Development Economics: Lecture 4

Energy Access and Electrification Puzzle

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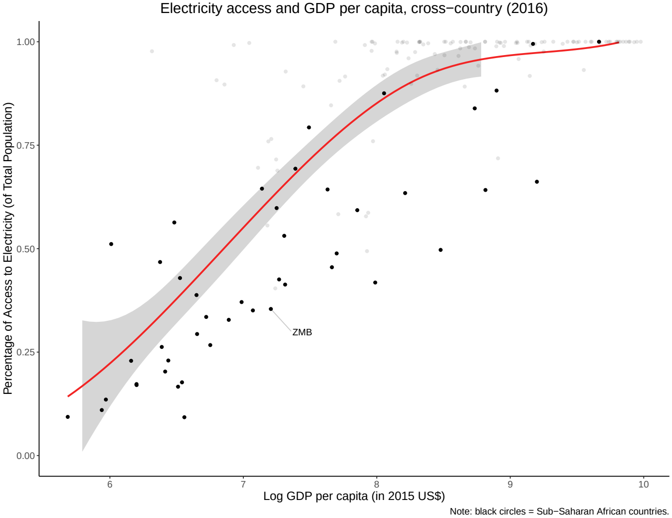
September 12, 2024

Structure of the course (days 1–5)

Topics 1-5 (Moneke)

- Topic 1 (Mon 09/09): Econ. Growth and Transformation
- Topic 2 (Tue 10/09): Poverty Traps and Policy Scale-up
- Topic 3 (Wed 11/09): Infrastructure and Spatial Development
- Topic 4 (Thu 12/09): Energy Access and Electrification Puzzle
- Topic 5 (Fri 13/09): Climate Change, Environment and Dev.

Energy crucial for development



Source: Figueiredo Walter, T., & Moneke, N. (2023). When does electrification work? Evidence from Zambia. *University of Oxford mimeo*.

Energy and development

Historically:

- industrialisation coincided with adoption of modern energy sources
- electricity one of few modern, major breakthrough innovations
- supposedly large, unquantified productivity gains from 1880s to 1920s
- large long-run effects of historic 1930s ‘big push’ electrification

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Today:

- energy access and supply prerequisite for any modern production
- one billion people without electricity across low income countries
- SDG 7 aims for universal access by 2030

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Today:

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- SDG 7 aims for universal access by 2030

→ policy implication: connect everybody, growth will ensue?

The electrification puzzle

- energy access strongly associated with economic development ▸ Figure
- electrification shown to be transformative for development
  [Dinkelman (2011), Rud (2012), Lipscomb et al. (2013) and Kassem (2018)]
- surprisingly, no clear micro link from (rural) electrification to develop.
  [Lee et al. (2020b), Burgess et al. (2020) and Burlig and Preonas (forthcoming)]

*** Lipscomb, M., Mobarak, A. M., & Barham, T. (2013). Development effects of electrification: Evidence from the topographic placement of hydropower plants in Brazil. *American Economic Journal: Applied Economics*, *5*(2), 200–231.

Lipscomb et al. (2013): long-run development effects

- estimate long-run effects of electrification in Brazil from 1960-2000
- particularly interested in long-run 'macro-development' outcomes
- construct predicted grid expansion as instrument to estimate causal effects
- document large, positive effects on human development and labour productivity
- mechanism: sector- and location-wide labour productivity gains

Lipscomb et al. (2013): identification strategy

Instrumental variable to predict both spatial and temporal grid expansion:

- exploit geographical characteristics of dam placement for spatial variation:
  - efficiency of building a dam depends on gradient of river, water flow
  - produce a lowest-cost network
  - lowest cost $\equiv$ the network that maximises the area covered with electricity for a given number of dams
- national budget for hydropower plants determines temporal dimension of expansion
- combine spatial extent of grid with budgeting rule to generate predicted network expansion over time and across space
- relevance (predicted and actual grid expansion correlate) and validity assumptions (predicted grid expansion exogenous to local growth)

Lipscomb et al. (2013): predicting hydropower generation

Table 1—Probit Regression for Hydropower Geographic Cost Parameters

Log of maximum flow accumulation	0.029**
	(0.014)
Average slope in the river	0.044
	(0.030)
Maximum slope in the river	0.062***
	(0.012)
Amazon indicator	–0.753***
	(0.066)
Indicator for location has a river	–0.030
	(0.063)
Observations	33,342

Notes: The dependent variable is an indicator for location has a hydropower plant. Standard errors clustered by county in parentheses.

*** Significant at the 1 percent level.
** Significant at the 5 percent level.
* Significant at the 10 percent level.

Source: Lipscomb, M., Mobarak, A. M., & Barham, T. (2013). Development effects of electrification: Evidence from the topographic placement of hydropower plants in Brazil. *American Economic Journal: Applied Economics*, *5*(2), 200–231.

Lipscomb et al. (2013): actual grid expansion over time

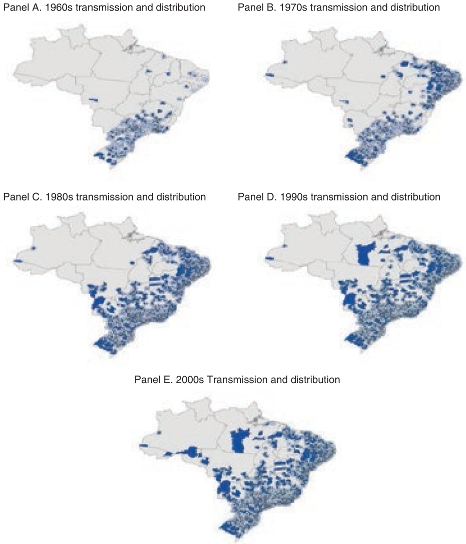

FIGURE 1

Source: Lipscomb, M., Mobarak, A. M., & Barham, T. (2013). Development effects of electrification: Evidence from the topographic placement of hydropower plants in Brazil. *American Economic Journal: Applied Economics*, 5(2), 200–231.

Lipscomb et al. (2013): predicted grid expansion over time

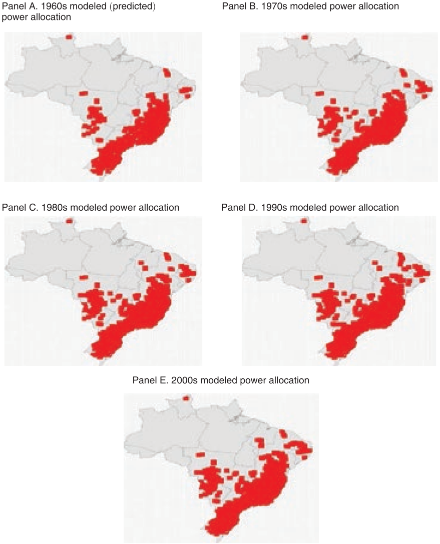

Figure 2

Source: Lipscomb, M., Mobarak, A. M., & Barham, T. (2013). Development effects of electrification: Evidence from the topographic placement of hydropower plants in Brazil. *American Economic Journal: Applied Economics*, *5*(2), 200–231.

Lipscomb et al. (2013): two-stage least squares estimation

Estimate two-stage least squares of outcomes on electrification:

$$Y_{ct} = \alpha_c^1 + \gamma_t^1 + \beta \hat{E}_{c,t-1} + \epsilon_{ct}$$

Lipscomb et al. (2013): two-stage least squares estimation

Estimate two-stage least squares of outcomes on electrification:

$$Y_{ct} = \alpha_c^1 + \gamma_t^1 + \beta \hat{E}_{c,t-1} + \epsilon_{ct}$$

where $\hat{E}_{c,t-1}$ is instrumented electricity access in county c at time $t-1$:

$$E_{c,t-1} = \alpha_c^2 + \gamma_t^1 + \theta Z_{c,t-1} + \eta_{ct}$$

- $E_{c,t-1}$ is the actual proportion of grid points in county c that are electrified at time $t-1$
- $Z_{c,t-1}$ is the equivalent proportion predicted to be electrified according to the least-cost model

Lipscomb et al. (2013): first stage results

TABLE 3—FIRST-STAGE REGRESSIONS
DEPENDENT VARIABLE: ACTUAL ELECTRICITY AVAILABILITY FROM INFRASTUCTURE INVENTORIES

Modeled electricity availability	0.563***	0.323***	0.222***
	(0.03)	(0.05)	(0.05)
Year FE	Yes	Yes	Yes
County FE	No	Yes	Yes
Amazon × year dummies	No	No	Yes
R^2	0.369	0.840	0.866
Observations	8,730	8,730	8,730
F-Stat	336.3	34.71	24.6
p-value	0.00	0.00	0.00

Notes: The dependent variable is prevalence of electricity infrastructure in the county. Regressions are weighted by county area. Standard errors clustered by county in parentheses. Measures of electrification are lagged by a decade in all our second-stage regressions, and the data used for the first-stage regression therefore covers 1960–1990. The Amazon and Pantanal are referred to jointly as the Amazon.

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Lipscomb et al. (2013): human development on electricity

Table 7—Human Development Index

	OLS			IV		
	(1)	(2)	(3)	(4)	(5)	(6)
Lagged electricity infrastructure	0.036**	0.009	0.006	0.091***	0.091***	0.109**
	(0.01)	(0.01)	(0.01)	(0.02)	(0.03)	(0.04)
Year FE?	Yes	Yes	Yes	Yes	Yes	Yes
County FE?	No	Yes	Yes	No	Yes	Yes
Jungle × year dummies[a]	No	No	Yes	No	No	Yes
R^2	0.657	0.960	0.960	0.640	0.931	0.930
Observations	8,730	8,730	8,730	8,730	8,730	8,730

Notes: Standard errors clustered by county in parentheses. The dependent variable is the human development index. Year dummies are included in all regressions. All regressions have county size weights. The average HDI value in the sample is 0.557.

[a]Topographic factor is interacted with a full set of decade fixed effects in order to flexibly control for differential trends by that Topographic factor.

