Efficiency and Equity Effects of Electricity Metering: Evidence from Colombia

Shaun McRae

University of Michigan

September 26, 2015

Outline of the talk

Meters play an essential role in the implementation of utility rate structures

- Three fundamental objectives of utility rate design (Bonbright, 1961)
  - Recover utility costs
  - Provide signals for efficient consumption of service
  - Allocate costs fairly across users
- Two opposite approaches for setting utility tariffs
  - Fixed charges: amount that consumers pay does not depend on usage
  - Volumetric charges: amount that consumers pay is a function of usage
- Charging based on usage requires meters to measure consumption

Consumption of metered and unmetered electricity consumers

- Electricity consumers without their own meter face a marginal price of zero
  - This is less than marginal cost (even more so if we consider marginal external costs)
  - Consumption will be greater than the socially optimal level
- Electricity consumers with a meter typically pay a low fixed charge and a high variable rate
  - In most cases the marginal price greatly exceeds social marginal cost (Davis & Muehlegger, 2010)
  - Consumption will be lower than the socially optimal level
- Understanding and quantifying these losses is necessary for understanding the welfare effects of metering and rate design

Is economic efficiency the only thing that matters for setting utility rate structure?

- But designing "fair" tariffs requires the elimination of undue cross-subsidization between customers
- Suppose unmetered customers are billed for the mean consumption of all users
  - Customers whose true unobserved usage is low will be subsidizing the customers with true unobserved usage that is high
- Lower-income customers will, on average, have lower consumption and will benefit the most from metering

Which of these two rationale for metering matter most?

- Relative importance of the efficiency and distributional motivations for metering will depend on:
  - Elasticity of demand for the service
  - Heterogeneity across consumers in the level of demand
- Electricity demand is relatively inelastic and there is a lot of heterogeneity across households
  - Therefore distributional concerns will be particularly relevant for metering analysis
- In this talk I will demonstrate this result using monthly electricity billing data for unmetered, metered, and newly metered households in Colombia

Overview of results

- Use billing data to show that in the months after metering, consumption falls by about 30 percent
- Lower income households (with low unobserved consumption) benefit the most by the change
- Overall welfare improvement from metering households is small
  - This is because of the structure of the price schedule: zero fixed fee, average cost price
- Metering + two-part tariff (monthly fee and marginal cost price) would have more substantive welfare effects and may be more politically feasible

Metering is an important policy issue for public utility regulators in developing countries


EL UNIVERSAL

Home › Cartagena ›

“Queremos que instalen los contadores y tomen lectura”

EL UNIVERSAL | CARTAGENA DE INDIAS | 14 de Agosto de 2013 12:20 am |

Varios moradores de este sector piden que se instalen los contadores. // ANTONIO CANCHILA GARCÍA - EL UNIVERSAL

Con extrañeza reciben los habitantes del barrio Luis Carlos Galán, sector Cooperativo, la llegada de recibos por cobro de energía eléctrica por parte de la empresa Electricaribe, pues aseguran que hasta la fecha no tiene contadores donde se ve el

- 624,000 complaints to regulator in Colombia in 2009 about metering or the estimation of unmetered consumption
- 22 percent of dwellings connected to network in Ecuador lacked a meter in 2010

Widespread concern about environmental effects of energy consumption in developing world

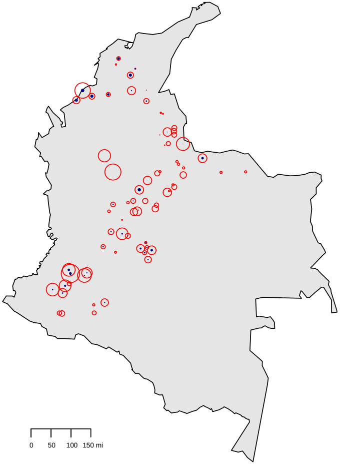
- Forecast growth in energy consumption by 2035: 14 percent in OECD, 84 percent in non-OECD
- Particular focus on overconsumption due to energy subsidies that reduce the price of energy below marginal social cost
  - But note that for electricity, retail price may be much higher than marginal cost
- Lack of metering is another factor that reduces marginal price below marginal cost

