Demand for Electricity in a Poor Economy

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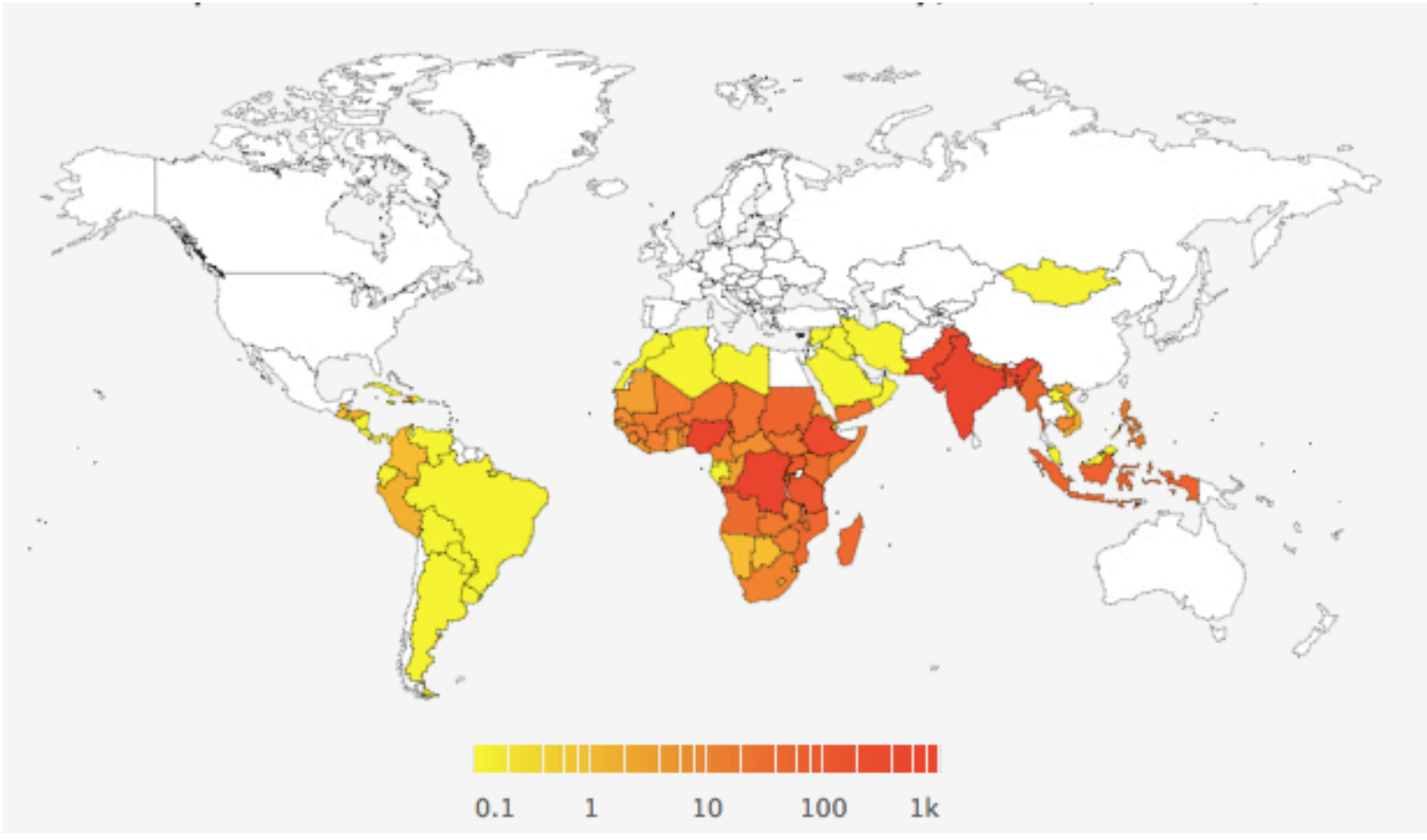
Over a billion people globally, nearly all in South Asia and Sub-Saharan Africa, do not have electricity in their homes