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Lipscomb et al. (2013): human development breakdown

Table 11—Human Development Index Components and Other Poverty Measures

	HDI: Longevity		HDI: Income		HDI: Education	
	OLS	IV	OLS	IV	OLS	IV
Panel A						
Lagged electricity infrastructure	0	−0.01	−0.03*	0.45***	0.03***	0.19***
	(0.01)	(0.05)	(0.02)	(0.15)	(0.01)	(0.06)
R^2	0.84	0.8	0.89	0.5	0.91	0.65
Observations	8,730	8,730	8,730	8,730	8,730	8,730
Mean of dep var	0.569		0.472		0.515	
	Infant mortality		Gross income PC		Poverty	
	OLS	IV	OLS	IV	OLS	IV
Panel B						
Lagged electricity infrastructure	−7.99***	−11.97	−0.01	0.11**	−0.76	−42.17***
	(2.42)	(18.08)	(0.01)	(0.05)	(1.39)	(13.84)
R^2	0.9	0.86	0.84	0.58	0.85	0.53
Observations	8,730	8,730	8,730	8,730	8,730	8,730
Mean of dep var	71.96		0.114		60.469	

Notes: Standard errors clustered by county in parentheses. Dependent variables are the component indices of the HDI. All regressions have county size weights, year dummies, and jungle × year dummies.

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Lipscomb et al. (2013): education on electricity

TABLE 13—DEPENDENT VARIABLES: MEASURES OF EDUCATION EFFECTS

	Illiteracy		Less than four years education		Years in school		Human capital	
	OLS	IV	OLS	IV	OLS	IV	OLS	IV
Lagged electricity infrastructure	−2.700***	−8.350*	−0.359	−21.253***	0.062	2.022***	2.092***	11.541
	(0.72)	(4.78)	(0.90)	(7.75)	(0.08)	(0.67)	(0.41)	(7.30)
R^2	0.944	0.815	0.944	0.871	0.936	0.791	0.965	0.887
Observations	8,730	8,730	8,730	8,730	8,730	8,730	6,549	6,549
Mean of dep var	32.00		65.248		2.77		19.06	

Notes: Standard errors clustered by county in parentheses. Dependent variables are education and salary variables. All regressions have county size weights, year dummies, and jungle × year dummies.

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Lipscomb et al. (2013): employment on electricity

TABLE 12—DEPENDENT VARIABLES: MEASURES OF EMPLOYMENT EFFECTS

	Economically active		Formal employment		Formal employment (urban)		Formal employment (rural)	
	OLS	IV	OLS	IV	OLS	IV	OLS	IV
Lagged electricity infrastructure	0.011* (0.01)	0.173*** (0.05)	0.010* (0.01)	0.184*** (0.05)	0.009* (0.00)	0.176*** (0.05)	0.007 (0.01)	0.165*** (0.05)
R^2	0.759	0.349	0.689	−0.171	0.791	0.244	0.612	−0.129
Observations	8,730	8,730	8,730	8,730	8,730	8,730	8,685	8,678
Mean of dep var	0.364		0.347		0.338		0.349	

Notes: Standard errors clustered by county in parentheses. Dependent variables are employment variables. All regressions have county size weights, year dummies, and jungle × year dummies.

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Lipscomb et al. (2013): urbanisation on electricity

TABLE 14—POPULATION CHANGES
DEPENDENT VARIABLES: MEASURES OF POPULATION EFFECTS

	In-migration rate		Life expectancy		Population density		Urban percent of pop.	
	OLS	IV	OLS	IV	OLS	IV	OLS	IV
Lagged electricity infrastructure	0.010	0.102	−0.437	−1.034	−1.107	−23.618	0.013	0.238**
	(0.03)	(0.09)	(0.32)	(2.39)	(3.74)	(19.20)	(0.01)	(0.11)
R^2	0.951	0.371	0.935	0.924	0.940	0.010	0.928	0.742
Observations	4,366	4,366	8,730	8,730	8,730	8,730	8,730	8,730
Mean of dep var	0.072		60.098		78.502		0.517	

Notes: Standard errors clustered by county in parentheses. Dependent variables are population change variables. Migration data is available only for 1990 and 2000, making the panel substantially shorter. All regressions have county size weights, year dummies, and jungle × year dummies.

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Lipscomb et al. (2013): housing values on electricity

Table 6—Housing Values
Dependent Variable: Average Value of Housing

	OLS			IV		
	(1)	(2)	(3)	(4)	(5)	(6)
Lagged electricity infrastructure	5.023***	1.326***	0.801***	8.468***	7.792***	8.811***
	(0.90)	(0.35)	(0.27)	(1.52)	(1.72)	(3.03)
Year FE?	Yes	Yes	Yes	Yes	Yes	Yes
County FE?	No	Yes	Yes	No	Yes	Yes
Amazon × year dummies[a]	No	No	Yes	No	No	Yes
R^2	0.153	0.922	0.925	0.106	0.191	0.151
Observations	8,730	8,730	8,730	8,730	8,730	8,730

Notes: Standard errors clustered by county in parentheses. The dependent variable is average housing value in thousands of reais. All regressions have county size weights and year dummies. The average housing value in the sample is 13.048.

[a] Topographic factor is interacted with a full set of decade fixed effects in order to flexibly control for differential trends by that Topographic factor.

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Lipscomb et al. (2013): other infrastructure expansions?

TABLE 8—ROBUSTNESS TESTS: INFRASTRUCTURE CONTROLS

	Percent HH with cars		Housing value	HDI
	OLS		IV	IV
Lagged electricity infrastructure			13.708*	0.286**
			(7.14)	(0.14)
Lagged running water			−0.352	−0.110***
			(1.60)	(0.02)
Lagged sanitation access			−3.378*	−0.124***
			(1.93)	(0.02)
Water trend	0.016***	0.052***	−0.455	−0.012
	(0.00)	(0.02)	(0.37)	(0.01)
Landslope trend	−0.002**	−0.004	0.056	−0.002
	(0.00)	(0.00)	(0.16)	(0.00)
Year dummies?	Yes	Yes	Yes	Yes
R^2			0.051	0.739
Observations	4,366	4,366	6,549	6,549
Mean of dep var:			13.048	0.557

Notes: Dependent variables are average housing value and HDI. Standard errors clustered by county in parentheses. Decade dummies are included in all regressions. All regressions have county size weights. Water trend and landslope trend are included as proxies for the evolving availability of road infrastructure, for which we do not have available data spanning the time period of interest.

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Bensch et al. (2021): sample definition drives results

Bensch et al. (2021) perform careful replication of Lipscomb et al. (2013):

- find that key results lose significance once inconsistencies corrected for
- critique centres around ‘correct’ (and consistent!) definition of spatial extent of the Amazon
- demarcation of Amazon determines where grid could possibly be built
- Lipscomb et al. (2013) appear to use:
  - self-defined demarcation of Amazon
  - switch between definitions from first-stage to second-stage
  - only self-defined demarcation appears to reliably yield significant results

$\rightarrow$ very lively debate that calls for renewed interest in large historical quasi-experiments of grid expansion

Takeaways from Lipscomb et al. (2013)

- evidence suggestive of major, transformative economic effects of electrification at scale and in the long run
- large effects on human development, educational attainment, employment, housing value (as GDP proxy)

Takeaways from Lipscomb et al. (2013)

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↯ methodological concerns about sample definition and IV

↯ unclear mechanism of how effects may have unfolded

↯ unclear complementarity with other infrastructure expansions (market access [roads, trade liberalisation], educational expansion [schools], health interventions [DEET/malaria, modern medicine])

→ serious concerns about causal interpretation of 'macro' results

4. Energy Access and Electrification Puzzle

4.1 Energy and economic growth

4.2 Causal evidence on electrification

4.3 Determinants of success and potential complementarities

*** Lee, K., Miguel, E., & Wolfram, C. (2020b). Experimental evidence on the economics of rural electrification. *Journal of Political Economy, 128*(4), 1523–1565.

A natural monopoly, subsidies and externalities

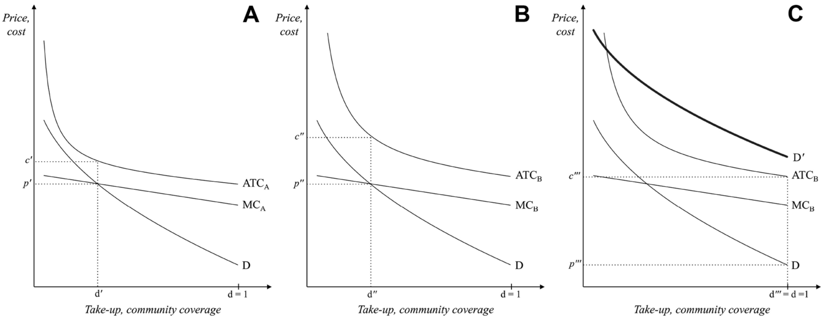


FIG. 1.—The electric utility as a natural monopoly. In *A*, the electric utility is a natural monopoly facing high fixed costs, decreasing marginal costs (MC_A), and decreasing average total costs (ATC_A). MC_A intersects demand (*D*) at d'. At d', a government-subsidized mass electrification program would increase social surplus, since consumer surplus (i.e., the area under the demand curve) is greater than total cost. *B*, Alternative scenario with higher fixed costs. In this case, consumer surplus is less than total cost at all quantities. A mass electrification program would not increase social surplus unless there are, for instance, positive externalities from private grid connections. *C*, Scenario in which social demand (D') is sufficiently high for the ideal outcome to be full coverage, subsidized by the government.

Source: Lee, K., Miguel, E., & Wolfram, C. (2020b). Experimental evidence on the economics of rural electrification. *Journal of Political Economy*, *128*(4), 1523–1565.

Lee et al. (2020b): non-adoption at baseline a choice

TABLE 1
Differences between Unconnected and Grid-Connected Households at Baseline

	Unconnected (1)	Connected (2)	p-Value of Difference (3)
Sample size	2,289	215	
	A. Household Head (Respondent) Characteristics		
Female (%)	62.9	58.6	.22
Age (years)	52.3	55.8	<.01
Senior citizen (%)	27.5	32.6	.11
Attended secondary schooling (%)	13.3	45.1	<.01
Married (%)	66.0	76.7	<.01
Not a farmer (%)	22.5	39.5	<.01
Employed (%)	36.1	47.0	<.01
Basic political awareness (%)	11.4	36.7	<.01
Has bank account (%)	18.3	60.9	<.01
Monthly earnings (USD)	16.9	50.6	<.01
	B. Household Characteristics		
No. of members	5.2	5.3	.76
Youth members (age ≤ 18)	3.0	2.6	.01
High-quality walls (%)	16.0	80.0	<.01
Land (acres)	1.9	3.7	<.01
Distance to transformer (m)	356.5	350.9	.58
Monthly (noncharcoal) energy spending (USD)	5.5	15.4	<.01
	C. Household Assets		
Bednets	2.3	3.4	<.01
Sofa pieces	6.0	12.5	<.01
Chickens	7.0	14.3	<.01
Owns radio (%)	34.8	62.3	<.01
Owns television (%)	15.2	80.9	<.01

Note.—Columns 1 and 2 report sample means for households that were unconnected or connected at the time of the baseline survey. Column 3 reports the p-value of the difference between the means. The basic political awareness indicator captures whether the household head was able to correctly identify the presidents of Tanzania, Uganda, and the United States. Monthly earnings (USD) includes the respondent's profits from businesses and self-employment, salary and benefits from employment, and agricultural sales for the entire household. In the 2013 census of all unconnected households, just 5% of rural households were connected to the grid. In our sample of respondents, we oversampled the number of connected households.