Parallels to debate in U.S. about real-time metering and billing

- Although real-time meters have been widely installed, very few utilities offer real-time pricing to residential customers
- Interval metering creates a cross-subsidy from consumers with low peak consumption to consumers with high peak consumption (Borenstein 2012)
- Real-time pricing would make a small number of customers much worse off
- This limits the political feasibility of real-time metering—and exactly parallels the findings for Colombia
- Similar related setting: "unmetered" broadband packages (Nevo, Turner, Williams 2014)

Outline of the talk

Random sample of municipalities from most parts of Colombia that are connected to national grid



- 73 municipalities in 15 departments
    - Mostly rural with small urban centers
- 13 distribution/retail firms
- Wide variety of climate conditions

Six years of billing data for all residential customers in the 73 municipalities

- Connection identifiers extracted for 2004 and used to track customers from 2003 through to the end of 2008
  - New connections after 2004 will not be in the data (though can be quantified using transformer data)
- Data obtained from all monthly bills over six years: address, transformer ID, meter type, billed consumption, price schedule category, other charges, overdue amounts, etc
- Monthly data also obtained for individual transformers: location, capacity, number of users, total consumption, number and length of outages, etc

Complete long-form census data available for everyone in the 73 municipalities

- Data includes dwelling characteristics, household demographics, and appliance holdings
- Matched to billing data for a subset of the bills (currently less than 10 percent)
- For now: use only in the analysis of the distributional effect of metering

About 7 percent of observations switch from being unmetered to metered during the sample period

Table: Summary statistics for household and billing types

Classification	Users	Number of Bills			
		Total	% M	% U	% E
Always metered	72,347	3,645,665	94.2	0.0	5.8
Always unmetered	8,751	323,292	0.0	96.4	3.6
Switch to metered	6,645	314,195	54.9	39.5	5.5

Why are meters being installed?

- Given the structure of electricity prices and subsidies in Colombia, firms on their own have little incentive to upgrade users and install meters
- Public Utilities Law of 1994: within 3 years every utility required to increase proportion of metered users to 95% of total
- By 2009: 8 out of 30 retailers had still not met this target
- Meter installation occurs gradually throughout the sample period: 1,300 in 2004, 1,848 in 2005, 1,823 in 2006, etc

Outline of the talk

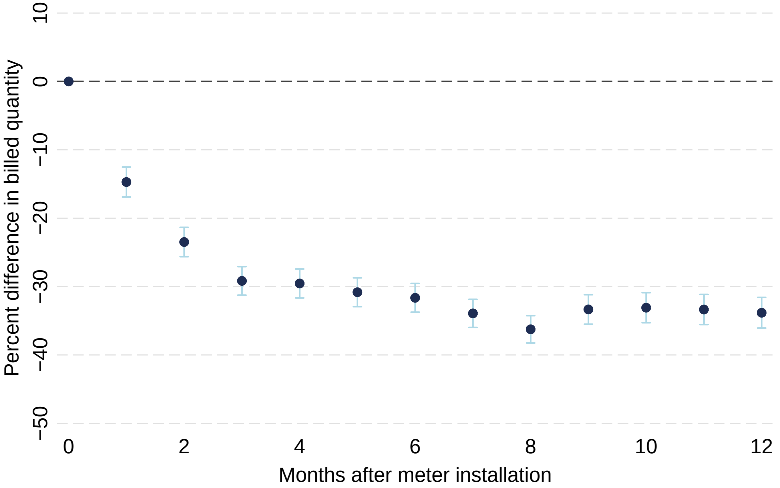
Framework for analyzing the change in metered quantity after meter installation