Figure: Population without electricity (millions), 2016 (IEA)



Cheap solar makes distributed power easier

Figure: Grid electrification

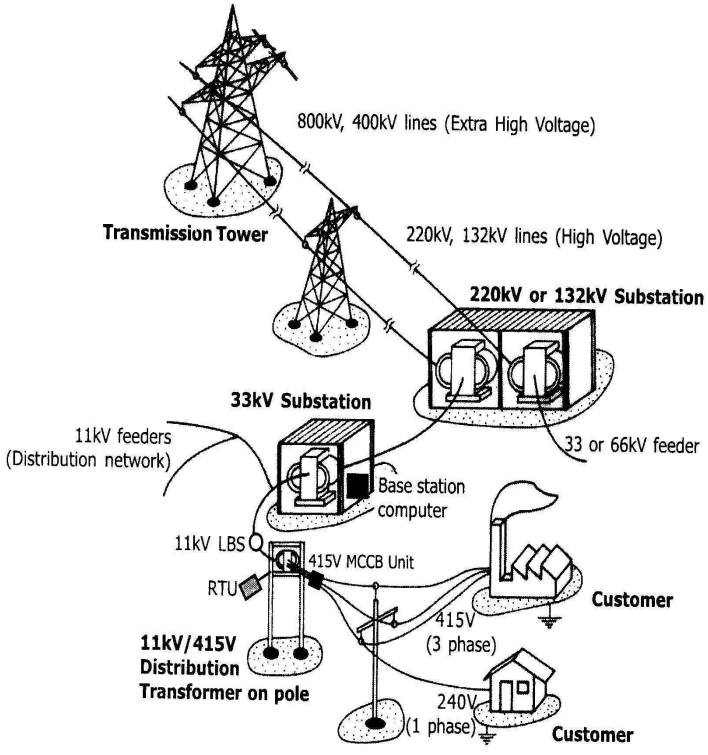


Figure: Distributed electrification

This paper conducts an experiment to measure willingness to pay for electricity by randomizing the price of solar micro-grids

- We ran a randomized experiment in partnership with a micro-grids solar company, Husk Power Systems (HPS).
- Sample of 100 villages in Bihar, India
- 3 randomly assigned prices
  - 34 control villages where HPS system was not offered
  - 33 treatment 1 villages where system was offered at market price of 200 INR (later cut to 160 INR)
  - 33 treatment 2 villages where system was offered at below market price of 100 INR
- Surveyed households before and after, and collected administrative payment data

But we found there is a surprisingly competitive retail power sector in Bihar, India

HPS solar product: A 240 watt micro-grid typically shared among 6 households

- Provides 25-40 watts of power, 5-7 hours of supply per day
- Each household gets a meter with keypad, two LED bulbs, socket to charge mobile phone
- Payment is 200 INR (later reduced to 160 INR) monthly and customers recharge their connection by buying a code

Figure: HPS Panel

Diesel electricity

- Village members own and run diesel generators, sell electricity within village
- Most operators offer at least one standard plan, of 100 INR / month for 100 watts
- Turned on for predictable hours during peak demand, averaging about 3.5 hours per day (all during night time hours)
- Need a sufficient number of customers to cover fixed costs, so the availability of diesel is highly dependent on the number of local customers

Own solar electricity

- Off-grid solar option, as opposed to micro grid HPS
- Most panels are small and service lightbulbs and mobile phone chargers
- Provide similar hours of supply to HPS micro grid
- We amortize own solar one-time costs to monthly payments assuming 7 year panel life and 20% interest rate