Source: Lee, K., Miguel, E., & Wolfram, C. (2020b). Experimental evidence on the economics of rural electrification. *Journal of Political Economy*, *128*(4), 1523–1565.

Lee et al. (2020b): strong (causal) effect on adoption

TABLE 3
POOLED TREATMENT EFFECTS ON KEY OUTCOMES

	Control (1)	ITT (2)	TOT (3)	FDR q-value (4)
	A. Primary Energy Outcomes			
Al. Grid connected (%)	12.2	82.8***	. . .	. . .
	[32.7]	(1.8)		
A2. Monthly electricity spending (USD)	.33	1.80***	2.17***	. . .
	[1.36]	(.13)	(.14)	
	B. Additional Energy Outcomes			
Bl. Electricity as main lighting source (%)	10.6	72.0***	86.8***	.001
	[30.8]	(2.1)	(2.1)	
B2. Number of appliance types owned	2.0	.3***	.4***	.002
	[1.4]	(.1)	(.1)	
B3. Owns mobile phone (%)	85.2	−2.4	−2.2	.246
	[35.5]	(1.5)	(1.8)	
B4. Owns radio (%)	57.6	4.6**	7.1***	.010
	[49.4]	(2.3)	(2.6)	
B5. Owns television (%)	21.3	9.3***	11.6***	.002
	[40.9]	(2.8)	(3.5)	
B6. Owns iron (%)	5.2	2.9**	3.8***	.010
	[22.2]	(1.2)	(1.4)	
B7. Monthly kerosene spending (USD)	2.64	−.90***	−1.00***	.001
	[2.75]	(.11)	(.13)	
B8. Monthly total energy spending (USD)	10.83	−.36	−.19	.870
	[21.83]	(.99)	(1.18)	
B9. Solar home system as main lighting source (%)	14.1	−13.0***	−16.1***	.001
	[34.8]	(1.2)	(1.3)	

Source: Lee, K., Miguel, E., & Wolfram, C. (2020b). Experimental evidence on the economics of rural electrification. *Journal of Political Economy*, *128*(4), 1523–1565.

Lee et al. (2020b): no (causal) effect on outcomes

	C. Primary Economic Outcomes			
Cl. Household employed or own business (%)	36.0	2.9	2.2	.619
	[38.4]	(2.2)	(2.5)	
C2. Per capita monthly household earnings (USD)	12	−1	−2	.688
	[42]	(2)	(2)	
C3. Total hours worked last week	50.3	−2.6**	−3.5**	.095
	[24.4]	(1.2)	(1.5)	
C4. Total asset value (USD)	1,237	102	117	.457
	[1,110]	(76)	(93)	
C5. Per capita consumption of major items (USD)	185	−3	−4	.721
	[186]	(8)	(9)	
	D. Primary Noneconomic Outcomes			
D1. Recent health symptoms index	0	−.03	−.03	.721
	[1]	(.06)	(.07)	
D2. Normalized life satisfaction	0	.16***	.19***	.001
	[1]	(.04)	(.04)	
D3. Average student test *Z*-score	0	−.09	−.13	.457
	[1]	(.09)	(.10)	

Source: Lee, K., Miguel, E., & Wolfram, C. (2020b). Experimental evidence on the economics of rural electrification. *Journal of Political Economy*, *128*(4), 1523–1565.

Lee et al. (2020b): no (causal) effect on outcomes, cont'd

TABLE 3 (*Continued*)

	Control (1)	ITT (2)	TOT (3)	FDR *q*-value (4)
D4. Average student KCPE test *Z*-score	0	−.12	−.17	.550
	[1]	(.13)	(.17)	
D5. Political and social awareness index	0	−.03	−.01	.861
	[1]	(.05)	(.05)	
D6. Perceptions of security index	0	.08	.13*	.303
	[1]	(.06)	(.08)	
	E. Mean Treatment Effects on Grouped Outcomes			
E1. Economic index (C outcomes)	0	.02	0	. . .
	[1]	(.06)	(.07)	
E2. Noneconomic index (D outcomes)	0	.01	0	. . .
	[1]	(.04)	(.05)	

NOTE.—Round 1 and 2 follow-up survey data are pooled together. Column 1 reports mean values in the control group, with standard deviations in brackets. Column 2 reports coefficients from separate ITT regressions in which the dependent variable (e.g., A1) is regressed on the high-subsidy-treatment indicator. The low- and medium-subsidy groups are excluded from these regressions. Sample sizes range from 1,419 to 2,894 for these regressions, except for the D3 and D4 regressions, which have sample sizes of 941 and 417, respectively. Column 3 reports coefficients from separate TOT (instrumental variable) regressions in which household electrification status is instrumented with the three subsidy-treatment indicators. Sample sizes range from 2,094 to 4,295 for these regressions, except for the D3 and D4 regressions, which have sample sizes of 1,411 and 644, respectively. All specifications include prespecified household, student, and community covariates, as well as a survey-round fixed effect. Column 4 reports the FDR-adjusted *q*-values associated with the coefficient estimates in col. 3. FDR-adjusted *q*-values are computed for each outcome within the additional energy outcomes group (panel B) and for each outcome within the primary outcomes group (panels C and D combined). In panel E, we report mean treatment effects on outcomes grouped into an economic and a noneconomic index. These groupings were not prespecified. Robust standard errors clustered at the community level are in parentheses. The D4 outcome is the average student *Z*-score on the Kenya Certificate of Primary Education (KCPE) test.

* $p < .10$ (two-tailed).
** $p < .05$ (two-tailed).
*** $p < .01$ (two-tailed).

Source: Lee, K., Miguel, E., & Wolfram, C. (2020b). Experimental evidence on the economics of rural electrification. *Journal of Political Economy*, *128*(4), 1523–1565.

Lee et al. (2020b): demand and supply do not intersect

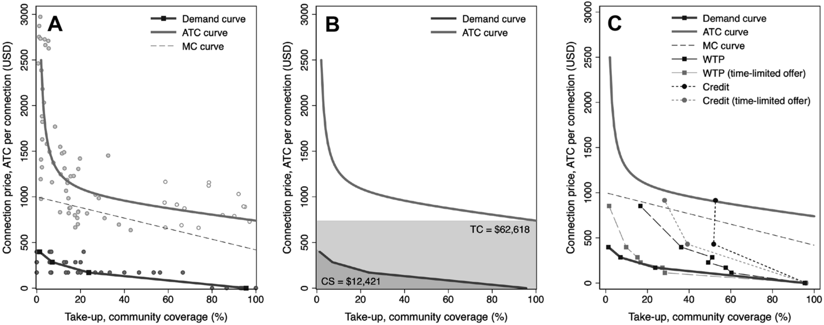


FIG. 3.—Experimental evidence on the social surplus implications of rural electrification. *A* combines the experimental demand curve with the population-weighted ATC curve corresponding to the predicted cost of connecting various population shares, based on the nonlinear estimation of $ATC = b_0/M + b_1 + b_2 M$. Each point represents the community-level, budgeted estimate of ATC at a specific level of coverage. MC = marginal cost. *B* demonstrates that the estimated total cost of community electrification is $62,618, based on average community density of 84.7 households. The area under the demand curve (consumer surplus [CS]) is estimated to be $12,421. These estimates suggest that a mass electrification program would result in a social surplus loss of $50,197 per community (i.e., $593 per household). *C* combines the curves in *A* with the contingent-valuation (CV) questions included in the baseline survey. The CV questions included (1) whether the household would accept a hypothetical offer (i.e., at a randomly assigned price) to connect to the grid and (2) whether the household would accept the same offer if required to complete the payment in 6 weeks. The credit offer consisted of an up-front payment (ranging from $39.80 to $79.60), a monthly payment (ranging from $11.84 to $17.22), and a contract length (either 24 or 36 months). We plot the net present value of the credit offers, assuming a 15% discount rate. Additional details on the credit offers are provided in table B9.

Source: Lee, K., Miguel, E., & Wolfram, C. (2020b). Experimental evidence on the economics of rural electrification. *Journal of Political Economy*, *128*(4), 1523–1565.

Lee et al. (2020b): rural electrification destroying welfare?

TABLE 5
PREDICTING SOCIAL SURPLUS PER HOUSEHOLD UNDER DIFFERENT ASSUMPTIONS

		EXPERIMENTAL APPROACH		ALTERNATIVE APPROACH		
	C	CS	SS	CS	SS	KEY ASSUMPTION(S)
Main estimates	739	147	−593	293	−446	
1A. Income growth (experimental approach)	. . .	+139		. . .		Growth of 3% per annum over 30 years (based on fig. 2*B*)
1B. Electricity consumption growth (alternative approach)		. . .		+365		Growth of 10% per annum over 30 years (see table 4, col. 2, row 3)
2. No credit constraints for grid connections	. . .	+301		. . .		Stated WTP without time constraints (see fig. 3*C*)
3. No transformer breakdowns	. . .	+33		+37		Reduce transformer breakdowns from 5.4% to 0% (see table B10)
4. No connection delays	. . .	+46		+52		Reduce waiting period from 188 to 0 days (see fig. A1)
5. No construction cost leakage	−157	. . .		. . .		Decrease total construction costs by 21.3% (see table B11)
Ideal scenario	582	665	83	747	166	

NOTE.—Main estimates of C (average connection cost), CS (consumer surplus), and SS (social surplus) correspond to fig. 3*B* (for the experimental approach) and table 4, col. 1, row 3 (for the alternative approach). Table B13 includes an additional row to account for the consumer surplus associated with baseline connected households.

Source: Lee, K., Miguel, E., & Wolfram, C. (2020b). Experimental evidence on the economics of rural electrification. *Journal of Political Economy*, *128*(4), 1523–1565.