- Model log metered consumption in an event study framework

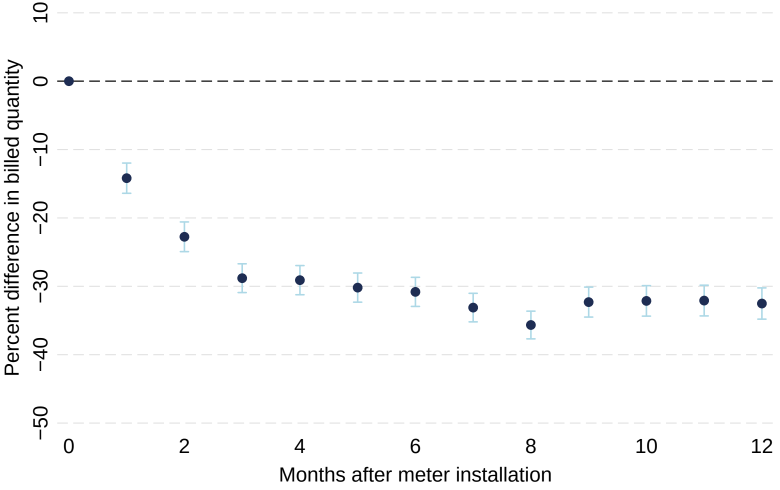
$$\log q_{irt} = \sum_{\tau=1}^{12} \kappa_\tau I(T_i + \tau = t) + \lambda_i + \theta_{rt} + \varepsilon_{it}$$

- q_{irt} is billed consumption in month-of-sample t for household i in region r
- T_i is the date of first metered bill received by household i (this is the excluded group in the sum)
- λ_i is a household fixed effect; θ_{rt} is region-specific month-of-sample effect

In the months after metering, consumption falls by more than 30 percent



Similar result seen using transformer×month-of-sample fixed effects (instead of household fixed effects)



Is the magnitude of the reduction in consumption after metering reasonable?

- Casillas and Kammens (2011): load fell by 28 percent following installation of individual meters in two non-grid-connected villages in Nicaragua
- USAID (2009): metering and billing in a *favela* in Sao Paulo led to a 23 percent reduction in consumption
- Munley et al (1990): randomized trial of sub-metering in apartment complex saw consumption fall by 24 percent for billed users
- New York Times (2010): electricity consumption for non-submetered apartments is 30 percent higher

Outline of the talk

Requirements for welfare analysis of the effects of metering

1. Estimates of consumer preferences
2. Estimates of marginal cost of electricity
3. Estimates of marginal external cost

Log-linear model of demand for electricity

- Assume price enters linearly in order to model consumption with price of zero (unmetered)

$$\log q_{irt} = \beta p_{it} + \lambda_i + \theta_{rt} + \varepsilon_{it}$$

- p_{it} is the marginal price of electricity faced by the household
  - Assume that this is zero for the first metered observation for the users who switch from unmetered to metered
- Complication for estimation: the price schedule is non-linear with an initial subsidized block targeted to lower-income neighborhoods
  - Instrument for marginal price using "height" and "width" of first block on price schedule

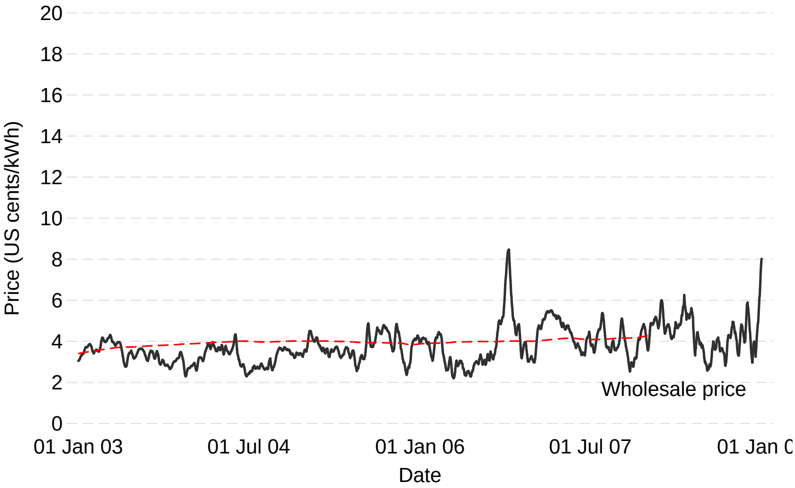
Targeted, quantity-based, fully-funded subsidy program for electricity in Colombia