Grid electricity

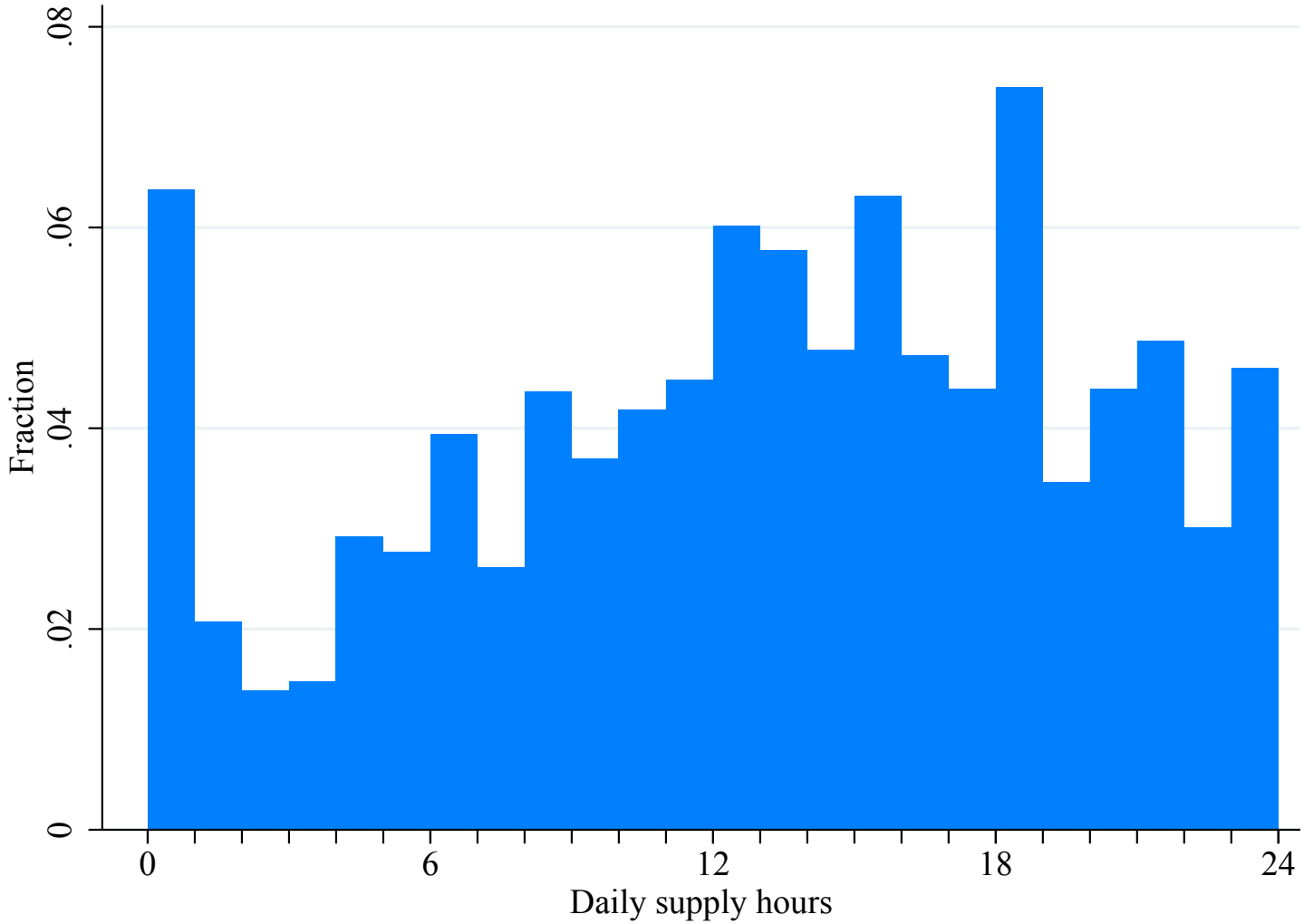
- Load is practically unlimited with respect to appliances that these households own
- Supply is unpredictable due to extensive load shedding, or supply rationing but averages 13 hours per day in connected villages
- Our best estimate is that these consumers use about 60-100 kWh per month
- Formal tariffs set by distribution companies
- Very poor bill collection in practice
  - **Distribution companies lose about 43 INR for every 100 INR of costs**