Takeaways from Lee et al. (2020b)

- incentivising grid adoption can increase electricity uptake
- electricity-using asset ownership increases
- technically zero economic effects across wide range of relevant development outcomes
- life satisfaction unambiguously improves for connected HHs

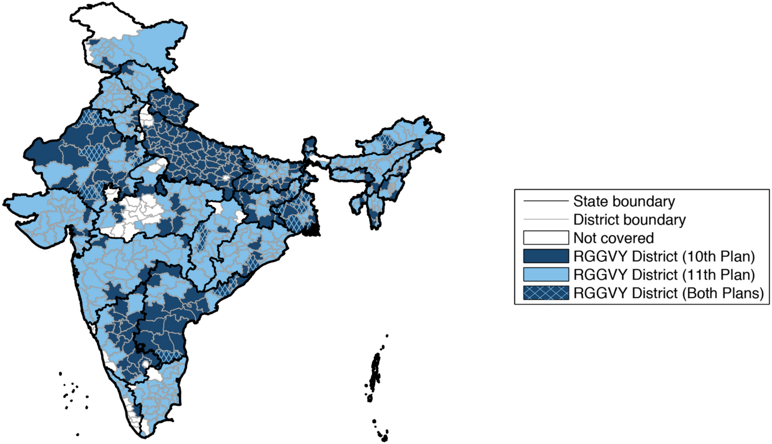
↯ specific margin: under-grid HHs that did not previously connect

→ strong evidence net welfare gain of rural electrification hard to achieve via rural household connections

*** Burlig, F., & Preonas, L. (forthcoming). Out of the darkness and into the light? Development effects of rural electrification. *Journal of Political Economy*

The Indian RGGVY electrification program

Figure 2: Indian districts by RGGVY implementation phase

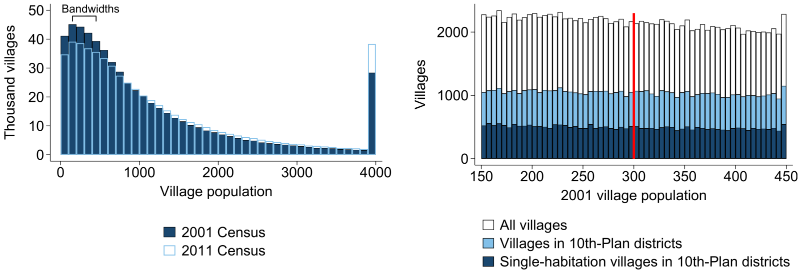


Note. — We shades 2001 districts by RGGVY coverage status. Navy districts were covered under the 10th Plan (RGGVY's first wave), light blue districts were covered under the 11th Plan (RGGVY's second wave), cross-hatched districts were covered under both 10th and 11th Plans, and white districts were not covered by RGGVY. In 2001, India had 584 districts across its 28 states and 7 Union Territories. RGGVY covered 530 total districts in 27 states (neither Goa nor the Union Territories were eligible). 30 districts were split between the 10th and 11th Plans; 23 states contain both 10th- and 11th-Plan districts.

Source: Burlig, F., & Preonas, L. (forthcoming). Out of the darkness and into the light? Development effects of rural electrification. *Journal of Political Economy*.

Smooth running variable around program cutoff

Figure 3: Density of RD running variable



Note. — The left histogram shows village populations for 2001 (navy) and 2011 (hollow blue), top-coding each distribution at 4000. The right histogram zooms in on villages close to RGGVY's 300-person population cutoff, with 2001 populations between 150 and 450 (slightly wider than our optimal RD bandwidths). Navy bars show the sample of single-habitation 10th-Plan villages used in our RD analysis, relative to all Indian villages (white) and all villages in 10th-Plan districts (light blue).

Source: Burlig, F., & Preonas, L. (forthcoming). Out of the darkness and into the light? Development effects of rural electrification. *Journal of Political Economy*.

Village-level RDD: power access

Table 2: Village-level RD in 2011 electricity access, by sector

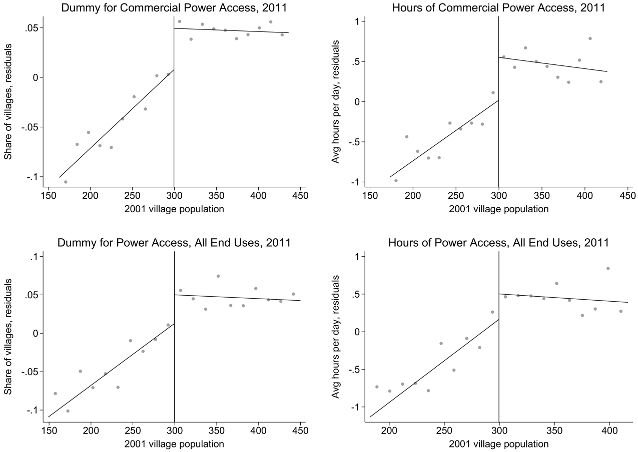
	Outcome: Village-level electricity access			
	Domestic (1)	Agricultural (2)	Commercial (3)	All 3 sectors (4)
A. Dummy for any power access				
$\mathbf{1}[2001 \text{ pop} \geq 300]$	-0.004	-0.001	0.043^{***}	0.038^{**}
	(0.010)	(0.020)	(0.017)	(0.016)
Mean of dep var (< 300)	0.906	0.669	0.436	0.417
Optimal bandwidth	108	78	136	150
Village observations	13,517	9,836	16,900	18,574
B. Hours/day of power supply				
$\mathbf{1}[2001 \text{ pop} \geq 300]$	-0.042	-0.252	0.555^{**}	0.283
	(0.207)	(0.257)	(0.220)	(0.240)
Mean of dep var (< 300)	11.386	5.382	3.957	5.050
Optimal bandwidth	88	82	126	117
Village observations	9,284	8,575	12,897	14,336

Note. — `rdrobust` estimates use linear polynomials, triangular kernels, MSE-optimal bandwidth, and nearest-neighbor standard errors. Regression samples include within-bandwidth single-habitation villages in RGGVY 10th-Plan districts (i.e. the first wave of RGGVY project implementation, for which 300 people is the relevant 2001 population-based eligibility cutoff). Each regression controls for pre-2005 nighttime brightness at the village level, and state fixed effects. Optimal bandwidths are symmetric above and below the 300-person cutoff, and we report means of the dependent variable for villages below the cutoff. In Panel A, outcomes are dummy variables for electricity access at the village level. In Panel B, outcomes are the average hours of power available per day in the village. Results are robust to alternative controls, kernels, bandwidth algorithms, and standard errors. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Source: Burlig, F., & Preonas, L. (forthcoming). Out of the darkness and into the light? Development effects of rural electrification. *Journal of Political Economy*.

Village-level RDD: commercial power access

Figure 4: Village-level RDs in 2011 electricity access



Note. — The top RD plots correspond to Column (3) of Table 2. The bottom RD plots correspond to Column (4) of Table 2. See table notes for details. Appendix Figure A4 displays RD plots corresponding to the other four regressions in Table 2.

Source: Burlig, F., & Preonas, L. (forthcoming). Out of the darkness and into the light? Development effects of rural electrification. *Journal of Political Economy*.

District-level D-in-D: household electricity access and usage

Table 3: District-level DD of household electricity access and usage

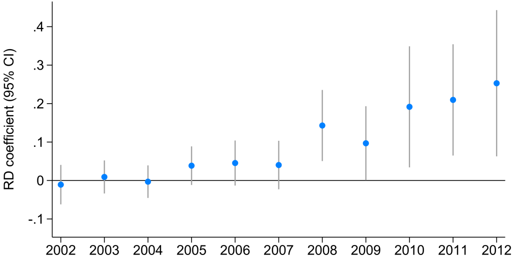
	HH elec use (kWh/month)			**1**[HH owns electric appliance]				
	1[$Q > 0$]	Levels	Logs	Lighting	Fan	TV	Fridge	AC
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1[10th-Plan]	0.056***	3.95**	0.171**	0.049***	0.045***	0.010	0.002	0.007
× **1**[2010]	(0.014)	(1.75)	(0.075)	(0.015)	(0.016)	(0.014)	(0.007)	(0.005)
Mean of dep var	0.590	31.45	3.038	0.598	0.382	0.289	0.055	0.038
Clusters	552	552	550	552	552	552	552	552
Observations	1670	1670	1661	1670	1670	1670	1670	1670

Note. — District-level DD with three NSS years (2000, 2005, 2010). We aggregate household-level data up to the district using sampling weights, for rural households only. Outcome variables are an indicator for whether a household consumed any electricity (Column (1)), monthly household electricity consumption in levels and in natural logs (Columns (2)–(3)), and indicators for whether a household owned electric lighting, an electric fan, a television, a refrigerator, or air conditioning (Columns (4)–(8)). DD treatment is assigned at the district level, for 10th-Plan districts. All regressions include: district fixed effects; year fixed effects; state-specific linear trends; linear trends in state quartiles of 2005 household expenditures per capita, to control for within-state selection in RGGVY implementation based on relative differences between districts (e.g. states prioritizing electrification in their poorest districts); and linear trends in national deciles of 2005 household expenditures per capita control for such selection in absolute terms. Standard errors are clustered at the district level, collapsing to a single cluster for (i) districts that split in the 2001 Census, but which the 2000 NSS sampled based on 1991 district definitions; and (ii) the few cases where an RGGVY DPR included multiple districts. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Source: Burlig, F., & Preonas, L. (forthcoming). Out of the darkness and into the light? Development effects of rural electrification. *Journal of Political Economy*.

Village-level RDD by year: nighttime luminosity

Figure 5: Village-level RD estimates in nighttime brightness, by year

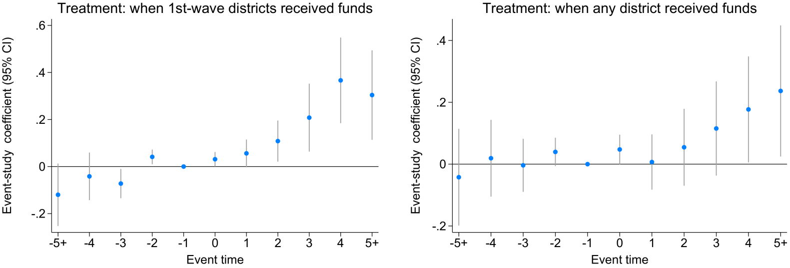


Note. — This figure plots RD coefficients for maximum nighttime brightness at the village level. We estimate a separate regression for each year, with `rdrobust` specifications identical to those in Table 2. Each regression controls for pre-2005 brightness at the village level; 2002–2005 regressions control for brightness in years preceding the outcome variable. Optimal bandwidths for these regressions range from 69 to 143. Results are robust to alternative controls, kernels, bandwidth algorithms, and standard errors. See notes under Table 2 for details. Appendix Tables A10 and B5 report these results numerically. Whiskers display 95% confidence intervals.