- Increasing Block Tariff targeted to poor households
  - Level of subsidy (15%, 40%, 50%) for first block of usage depends on neighborhood classification
- Funded by 20% surcharge on businesses and rich households, topped up by government
- Utility firms reimbursed for subsidy component of bills
  - Even unmetered households and those without formal connection are covered by subsidy program

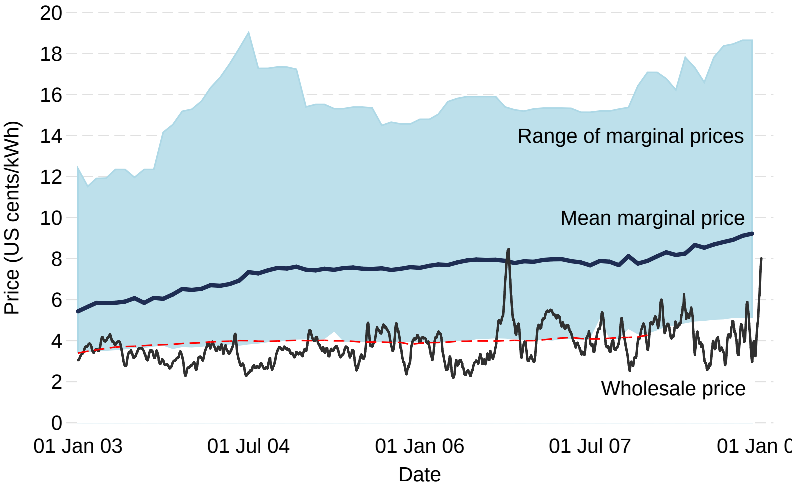
Mean price elasticity estimated to be -0.27 to -0.37

	(1)	(2)	(3)
Price (00 pesos/kWh)	0.662*	-0.211*	-0.156*
	(0.001)	(0.005)	(0.009)
I[Price = 0]	1.440*		0.127*
	(0.009)		(0.017)
Household FE	Y	Y	Y
Year-of-sample	Y	Y	Y
Instrument for price	.	Y	Y
Observations	3,605,640	3,605,640	3,605,640
No. of households	87,587	87,587	87,587
Implied elasticity	1.16	-0.37	-0.27

Wholesale electricity prices are relatively constant throughout the period under study



Marginal prices for the most subsidized users in the cheapest region are in line with marginal costs



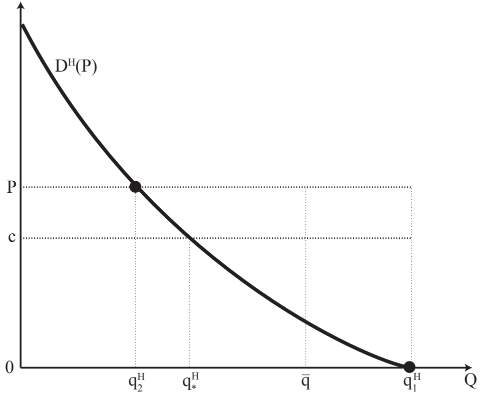
How to best calculate emissions factors in a hydro-dominated system?

