted category is $Dist \leq 3 \cup Dist > 7$ km. For villages with $Dist > 7$ km, the omitted category is $Dist \leq 7$ km. Each coefficient should be interpreted as the relative difference in post-2015 electrification between early and late adopters compared to villages outside that distance band.

Early vs. late access to PMGSY on MTF electricity access

Table 4 reports estimates of the effect of PMGSY road access on household electricity outcomes measured using the MTF indicators, conditional on households having a grid connection. We measure five aspects of electricity service such as capacity (ability to power appliances), duration (number of hours of grid electricity), reliability (frequency and duration of outages), quality (number of days low/high voltage), affordability (basic service less than 5% of a household income) and legality (having a legal electricity connection).

The results show that early road access is strongly associated with improvements in the electricity service levels. Most notably, reliability increases by 36 percentage points. This implies that the number and duration of power outages reduced for households with early access to PMGSY road and that had access to the grid. Similarly, the duration of power supply improves by 18 percentage points, and quality of supply measured by ability to power appliances improves by 22 percentage points.

In contrast, effects on capacity, affordability, and legality are small and statistically insignificant, suggesting that road access does not directly influence these dimensions of electricity access. The overall tier index shows a positive but modest improvement. This pattern indicates that the benefits of PMGSY roads are concentrated on improvements in quality and reliability of electricity supply rather than on easing affordability or increasing legality, which may be driven by mechanisms beyond infrastructure improvements. These findings provide evidence that road connectivity under PMGSY facilitated improvements beyond mere grid connectivity and had an impact on quality and reliability of electricity supply. By reducing the physical and logistical barriers to infrastructure provision, roads appear to have accelerated investments in high-quality and reliable supply.

Table 4: Effect of PMGSY road on MTF for households

	Reliability	Duration	Capacity	Quality	Affordability	Legality	Overall
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Early*Post	0.3610***	0.1757***	0.0264	0.2235***	0.0495	0.0302	0.0474
	(0.0841)	(0.0379)	(0.0200)	(0.0802)	(0.0756)	(0.0562)	(0.0392)
Constant	0.9143***	1.2572***	1.6674***	1.4413***	-3.4762***	0.6423***	-2.0455***
	(0.1886)	(0.2555)	(0.0746)	(0.1949)	(0.2710)	(0.2293)	(0.1669)
R^2	0.2230	0.4780	0.3776	0.1748	0.2689	0.3018	0.2082
Observations	11645	11645	11635	11645	11645	11135	11645
Village FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wave FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Source: PMGSY administrative data and ACCESS household survey. These estimates are generated conditional that households have access to gridded electricity. Controls and fixed effects are same as shown in equation 1. Standard errors in brackets. * $p < 0.10, * * p < 0.05, * * * p < 0.01$. Standard errors are clustered at the village level.

6 Potential Threat to Estimation Framework

A key concern for our identification strategy is that road placement under PMGSY may not be exogenous. Several studies document that road placement can be shaped by political favoritism, local economic potential, or pro-poor targeting [Bansal, 2025, Agarwal et al., 2023, Asher and Novosad, 2020]. If road construction were systematically targeted toward villages with higher growth potential or those aligned with political constituencies, estimates of the effect of roads on electrification would be biased. Indeed, Lehne et al. [2018] show that political connections can substantially influence the siting of infrastructure, raising the possibility that our panel fixed effects estimates using a matched sample confound the effect of road access with pre-existing political or economic advantages.

To address this concern, we follow the empirical strategy of Asher and Novosad [2020], who exploit the population-based eligibility rules embedded in the PMGSY program design. According to program guidelines, habitations with populations above 1,000 were prioritized for road connectivity, followed sequentially by those above 500 and then 250. While actual implementation may have deviated from these rules due to local political or economic factors, such factors are unlikely to change discontinuously at the policy thresholds. As long as the eligibility rules were enforced with some degree of fidelity, the probability of receiving a road increases sharply at these cutoffs, which can be leveraged in a fuzzy regression discontinuity (RD) design.

In ongoing work, we implement this strategy by constructing an instrumental variable for road access based on habitation population relative to the policy thresholds. Using the ACCESS survey data, which provides habitation- and village-level identifiers, we merge census data on habitation population from the PMGSY Online Management, Monitoring and Accounting System (OMMS) to generate a running variable defined as habitation population minus the relevant threshold. The intuition is that habitations just above and just below the cutoff are comparable on observable and unobservable characteristics, but differ in their likelihood of receiving a PMGSY road. The fuzzy RD estimator then recovers the local average treatment effect (LATE) of receiving a new road for habitations at the eligibility threshold, thereby mitigating concerns of endogenous placement.