Source: Burlig, F., & Preonas, L. (forthcoming). Out of the darkness and into the light? Development effects of rural electrification. *Journal of Political Economy*.

Village-level D-in-D: nighttime luminosity over time

Figure 6: Village-level DD event studies in nighttime brightness



Note. — Village-level DD event studies using annual nighttime brightness from 1998 to 2013. The outcome variable is maximum brightness in each year, for each village polygon. In the left panel, treatment (RGGVY eligibility) turns on in the year when each 10th-Plan district first received RGGVY project funds, using 11th-Plan districts as controls. In the right panel, treatment turns on for both 10th- and 11th-Plan districts, in the first year the district received RGGVY funds. 10th-Plan districts first received funds in 2005–2007, while 11th-Plan districts first received funds in 2008–2011. In both panels, the omitted year is the last year prior to a district's first receipt of funds. Regressions include village fixed effects, state-by-year fixed effects, and village-specific linear time trends. Estimation samples include 10th- and 11th-Plan districts in states with reliable shapefiles, without restricting village size. Whiskers display 95% confidence intervals, with standard errors clustered by Census block.

Source: Burlig, F., & Preonas, L. (forthcoming). Out of the darkness and into the light? Development effects of rural electrification. *Journal of Political Economy*.

Village-level RDD: development outcomes

Table 4: Village-level RD – reduced-form outcomes

	RD estimate	Std error	95% CI	Mean Y_v
A. Consumption and income (2011)				
Expenditure per capita (Rs/month)	−5.222	(17.565)	[−39.649, 29.206]	1365.353
Expenditure per capita (logged)	−0.010	(0.013)	[−0.034, 0.015]	9.668
Share HH with poverty indicator	−0.004	(0.013)	[−0.030, 0.022]	0.547
Share HH rely on cultivation income	−0.007	(0.012)	[−0.030, 0.016]	0.421
Share HH earning > Rs 5k/mth	0.002	(0.009)	[−0.016, 0.020]	0.070
Share HH with salaried job	0.004	(0.003)	[−0.003, 0.010]	0.012
B. Village demographics (2011)				
Population	6.213	(3.874)	[−1.379, 13.805]	296.447
Share population age 0–6	0.001	(0.002)	[−0.002, 0.004]	0.141
Average household size	0.024	(0.024)	[−0.023, 0.072]	4.908
C. Workers as share of population (2011)				
Ag workers, total	−0.006	(0.007)	[−0.019, 0.007]	0.399
Ag workers, male	−0.007	(0.006)	[−0.018, 0.004]	0.465
Ag workers, female	−0.005	(0.009)	[−0.024, 0.013]	0.329
Non-ag workers, total	0.004	(0.003)	[−0.002, 0.011]	0.075
Non-ag workers, male	0.004	(0.004)	[−0.005, 0.013]	0.096
Non-ag workers, female	0.005	(0.004)	[−0.003, 0.013]	0.053
D. Firm outcomes (2013)				
Number of firms	0.812	(0.716)	[−0.591, 2.214]	8.125
Number of firm employees	−2.173	(4.620)	[−11.228, 6.882]	15.969
E. School outcomes (2014–15 school year)				
# students enrolled, grades 1–5	3.086	(3.681)	[−4.128, 10.301]	46.417
# students enrolled, grades 6–8	−1.949	(2.394)	[−6.642, 2.744]	10.314
# students passed, grades 4–5	−0.438	(0.510)	[−1.437, 0.561]	5.150
# students passed, grades 7–8	−0.558	(0.418)	[−1.378, 0.261]	1.469

Note. — Each row reports results from a separate RD regression. In Panels B–C, we control for the 2001 level of the outcome variable. In Panels D–E, we control for the 2005 (or 2005–06) level of the outcome variable. RD robust regressions are otherwise identical to those in Table 2. Optimal bandwidths range from 71 to 136 above/below 300 people. Results are broadly robust to alternative controls, kernels, bandwidth algorithms, and standard errors. The right column reports means of the outcome variable for villages below the 300-person cutoff. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Source: Burlig, F., & Preonas, L. (forthcoming). Out of the darkness and into the light? Development effects of rural electrification. *Journal of Political Economy*.

District-level D-in-D: household expenditure

Table 5: District-level DD of household consumption expenditures

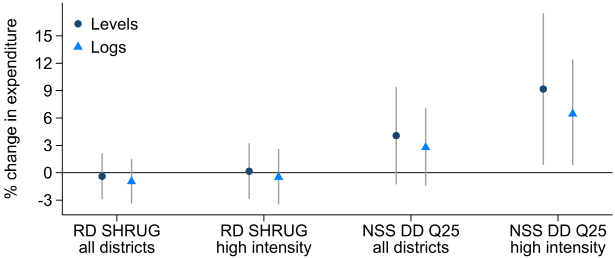
	Expenditure per capita (Rs/month)	
	Levels	Logs
	(1)	(2)
$\mathbf{1}[\text{10th-Plan}] \times \mathbf{1}[2010]$	27.47	0.029
	(24.05)	(0.022)
Mean of dep var	978.15	6.833
Clusters	552	552
Observations	1670	1670

Note. — District-level DD with three NSS years (2000, 2005, 2010). The outcome variable is total household expenditures per capita (net of electricity spending per capita), over the 30-day period period prior to survey enumeration, in 2010 rupees per month (Column (1)) and log-transformed (Column (2)). Both regressions include: district fixed effects; year fixed effects; state-specific linear trends; linear trends in state quartiles of 2005 household expenditures per capita; and linear trends in national deciles of 2005 household expenditures per capita. See notes under Table 3 for further details. Standard errors are clustered at the district level, collapsing to a single cluster for (i) districts that split in the 2001 Census, but which the 2000 NSS sampled based on 1991 district definitions; and (ii) the few cases where an RGGVY DPR included multiple districts. Significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Source: Burlig, F., & Preonas, L. (forthcoming). Out of the darkness and into the light? Development effects of rural electrification. *Journal of Political Economy*.

Districts' expenditure change across samples and designs

Figure 8: Reduced-form expenditure effects, all districts vs. high-intensity districts



Note. — This figure plots reduced-form estimates for expenditure per capita. For regressions where the outcome variable is in levels (circles), we divide point estimates by within-sample means of the outcome variable to interpret as percent changes. For regressions where the outcome variable is in logs (triangles), we convert point estimates to percent changes (i.e., $\exp(\beta) - 1$). "All districts" estimates pool all 130 RGGVY 10th-Plan districts. "High intensity" estimates use only the 90 RGGVY 10th-Plan districts where at least 60% of villages received treatment. Whiskers display 95% confidence intervals. We report the corresponding point estimates in (from left to right): Table 4; and Appendix Tables A15, A24, and A17.

Source: Burlig, F., & Preonas, L. (forthcoming). Out of the darkness and into the light? Development effects of rural electrification. *Journal of Political Economy*.

Takeaways from Burlig and Preonas (forthcoming)

- causal evidence of positive effects on some electrification uptake
- rural electrification may take time to unfold, electricity-using asset ownership increases
- technically zero economic effects across wide range of relevant development outcomes

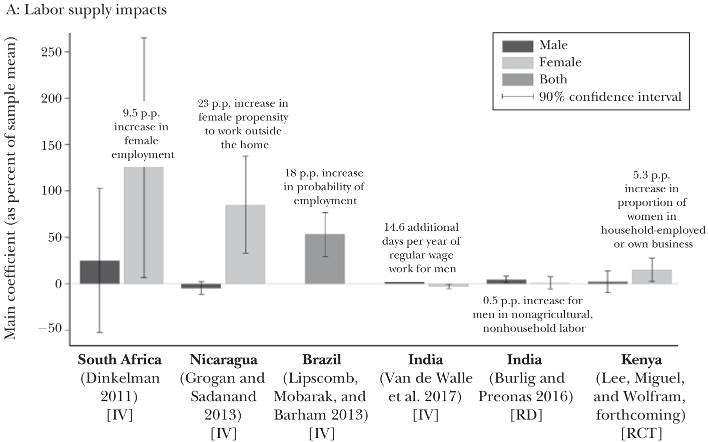
$\lightning$ specific margin: unelectrified villages around population of 300

$\rightarrow$ suggestive evidence of heterogeneity in effects across locations

$\rightarrow$ heterogeneity can potentially make or break rural electrification

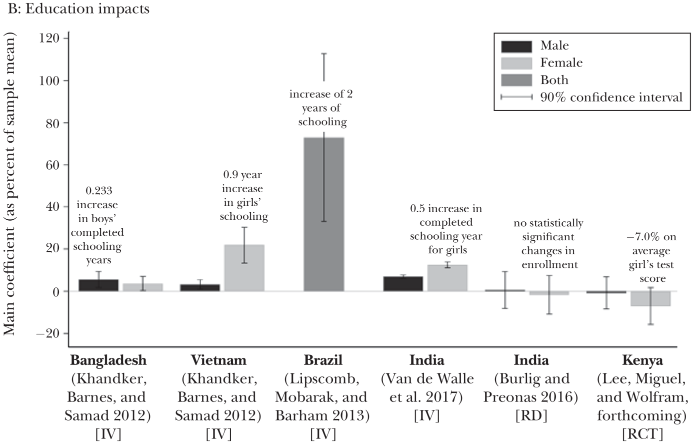
Lee, K., Miguel, E., & Wolfram, C. (2020a). Does household electrification supercharge economic development? *Journal of Economic Perspectives*, *34*(1), 122–144.

Taking stock (I): overview of findings on labour supply



Source: Lee, K., Miguel, E., & Wolfram, C. (2020a). Does household electrification supercharge economic development? *Journal of Economic Perspectives, 34*(1), 122–144.

Taking stock (II): overview of findings on education



Source: Lee, K., Miguel, E., & Wolfram, C. (2020a). Does household electrification supercharge economic development? *Journal of Economic Perspectives*, *34*(1), 122–144.

4. Energy Access and Electrification Puzzle

4.1 Energy and economic growth

4.2 Causal evidence on electrification

4.3 Determinants of success and potential complementarities

Does rural electrification ever work?

Research questions

Does rural electrification ever cause economic development?

If yes, what are the determinants of successful rural electrification?

How to measure 'successful' electrification?

i. line arrival (transformer present)
ii. line powered (transformer on)
iii. low-voltage network (poles behind transformer)
iv. adoption (line tap, metre and wiring)
v. usage (kWh consumption)
vi. outcomes (individual, household, firm, market, village)

Why could micro estimates of electrification fall short?