- Calculations based on an emissions factor used for calculation of CDM credits for Colombian electricity projects: 0.27 kg/kWh
- Difficult to calculate marginal emissions factor for hydro-dominated systems (80 percent of generation in Colombia)
  - Hydro can follow load and "save emissions" for later periods
- Transmission is constrained out of major hydro-producing regions during high water years
- This leads to large spatial and temporal heterogeneity in emissions factors

Overview of welfare calculations

- Use demand estimates from model including household fixed effects
- For each household-month, predict consumption under three assumed prices:
  - Zero price (unmetered)
  - Mean marginal cost for month (efficient quantity)
  - Regulated price schedule (metered)
- For unmetered households, assume households are billed for the mean unmetered quantity for each firm
  - Aggregate quantity billed by each retailer equals aggregate (unmetered) consumption
- Repeat calculation for second demand model
- Report results as means for the subset of users that switched from unmetered to metered, in the month of the switch

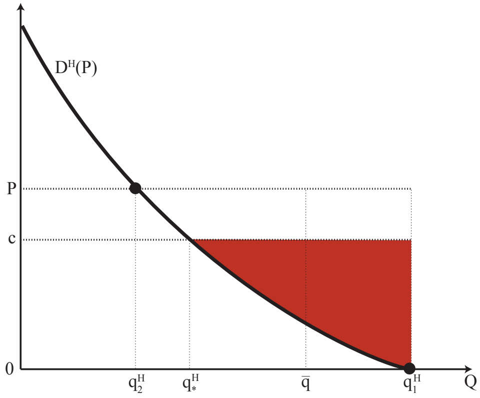
Mean consumption falls by 41 kWh/month after introduction of metering



Mean consumption per household-month

- Unmetered: 128 kWh
- Metered: 87 kWh

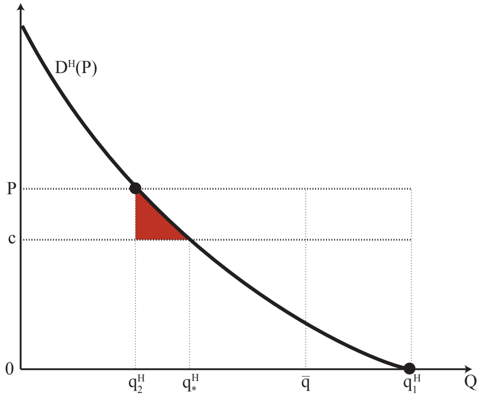
Metering eliminates deadweight loss from consumption at a price below marginal cost



Mean value of DWL per household-month

- Log-linear: \$0.40
- Discontinuous: \$0.84

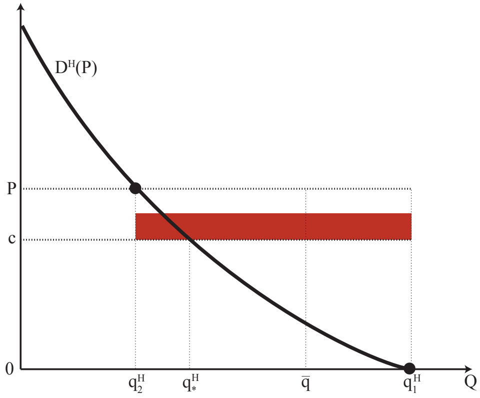
Metering creates deadweight loss from consumption at a price above marginal cost



Mean value of DWL per household-month

- Log-linear: \$0.27
- Discontinuous: \$0.18

Metering reduces electricity consumption and associated environmental externalities



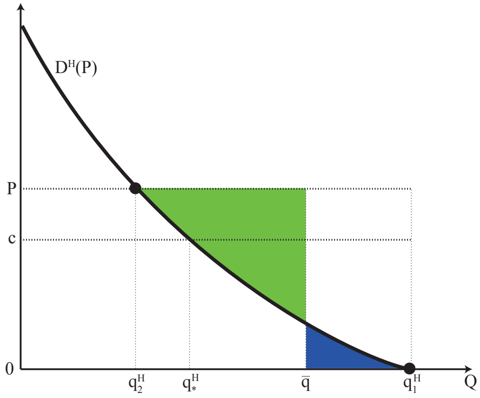
Mean reduction in external costs per household-month