Payments and supply on the grid

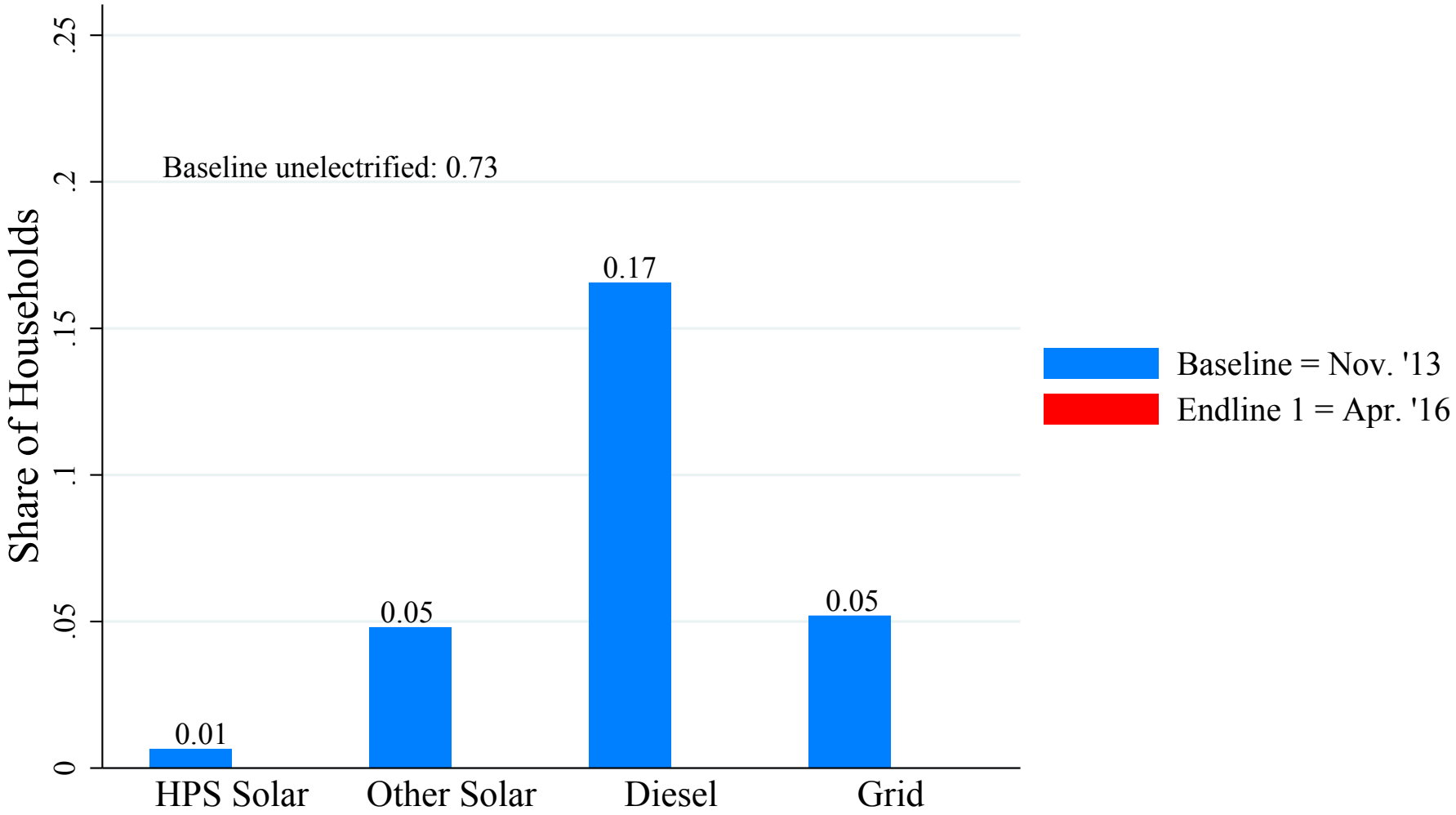
"Whenever I feel like paying the bill."

- Bihar villager in response to survey question "How often do you pay your bill?"