Potential (non-exhaustive) list of issues in rural electrification literature:

1. ‘wrong’ margin of study
   - wrong time: urban vs rural
   - wrong population: firms vs households
   - wrong place: low WTP (under-grid/off-grid) vs low ATP (remote/poor)
   - wrong side of market: extensive vs intensive margin supply expansion

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   - wrong side of market: extensive vs intensive margin supply expansion
2. insufficient heterogeneity in study locations’
   - size (Burlig & Preonas, forthcoming)
   - time of exposure (Figueiredo Walter & Moneke, 2023)
   - pre-existing productive capacity (Figueiredo Walter & Moneke, 2023)

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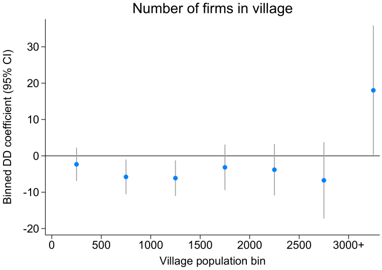
   - time of exposure (Figueiredo Walter & Moneke, 2023)
   - pre-existing productive capacity (Figueiredo Walter & Moneke, 2023)
3. complementarities with other infrastructure
   - roads/market access (Moneke, 2020; Kassem et al., 2022)
   - education provision (Figueiredo Walter & Moneke, 2023a)
   - public health (Figueiredo Walter & Moneke, 2023b)
   - water supply

Potential determinants: size – only large villages benefit

Figure 9: Village-level DD of Economic Census outcomes, by village population bin



Note. — This figure plots DD coefficients by village population bin, for outcomes in Panel D of Table 4. Regressions use a panel of four Economic Census waves (1990, 1998, 2005, 2013) with 814,715 village-year observations. We interact DD treatment ($\mathbf{1}$[10th-Plan district] $\times$ $\mathbf{1}$[2013]) with bins of 2001 village population ($\leq$500, 501–1000, . . . , 2501–3000, >3000). In the >3000 bin, the average village had 187 firms and 408 employees—meaning that our DD estimates for this bin represent 10% and 9% increases, respectively. We interact year fixed effects with population bins, and with two sets of quantiles in 2005 expenditure per capita at the district level (within-state quartiles and national deciles). Regressions also include village fixed effects, state-specific linear trends, and year-specific slopes in 2001 village-level covariates (which increase precision). Whiskers display 95% confidence intervals, with standard errors clustered by district.

Source: Burlig, F., & Preonas, L. (forthcoming). Out of the darkness and into the light? Development effects of rural electrification. *Journal of Political Economy*.

Back-of-the-envelope cost/benefit calculation

Table 8: Return on investment from electrification, using consumption expenditure

	Pr (20-year ROI > 0), by village population			
	300	300	1000	2000
Discount rate				
$r = 0.05$	0.176	0.268	0.090	0.910
$r = 0.10$	0.159	0.240	0.089	0.909
$r = 0.15$	0.140	0.213	0.086	0.908
Expenditure/capita	SHRUG	SHRUG	NSS	NSS
Endog. variable	Hours of power	Brightness	$\mathbf{1}$[HH elec > 0]	$\mathbf{1}$[HH elec > 0]
Instrument	300-person RD	300-person RD	1st-wave district	1st-wave district
Estimation sample	RD bandwidth	RD bandwidth	Quintile 1	Quintiles 2–5

Note. — We simulate expenditure benefits using our results from Columns (1) and (3) of Table 6, and from Columns (2)–(3) of Table 7. We rescale fuzzy RD estimates by 10 (for hours of commercial power) and 2.6 (for nighttime brightness), and convert all four estimates to annual expenditures per capita in 2010 rupees. Then, we make 10,000 draws from each rescaled sampling distribution (see Appendix Figure A15), and calculate the 20-year discounted sum of expenditure changes for villages of 300, 1000, or 2000 people. We assume a constant flow of annual benefits in the village, applying annual population growth rates from the 2001–2011 Census. Finally, we subtract upfront fixed and variable costs of electrification. Following Banerjee et al. (2014, p. 51), we assume fixed costs of Rs 1.8 million per village and variable costs of Rs 2,200 per household, inflating from 2008 to 2010 rupees. Appendix Table A25 repeats these simulations under alternative fixed costs and without population growth.

Source: Burlig, F., & Preonas, L. (forthcoming). Out of the darkness and into the light? Development effects of rural electrification. *Journal of Political Economy*.

Figueiredo Walter, T., & Moneke, N. (2023). When does electrification work? Evidence from Zambia. *University of Oxford mimeo*.

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$\Rightarrow$ find bimodal electricity adoption across villages in typical context

iii investigate determinants of adoption: pre-existing productive capacity

$\Rightarrow$ show crucial role of pre-existing commercial operations (here: **mills**)

Why Zambia? A promising empirical setting

a **Large-scale rural electrification expansion**
- electrification goal: 3% to 51% from 2008 to 2030 (REMP)
- comparable to many other rural electrification programs
- natural experiment: priority ranking of villages, bundled in packages
- exploit electrification of inconsequential, low-priority villages

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b **Novel measure of electrification status and progress**

- annual primary school headmaster reports from >14,000 schools
- school most common anchor load, determines village access ▸ Load Curves
- cross-validated with subset of engineering project records

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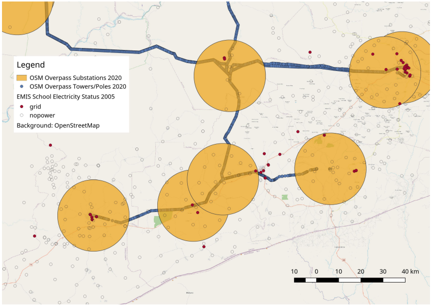
c **Rich data on pre-existing conditions, outcomes & infrastructure**
- two full rounds of Population & Housing Census [2000, 2010]
- nine Labour Force Surveys (LFS) [2005, 2008, 2012, 2015, 2017–2021]
- single cross-section of 58,500 geo-identified Points of Interest [2010]
- annual school census [2005–2020]
- three health facility censuses [2005, 2012, 2017]

Fundamental lack of data on rural electrification



Example: Grid-connected schools in Western Province, 2005 vs 2017

Zoom-in: Transmission Grid vs Health Facilities

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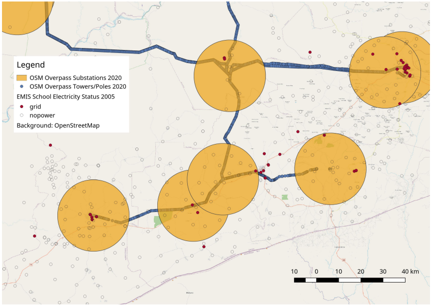
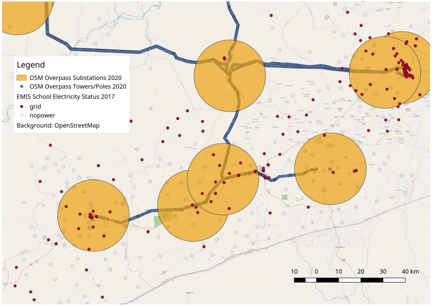




Example: Grid-connected schools in Western Province, 2005 vs 2017

▸ Zoom-in: Transmission Grid vs Health Facilities

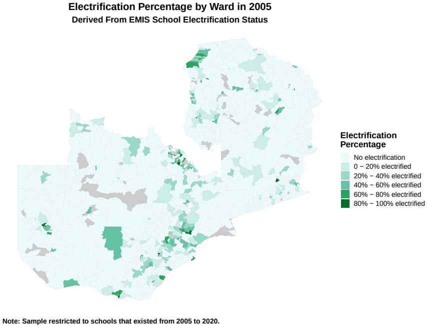
A novel measure of de facto rural electrification

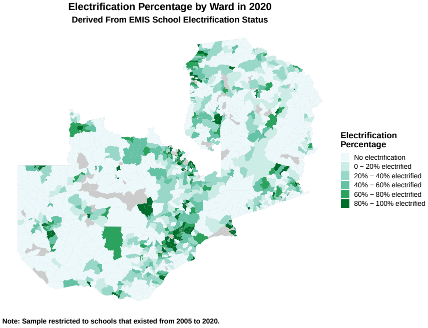
- annual headmaster reports submitted to Ministry of Education
- question on school's electricity connection
- reports over time allow to pinpoint year of school electrification
- legal requirement to connect school, crucial as anchor load ▸ Load Curves
- same measure available from (fewer) rural health centres

$\rightarrow$ school electrification = transformer next to school

$\rightarrow$ transformer = necessary for any village-level grid electrification

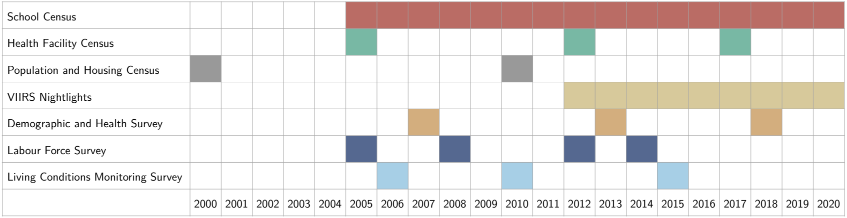
Rural electrification in Zambia: 2005 vs 2020 (schools)



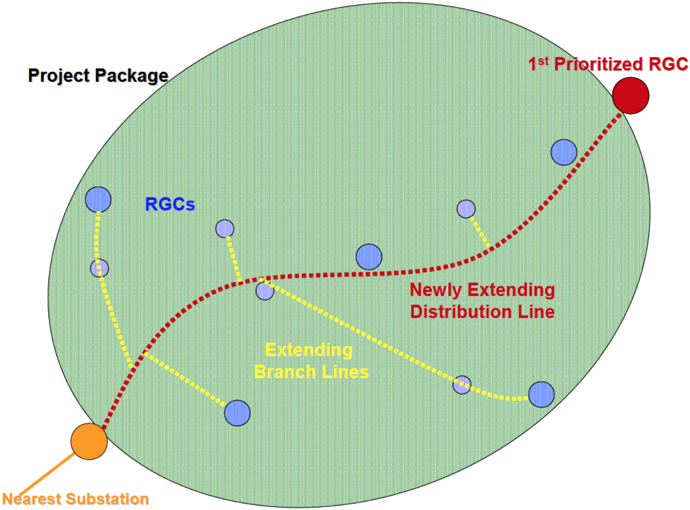


▸ Ward Electrification (Health Facilities)

Available sample coverage across datasets



Inconsequential units in electrification project packages

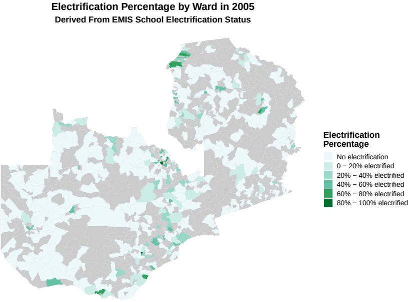


Identifying variation

- Focus on total of 970 RGCs to be electrified by distribution line
  - 180 consequential RGCs
  - 790 inconsequential RGCs
- Observe electrification of 303 inconsequential RGCs until 2020

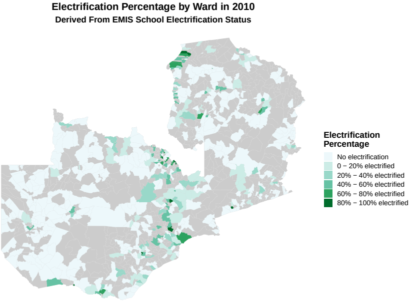
Electrification of wards with inconsequential RGCs

2005



Note: Sample restricted to schools that existed from 2005 to 2020, and wards with at least one inconsequential RGC.