- Log-linear: \$0.44
- Discontinuous: \$0.44

Overall welfare improvement from metering is relatively small

- For log-linear demand, mean increase in welfare is \$0.59 per household-month
- For demand with discontinuous jump at zero, mean increase in welfare is \$1.10 per household-month
- This calculation is before considering the capital and variable costs of metering
- After accounting for these costs, it is plausible that metering does not improve overall welfare for this group of low-consumption users

Most consumers better off from metering—even for some with higher unmetered consumption than they paid for



Mean increase in CS per household-month

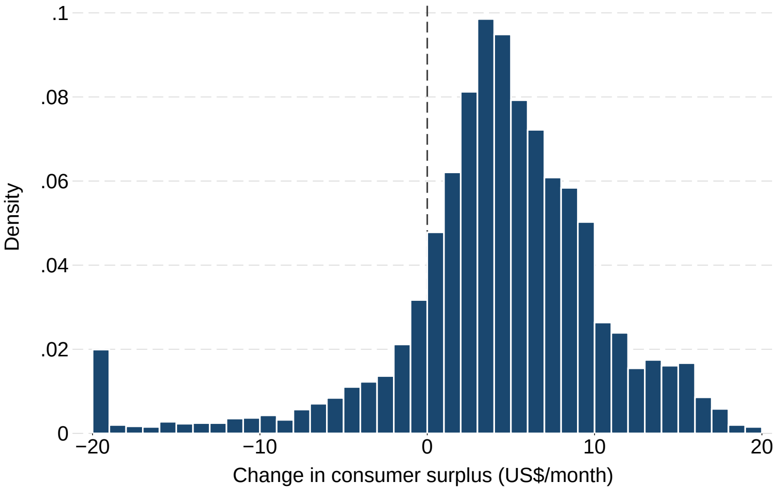
- Log-linear: \$3.06
- Discontinuous: \$3.72

Keeping the regulated price fixed, metering leaves the firm worse off

- Suppose we redo the calculation by increasing the regulated price to keep the firm whole (in each county)
- This increases the welfare loss from pricing above marginal cost: the change in welfare from metering becomes negative
- We can also adjust the subsidy percentages to keep the total subsidy transfer to each county constant
- Note that the subsidies reduce the welfare loss from average cost pricing (by bringing marginal price closer to marginal cost)
    - Important difference between subsidies for electricity/natural gas/water and other energy subsidies

Outline of the talk

Distribution of changes in consumer surplus from metering



Characteristics of the households who benefit or lose most from metering: consumption change

Table: Summary statistics for household and billing types

	Quartile of change in CS			
	1	2	3	4
Change in CS	-5.6	3.2	6.1	11.2
Consumption (kWh)				
Unmetered	263.2	92.2	75.3	90.6
Metered	166.2	63.6	52.4	65.0
Difference	-97.0	-28.6	-22.9	-25.4

Characteristics of the households who benefit or lose most from metering: household and dwelling size

Table: Summary statistics for household and billing types

	Quartile of change in CS			
	1	2	3	4
Monthly expenditure (USD)	315.37	365.92	297.57	223.70
Number of people	5.02	4.49	4.82	4.66
Number of rooms	3.64	3.04	2.82	2.75

Characteristics of the households who benefit or lose most from metering: mean appliance holdings

Table: Summary statistics for household and billing types

	Quartile of change in CS			
	1	2	3	4
Fridge	0.84	0.69	0.40	0.27
Washing machine	0.23	0.18	0.06	0.06
Fan	0.65	0.56	0.54	0.63
Air conditioner	0.03	0.01	0.00	0.00
Computer	0.06	0.00	0.01	0.02
Television	0.83	0.72	0.61	0.57

Outline of the talk

Why might metering be unpopular even though it benefits most consumers?