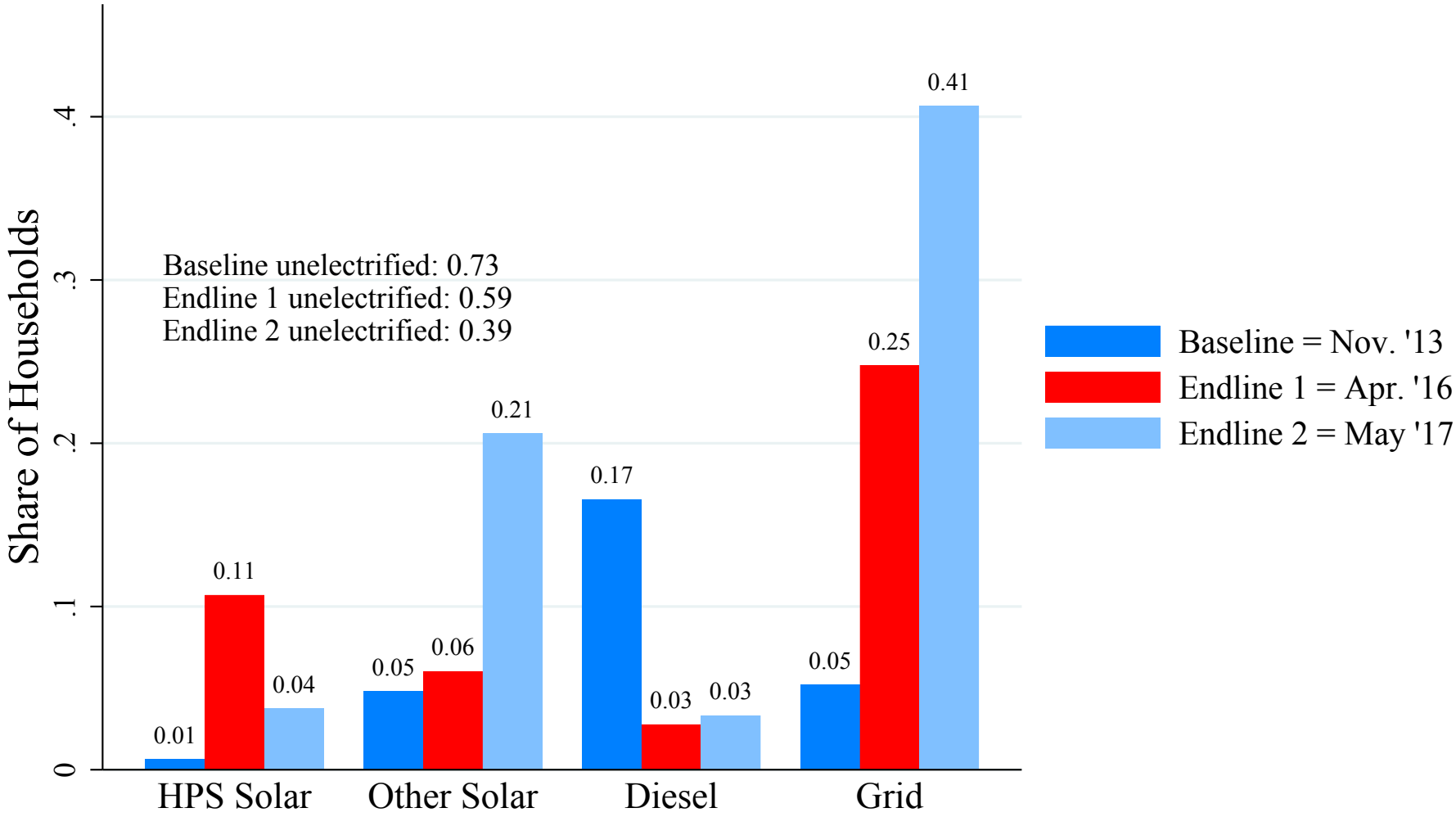
Variation in grid supply available to sample villages, March - May 2017



Substantial variation in sources over time: At baseline, diesel is the primary electricity source