2010



Note: Sample restricted to schools that existed from 2005 to 2020, and wards with at least one inconsequential RGC.

Electrification of wards with inconsequential RGCs

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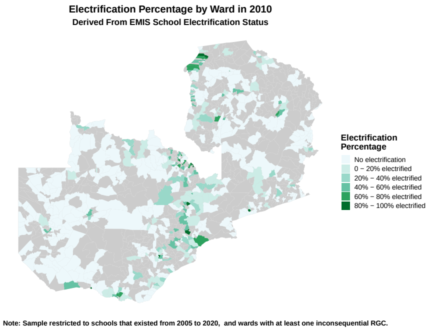
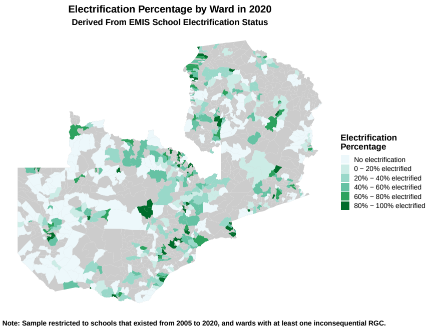


2020



Empirical approaches

- Pursue two empirical approaches:
  1. D-in-D on wards with inconsequential RGCs
  2. IV using the planned year of inconsequential RGC electrification as instrument for actual electrification at ward-level

→ Trade-off between statistical power and identification

RGCs treated by 2020 similarly inconsequential at baseline

Table 1: Baseline demand (REMP)

	Not treated by 2020		Treated by 2020		
Variable	Mean	Std. Dev.	Mean	Std. Dev.	Test
Avg RGC ranking	569	300	593	290	F= 0.806
Avg RGC size (# households)	390	350	374	379	F= 0.223
Avg predicted RGC demand	444,693	384,142	430,364	417,245	F= 0.154
Ward population (PHC 2010)	5,285	3,124	7,939	4,351	F= 56.117***
Pop Growth Rate (2000-2010)	0.29	0.78	0.33	0.67	F= 0.455

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

First stage: actual on predicted electrification

Table 2: First Stage – Actual on Planned Electrification (Schools)

	Actual Electrification (pct)			
	Full	VIIRS sample	DHS sample	LFS sample
Planned Elect. (pct)	0.09***	0.10**	0.09**	0.05
	(0.03)	(0.04)	(0.04)	(0.08)
Year FE	✓	✓	✓	✓
Ward FE	✓	✓	✓	✓
R^2	0.73	0.83	0.93	0.91
No. of Years	15	8	3	2
No. of Wards	502	502	307	155
Obs.	7530	4016	459	306
F statistic	13.81	5.96	1.07	0.42

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$. All standard errors clustered at ward-level. Sample of stable non-urban Census 2010 wards. Ward-level actual electrification derived from schools existing since 2005. F statistic denotes Kleibergen-Paap weak instrument F test.

Main specification: various outcomes on electrification

D-in-D / two-stage least squares run on data at the RGC-year-level:

$$Outcome_{i,t} = \alpha + \beta ActualElectPct_{i,t} + \gamma_i + \lambda_t + \delta_{d,t} + \epsilon_{i,t} \quad (1)$$

- where $Outcome_{i,t}$ denotes various village/household/individual-level outcomes, aggregated to the RGC i, in survey round year t
- $ActualElectPct_{i,t}$ represents school-derived percent of actual electrification for RGC i, year t
  (in 2SLS, denotes predicted values: $\widehat{ActualElectPct}_{i,t}$)
- γ_i denotes a RGC FE
- λ_t denotes a year FE
- $\delta_{d,t}$ denotes a district-specific time trend

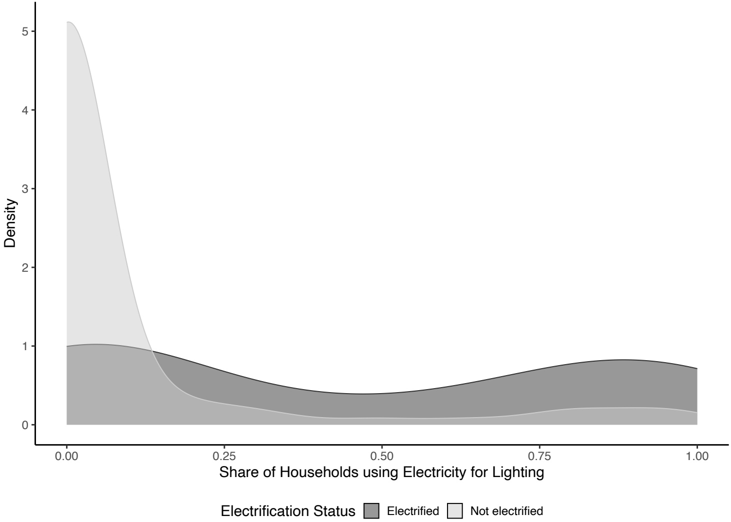
Are electrified locations brighter at night? (VIIRS)

Table 3: Nightlights on Actual Electrification across Specs. (Schools, 2012-2019)

	VIIRS Mean Nightlights				VIIRS Max Nightlights			
	OLS	OLS	DD	2SLS	OLS	OLS	DD	2SLS
Actual Elect. (pct)	0.02	-0.00	0.02^{*}	-0.05	0.17	0.19	0.25^{*}	2.47
	(0.06)	(0.06)	(0.01)	(0.26)	(0.38)	(0.38)	(0.13)	(4.03)
Year FE		✓	✓	✓		✓	✓	✓
RGC FE			✓	✓			✓	✓
Const-Year trends			✓	✓			✓	✓
R^2	0.00	0.01	0.95	0.96	0.00	0.00	0.82	0.82
No. of Years		8	9	8		8	9	8
No. of RGCs			708	708			708	708
No. of Const-Years			1197	1064			1197	1064
Obs.	5672	5672	6372	5664	5672	5672	6372	5664

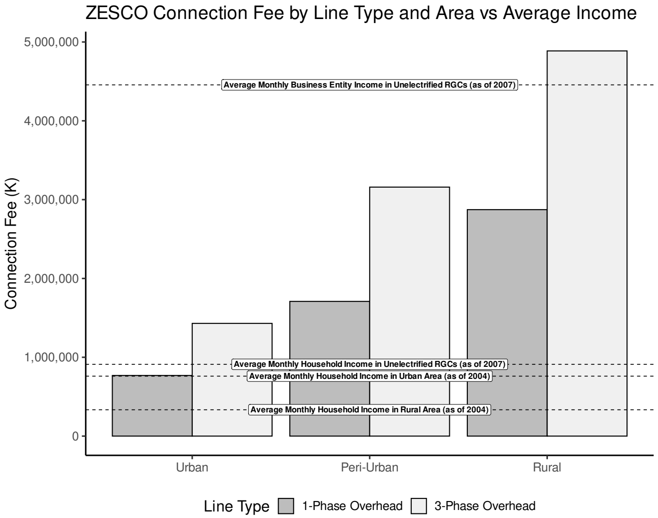
$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$. All standard errors clustered at electrification package-level. Sample of inconsequential, non-urban, non-solar home system Rural Growth Centres (RGCs) included in Rural Electrification Master Plan. RGC-level actual electrification derived from schools existing since 2005.

Do households in electrified locations adopt? (LCMS-2015)

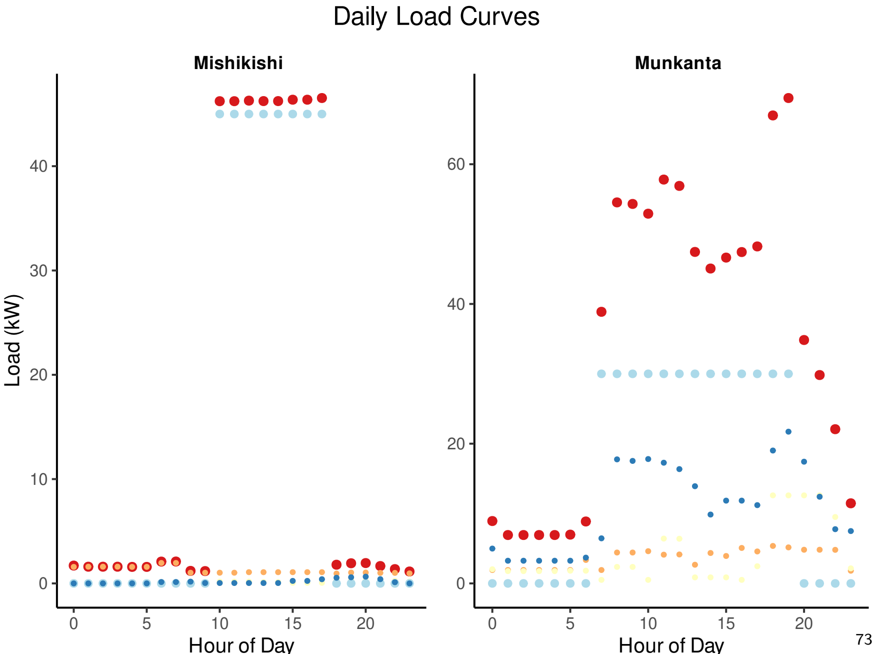


Note: Sample restricted to schools that existed from 2008 to 2020. Electrification status is a dummy variable that equals one when at least 80% of schools in ward are electrified.