- 2.3 percent of users would see their bills more than double after metering
  - They have a strong incentive to resist installation of meters
- In comparison, although majority of households are better off, in most cases it is only by a small amount
- This has parallels with the resistance to real-time metering in developed countries

How could we make metering and infrastructure upgrade programs more politically feasible?

- Switching from unmetered to **marginal cost pricing** reduces the impact on the high-consumption households
  - Price per unit equal to marginal cost, fixed monthly fee to recover fixed costs
  - Use existing subsidy transfers to reduce the monthly fee for the subsidized users
- Low-consumption households are still better off (though not by as much)
- This "smoothes out" the distributional gains and losses from metering

What role should electricity subsidies play in encouraging metering and infrastructure programs?

- Note that the subsidies reduce the welfare loss from average cost pricing (by bringing marginal price closer to marginal cost)
  - Important difference between subsidies for electricity/natural gas/water and other energy subsidies
- Subsidies towards a fixed fee under a two-part tariff could also make such a tariff program politically feasible (greatly reduces number of people with negative surplus)
- Assume subsidy transfers to each county are fixed: do not consider cost of public funds used for the subsidy
  - Portion of the subsidy is raised by a tax on electricity usage of commercial users which will also be distortionary

Conclusion

- The efficiency effect of metering is ambiguous: it switches consumers from a price that is too low to a price that is too high
- Metering also eliminates the cross-subsidy from low to high users without meters
- I quantified these effects using six years of billing from Colombia
  - Metering reduced consumption by about 30 percent
  - But overall welfare improvements small (or even negative)
- Lower income households benefit most from metering under current price schedule
- Metering combined with alternative pricing structures may increase both welfare and political feasibility

Households in rural areas (in places with fewer existing meters) are less likely to have meters installed

Dependent variable: Eventually metered (=1). Municipality FE.

	(1)	(2)
High stratum (0/1)	0.029*	0.025
	(0.013)	(0.013)
Distance to town center (km)	-0.001*	-0.001
	(0.001)	(0.001)
Monthly outages	-0.008*	-0.007*
	(0.001)	(0.001)
Share of metered users		0.090*
		(0.022)
Observations	12,082	12,082

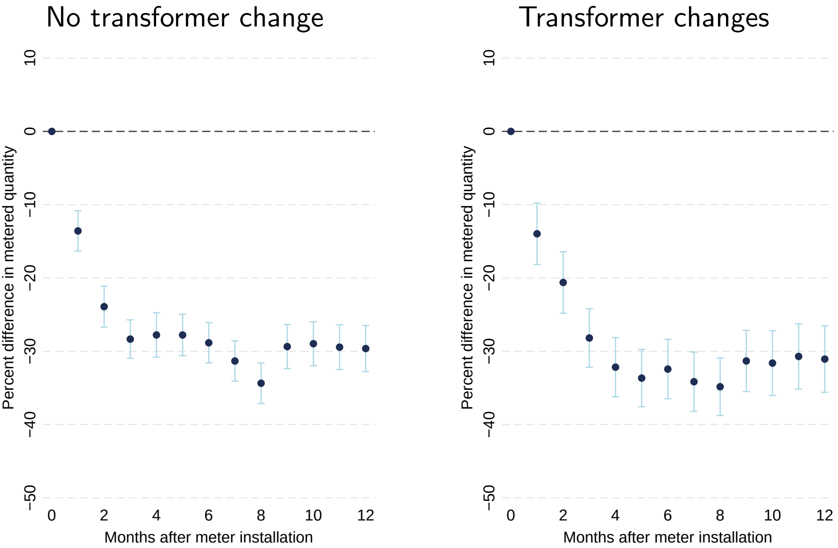
What else could be happening at the same time as meter installation?

- Metering is often part of a bundle of changes:
  - Upgrading of distribution network
  - Change in enforcement of bill payment
- Are the observed changes in consumption due to metering or due to other changes occurring at the same time?