7 Conclusion

This paper contributes to the literature on infrastructure and development by providing new evidence on the complementarity between rural roads and grid electricity in India. While previous studies have largely evaluated these investments in isolation, our results demonstrate that sequencing matters: roads laid prior to electrification significantly enhance the likelihood of household grid connection and improve electricity service levels. Importantly, the magnitude of complementarity depends on spatial proximity to the road network, with the largest effects observed within 3 km of a PMGSY road.

Methodologically, our use of matched household panels and creation of an instrumental variable strategy

based on population cut-offs strengthens the causal interpretation of these findings. Substantively, the results highlight the risks of evaluating infrastructure programs in isolation. Roads and electricity are not independent drivers of rural development but interact to shape the effectiveness of each other.

The policy implications are twofold. First, sequencing rural infrastructure investments to ensure that road construction precedes electrification can accelerate progress toward universal energy access. Second, the spatial design of infrastructure projects should consider how proximity shapes the gains from complementarities. More broadly, our study calls for a rethinking of infrastructure policy frameworks toward integrated planning, where complementarities across sectors are explicitly recognized and leveraged. Such an approach is likely to yield higher returns on public investment and contribute to more inclusive rural development.

Conflict of Interest

This study has not received funding from any research grant. The authors don't have any conflict of interest.

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A1 Appendix

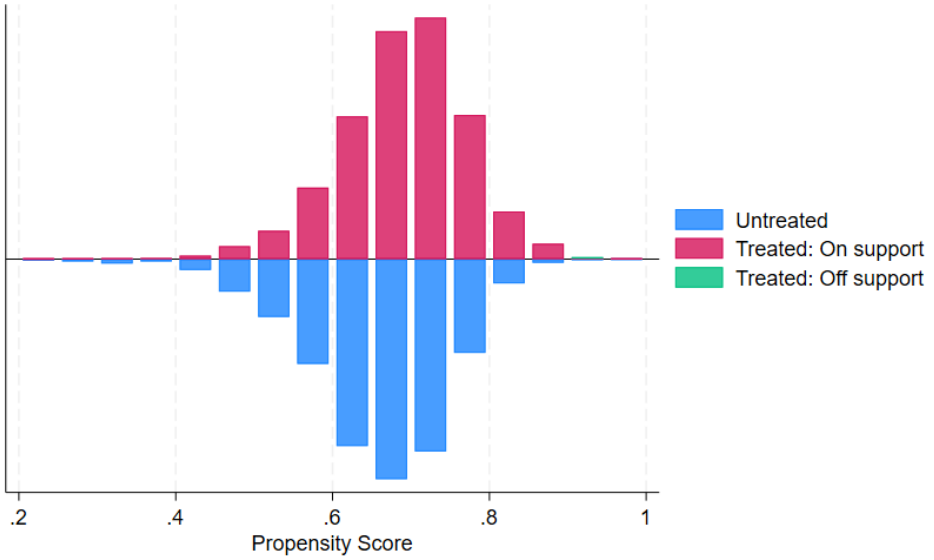


Figure A1: Matching Quality of Covariates

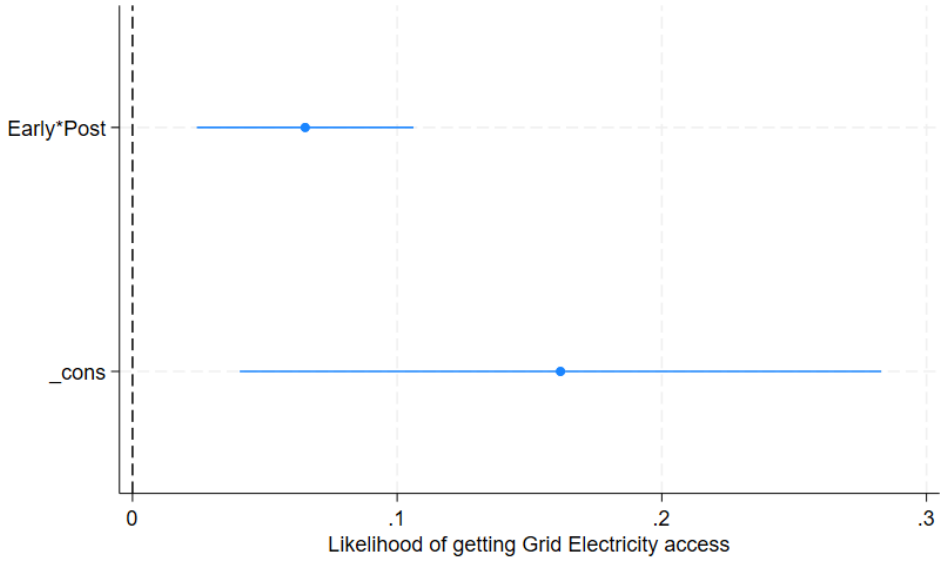


Figure A2: Effect of Distance from PMGSY road on Electrification

Source: PMGSY administrative data and ACCESS household survey.