Engineers' problem: high fixed cost of electrification



Engineers' solution: identify productive uses of electricity



Two measures of potential productive capacity

1. pre-existing points of interest (2010)
   - Census by-product of 58,500 points of interest
   - fully geo-identified
   - incl. 2,600 mills, 5,800 commercial entreprises, 14.200 churches, etc.

2. pre-existing 'productive' buildings (2010)
   - full Census includes all 2.1m Zambian buildings
   - two key variables:
     - 'occupancy' (e.g. residential, <u>non-residential</u>, vacant)
     - 'type' (e.g. flat, house, <u>commercial</u>, makeshift, mobile, etc.)
   - subset of points of interest probably enumerated as buildings, too

→ does pre-existing productive capacity matter for electrification?

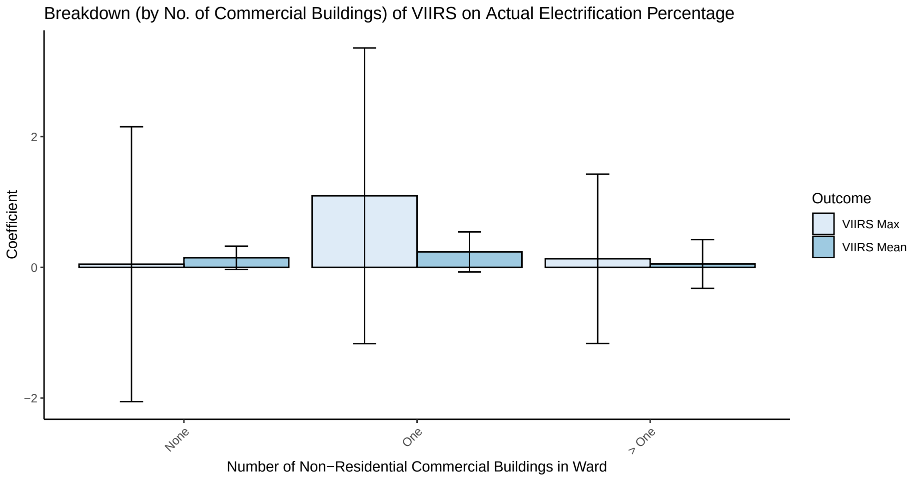
Does productive capacity matter? (points of interest)

Table 4: Nightlights on Actual Electr. and Mill Interaction (Schools, 2012-2019)

	VIIRS Mean Nightlights		VIIRS Max Nightlights	
	(1)	(2)	(3)	(4)
Actual Elect. (pct)	0.03	−0.01	0.28	0.03
	(0.03)	(0.02)	(0.19)	(0.14)
Actual Elect. (pct) * Mill in RGC		0.17^{*}		1.17
		(0.10)		(0.74)
Year FE	✓	✓	✓	✓
RGC FE	✓	✓	✓	✓
Const-Year trends	✓	✓	✓	✓
R^2	0.96	0.96	0.86	0.86
No. of Years	9	9	9	9
No. of RGCs	706	706	706	706
No. of Const-Years	1197	1197	1197	1197
Obs.	6354	6354	6354	6354

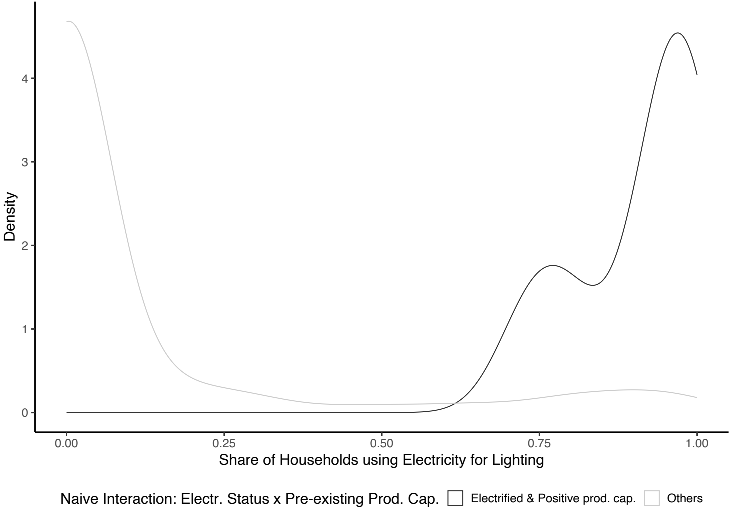
$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$. All standard errors clustered at electrification package-level. Sample of inconsequential, non-urban, non-solar home system Rural Growth Centres (RGCs) included in Rural Electrification Master Plan. RGC-level actual electrification derived from schools existing since 2005.

Does productive capacity matter? (buildings)



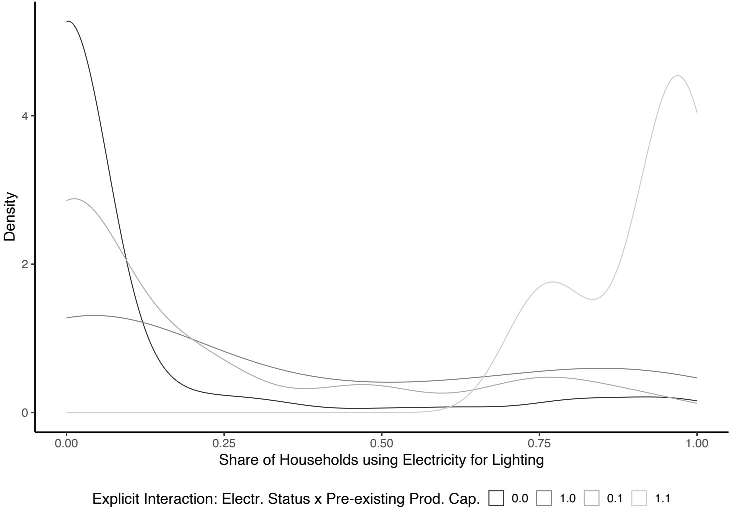
▸ Quintile Breakdown ▸ Collective Buildings ▸ Unintended Buildings ▸ Other Buildings ▸ Census & Prod. Cap.

Can productive capacity explain adoption patterns?



Note: Sample restricted to schools that existed from 2008 to 2020. Productive capacity is a dummy variable that equals one when the share of non-residential buildings is positive in ward. Electrification status is a dummy variable that equals one when at least 80% of schools in ward are electrified.

Interaction between electrification and productive capacity



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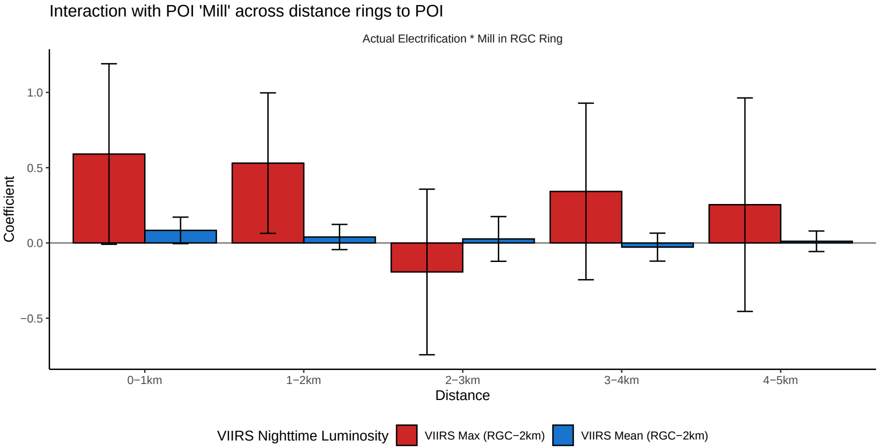
Mechanism: mills within 1-2km from centre most impactful



Mechanism: work-in-progress and next steps

Testable hypotheses how mill could be conducive for adoption:

- **capital**: entrepreneur lends to households
  $\rightarrow$ test for bank presence in RGC
- **market access**: mill situated at market or along major road
  $\rightarrow$ test for roads complementarity (cf. Moneke, 2023)
- **income effect**: electrified mill as productivity shock, HH incomes $\uparrow$
  $\rightarrow$ test for changes in household real consumption proxies
- **fixed cost**: mill invests in trunk line, HHs receive connection subsidy
  $\rightarrow$ test for differential effects of centre to mill corridor vs other direction
  $\rightarrow$ test for initial length of trunk line built by REA across villages

Takeaways from Figueiredo Walter & Moneke (2023)

1. Novel measure allows effective tracking of rural electrification
2. Rural electrification plan succeeded in connecting villages
3. However, village connection masks bimodal adoption, noisy LATE
4. Pre-existing productive capacity (mills) key for electrification success
5. Ongoing work tests mechanism translating mill presence into adoption

References I

Bensch, G., Peters, J., & Vance, C. (2021). Development effects of electrification in Brazil – a comment on Lipscom et al. (2013). *RWI Essen mimeo.*

Burgess, R., Greenstone, M., Ryan, N., & Sudarshan, A. (2020). Demand for electricity on the global electrification frontier. *Cowles Foundation Discussion Paper Series*, (2222).

Burlig, F., & Preonas, L. (forthcoming). Out of the darkness and into the light? Development effects of rural electrification. *Journal of Political Economy.*

Dinkelman, T. (2011). The effects of rural electrification on employment: New evidence from South Africa. *American Economic Review*, *101*(7), 3078–3108.

Figueiredo Walter, T., & Moneke, N. (2023). When does electrification work? Evidence from Zambia. *University of Oxford mimeo.*

Kassem, D. (2018). Does electrification cause industrial development? Grid expansion and firm turnover in Indonesia. *London School of Economics mimeo.*

References II

Kassem, D., Zane, G., & Uzor, E. (2022). Revisiting the last mile: The development effects of a mass electrification program in Kenya. *University of Mannheim mimeo.*

Lee, K., Miguel, E., & Wolfram, C. (2020a). Does household electrification supercharge economic development? *Journal of Economic Perspectives, 34*(1), 122–144.

Lee, K., Miguel, E., & Wolfram, C. (2020b). Experimental evidence on the economics of rural electrification. *Journal of Political Economy, 128*(4), 1523–1565.

Lipscomb, M., Mobarak, A. M., & Barham, T. (2013). Development effects of electrification: Evidence from the topographic placement of hydropower plants in Brazil. *American Economic Journal: Applied Economics, 5*(2), 200–231.

Moneke, N. (2020). Can Big Push infrastructure unlock development? Evidence from Ethiopia. *University of Oxford mimeo.*

Rud, J. P. (2012). Electricity provision and industrial development: Evidence from India. *Journal of Development Economics, 97*(2).