Continued grid and solar expansion in 2017



Rich data with information on households and all energy sources that characterizes the retail electricity market

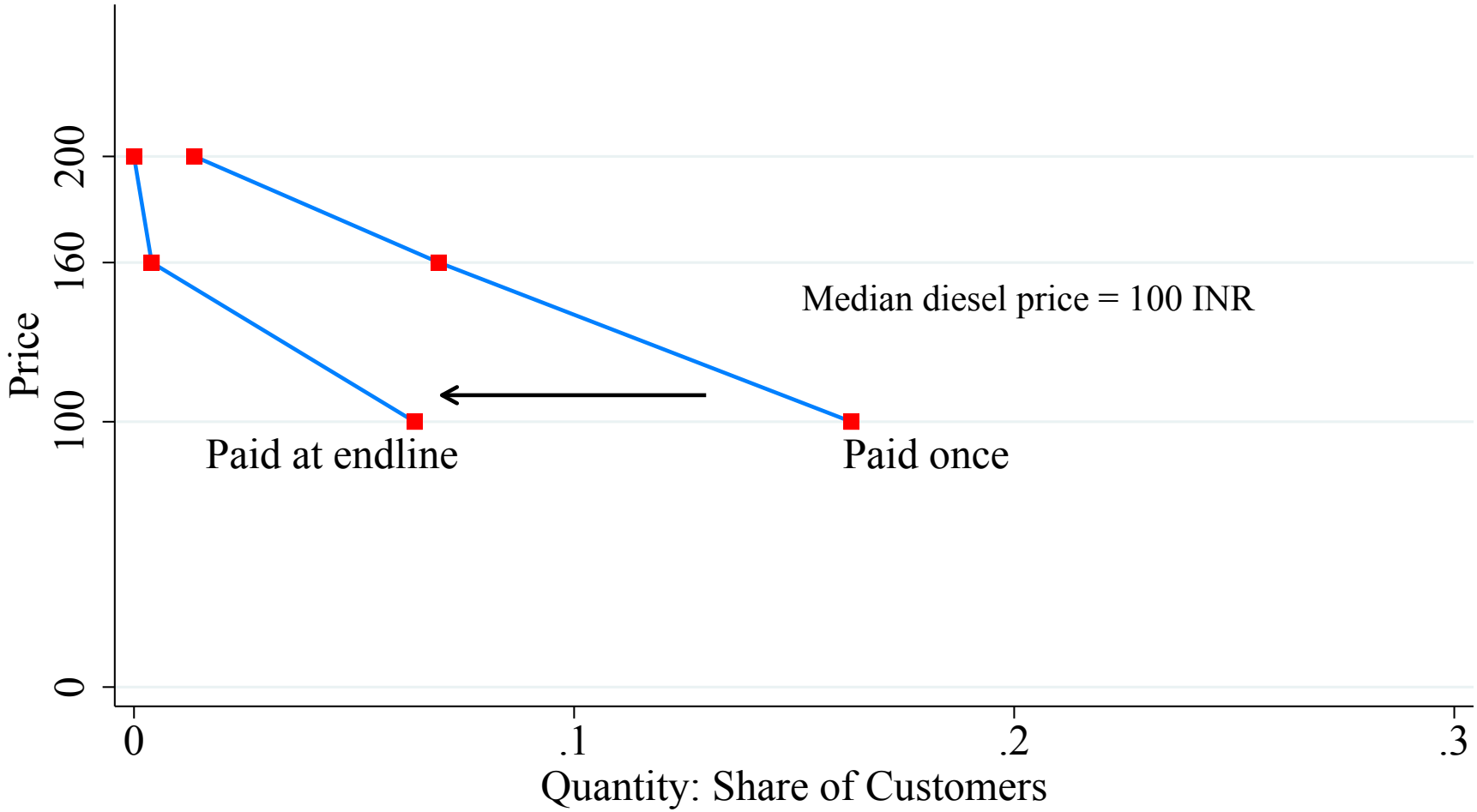
- **Household survey.** Baseline (Nov, 2013) and endline 1 (Apr, 2016) and endline 2 (May, 2017) surveys of 3,000 households in 100 rural villages of Bihar.
- **Administrative 1.** Payments data from solar provider.
- **Administrative 2.** Supply and payment records from state utility.
- **Supplier survey.** Survey all diesel generators on hours of supply.