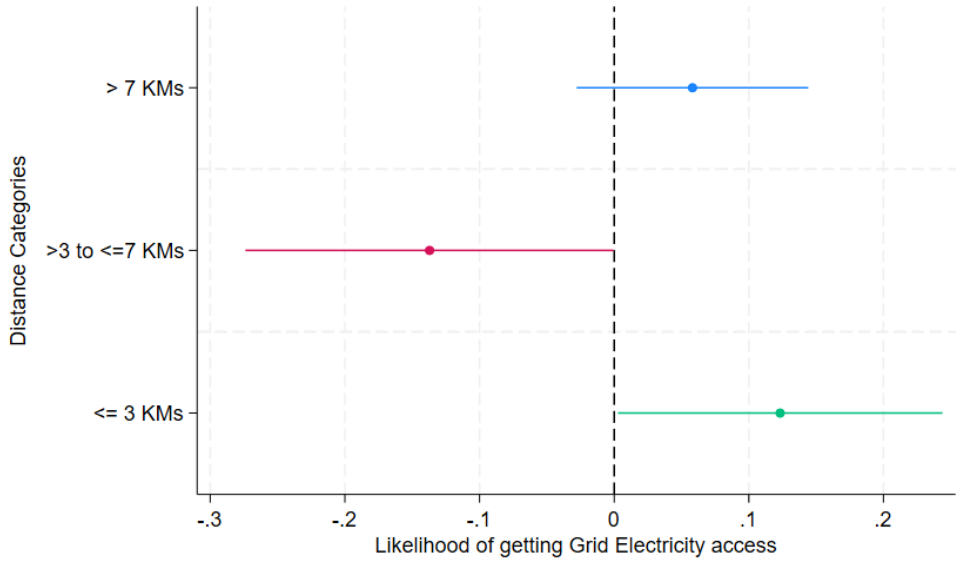


Figure A3: Effect of Distance from PMGSY road on Electrification

Source: PMGSY administrative data and ACCESS household survey. Notes: Each distance category is defined relative to the omitted category. For villages with $Dist \leq 3$ km, the omitted category is $Dist > 3$ km. For villages with $3 < Dist \leq 7$ km, the omitted category is $Dist \leq 3 \cup Dist > 7$ km. For villages with $Dist > 7$ km, the omitted category is $Dist \leq 7$ km. Each coefficient should be interpreted as the relative difference in post-2015 access to grid electricity between early and late access villages compared to villages outside that distance band.

Table A1: Covariate Balance Before and After Matching

	Unmatched		Matched		%Bias	%Reduct. Bias	t-stat	p-value
Variable	Treat	Control	Treat	Control				
Asset Index	-0.058	-0.104	-0.060	-0.081	4.6	54.4	1.11	0.268
Log Monthly Expenditure	8.415	8.333	8.414	8.409	14.1	93.6	0.48	0.634
Gender (=1 Female)	0.858	0.843	0.858	0.867	4.4	42.6	-1.40	0.161
No. of Children	2.621	2.161	2.614	2.619	23.6	99.0	-0.13	0.900
No. of Adults	4.372	4.032	4.366	4.352	15.3	96.0	0.31	0.756
Educ. $\leq$ 5th Std.	0.290	0.350	0.290	0.298	-13.0	86.4	-0.98	0.329
Educ. $\leq$ 10th Std.	0.203	0.194	0.203	0.199	2.3	62.5	0.46	0.644
Educ. $\leq$ 12th/Diploma	0.106	0.073	0.106	0.102	11.8	87.8	0.73	0.466
Educ. Graduate+	0.081	0.065	0.081	0.085	6.0	71.3	-0.87	0.382
Muslim (=1)	0.120	0.128	0.121	0.110	-2.1	-47.1	1.74	0.082
Other Religions (=1)	0.003	0.012	0.003	0.003	-10.8	98.1	-0.17	0.862
Scheduled Tribe (=1)	0.079	0.147	0.079	0.083	-21.7	93.7	-0.85	0.395
OBC (=1)	0.506	0.415	0.506	0.508	18.3	97.7	-0.22	0.824
General Class (=1)	0.234	0.252	0.234	0.227	-4.3	59.7	0.95	0.344

Notes: Columns report covariate means for treated and control groups before (Unmatched) and after (Matched) matching. Percent bias and its reduction are based on standardized mean differences. The matching is performed based on nearest neighbor and caliper matching algorithm.