This paper addresses 3 sets of questions

1. Experimental estimates of the demand for solar microgrids and their benefits.

- Trace out demand curve.
  - At 2013-2016 unsubsidized prices, near zero demand.
  - Demand is very elastic and at prices about 1/2 of true cost, HPS microgrids capture 7% of the market.
  - Traditional analysis
    - Users experience increase in light bulb ownership, hours of electricity use and mobile phone ownership
    - No meaningful effect on health, children's test scores, or income

Demand curve for HPS solar



This paper addresses 3 sets of questions

2. Estimate nested logit with IV model of electricity source demand with 4 sources to account for heterogeneity in sources and substitution opportunities.

- Households are price sensitive– increasing the monthly price by 10 INR ($0.16) reduces...
  - HPS market share by 0.6 percentage points
  - Own solar market share by 0.8 pp
  - Diesel market share by 0.35 pp
  - Grid market share by 1.3 pp
- Night time electricity is valued highly: annual WTP for an additional hour of peak period electricity is 473 INR, compared to annual household income of roughly 90,000 INR.

Today: Nested logit with IV

- **Data**. Households choose one of $\{Grid, Diesel, Own\ Solar, HPS\ Solar\ Microgrid, None\}$.
  - Prices and availability at village-level.
  - Extraordinarily detailed household covariates.

- **Model**. Nested logit model with three nests of
  1. $\{Grid\}$
  2. $\{Diesel, Own\ Solar, HPS\ Solar\ Microgrid\}$
  3. $\{None\}$

- **Variation**.
  - Use experimental price variation for HPS solar
  - Treat availability and price of other sources as exogenous

Nested logit model

- Indirect utility for household i in village v and time t from electricity sources j is given by

$$\begin{aligned} U_{vtij} &= \delta_{vtj} + z_{tir}\beta_{rj} + \sum_g d_{jg}\zeta_{gi} + (1-\sigma_g)\epsilon_{vtij} \\ \delta_{vtj} &\equiv \sum_k x_{vtjk}\bar{\beta}_k + \xi_{vtj}. \end{aligned}$$

- x_{vtjk} are source characteristics.
- z_{tir} are household characteristics (income, number of adults, ownership of agricultural land).
- $\zeta_{gi} + (1-\sigma_g)\epsilon_{vtij} \sim$ EV-I, $\epsilon_{vtij} \sim$ EV-I (nested logit model)
- ξ_{vtj} is the mean unobserved utility of a source.

Experiment estimates structural parameters

Several candidate instruments for demand

1. **Supply / cost shifter.** Prices in other markets (Hausman instruments).
2. **Mark-up shifter.** Characteristics of other products in the same market (BLP instruments).
3. **Mark-up shifter.** Randomized experiment assigning price of HPS solar.

We opt to use (3)

- Perhaps the first experimental estimate of discrete choice (Kremer, Leino, Miguel and Zwane (2011) identify mixed logit model with travel cost, not experiment)

Electricity source characteristics x_{vtj}

Table: Summary of electricity sources

	Grid	Diesel	HPS	Own solar
		Monthly price (INR)		
Baseline	73.84	126.6	200	100.5
Endline 1	61.64	104.8	163.8	99.55
Endline 2	61.64	104.8	170	90.95
		Peak hours (5pm - 10pm)		
Baseline	2.076	3.375	4.300	4.717
Endline 1	2.497	3.083	5	5
Endline 2	2.952	3.083	5	5
		Off hours		
Baseline	10.58	0	1	2.714
Endline 1	10.62	0	0.714	0.808
Endline 2	10.59	0	0.714	0.808

Estimation results: linear part

Table: Linear Price IV

	OLS (1)	Second Stage Price IV (2)
Price (Rs. 100)	-0.26**	-1.32*
	(0.11)	(0.76)
Hours of supply on peak	0.50*	0.52**
	(0.26)	(0.26)
Hours of supply off peak	-0.12*	-0.14**
	(0.070)	(0.068)
ξ_{tj} mean effects	Yes	Yes
Observations	996	996

Standard errors cluster at the village level in parentheses. Includes mean unobserved energy source by time effects, ξ_{tj}.

Key Findings

1. Households are price sensitive – increasing the monthly price by 10 INR ($0.16) reduces...
   - HPS market share by 0.6 percentage points
   - Own solar market share by 0.8 pp
   - Diesel market share by 0.4 pp
   - Grid market share by 1.3 pp
2. Households highly value night time hours
   - Annual MWTP for an additional hour of night time electricity is 473 INR.
   - Annual household income is roughly 90,000 INR
3. Wealth proxies increase demand for electricity, particularly the grid
4. Estimation details
   - Load is in the constant, suggesting that it is part of the grid's appeal

This paper addresses 3 sets of questions

3. Counterfactuals: Improvements in the Grid are Valued Highly

- **Extending the grid everywhere** decreases unelectrified (from 42 pp to 23 pp), increases WTP by 89 INR per household annually, and greatly increases utility losses
- **Introduction of solar to market.**
  - Solar's market share is highly dependent on grid availability
  - WTP for introducing solar into the market declines from about 400 INR per year per household when the grid isn't available to 90 INR when it is available everywhere
- **Optimistic solar innovation scenario.**
  - Decreases the share of households that are unelectrified by only 2 percentage points
  - Low WTP for solar innovation, approximately equal to 63 INR per household annually

This paper addresses 3 sets of questions

3. Counterfactuals (cont.): Improvements in the Grid are Valued Highly

- **Distribution reforms.**
  - A 1 hour increase in night time supply of electricity decreases unelectrified by 6 pp, increases annual WTP by 415 INR, and greatly increases distribution company losses.
  - Ending theft increases unelectrified from 42 pp to 47 pp, reduces annual WTP by 536 INR, and greatly reduces losses
  - Budget neutral increase to full supply of night time hours to 5 and reduction in theft decreases unelectrified by 6 pp and increases annual WTP by 381 INR.

Distribution company potential policy reforms

Table: Distribution company policy reform counterfactuals: market shares and WTP

	Market shares					Annual WTP per HH (INR)	Annual Losses per HH (INR)
	Grid	Diesel	Own solar	HPS	None		
Actual	0.41	0.05	0.07	0.05	0.42		861.45
i. Expand availability and supply							
Grid everywhere	0.69	0.02	0.03	0.03	0.23	89.38	1436.57
Extra 1 Hour	0.45	0.05	0.08	0.06	0.36	414.97	1042.04
Extra 2 Hours	0.51	0.04	0.07	0.06	0.32	1041.80	1287.86
ii. Remove theft							
Grid INR 140	0.29	0.06	0.10	0.08	0.47	-535.93	321.74
iii. Budget neutral reduction in theft and 5 peak hours							
Grid INR 120	0.45	0.05	0.08	0.06	0.36	381.13	843.04

We model removing theft by raising the grid price to reported survey bill values, assuming payment rate is 100%. In the budget neutral theft reduction with increased supply hours, we set peak hours equal to its maximum of 5 and raise the grid price until annual losses are equivalent to actual annual losses.

Bihar village clamours for real electricity

The residents of Dharnai are far from satisfied to see lights for the first time in 33 years, courtesy a solar-powered micro-grid set up by the environment watchdog Greenpeace India.

Giridhar Jha
Patna, August 6, 2014 | UPDATED 09:07 IST

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The least you would expect when you bring electricity to an entire village, ending over three decades of darkness, is a 'thank you' from its residents. But no such niceties here in Dharnai, a nondescript village tucked away in the Naxal heartland of Bihar.

The residents of Dharnai are far from satisfied to see lights for the first time in 33 years,