At least a quarter of meter installations occur as part of distribution network upgrades

- Change in transformer ID: 23% of metering events
- Change in transformer capacity: 19% of metering events (12% increased capacity, 7% decreased capacity)
- Compare consumption after metering for consumers with and without these transformer changes

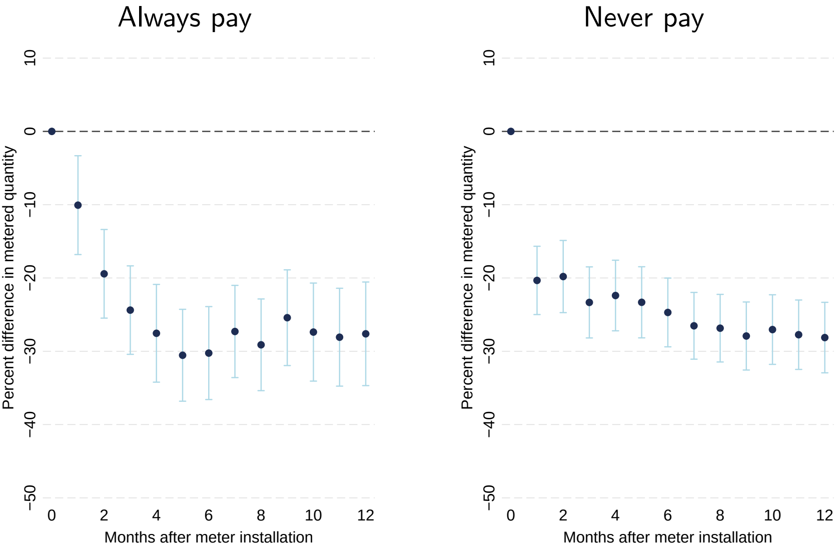
Slightly greater reduction in consumption when metering occurs with distribution upgrades



Nearly two thirds of the unmetered users who were upgraded had no outstanding balance

- 62% of the metered installations had no (or low) outstanding bill balances during the previous six months
  - 55% paid their bill both before and after being metered
  - 7% paid their bill before but not after being metered (mean outstanding balance greater than $1)
  - 29% did not pay their bill either before or after being metered
  - 9% did not pay their bill before, but paid after
- Compare the consumption changes for “always paying” and “never paying” consumers

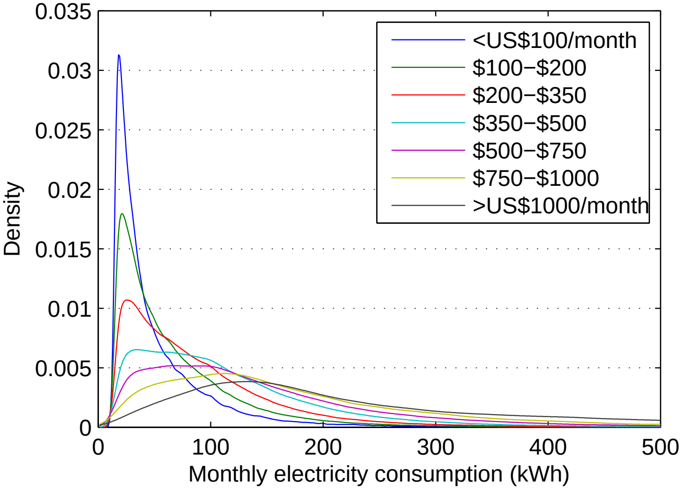
Long-term reduction in consumption similar for both groups



Match census data (including “income”) to electricity consumption data

- Key consideration for distributional analysis: correlation between electricity consumption and income
- Household level data can be matched to billing data for a subset of households
- For these households: estimate model of electricity consumption on observables (income, household and dwelling size, appliance ownership)
- Use this model to predict electricity consumption for all households
- Match households to electricity bills using within-county rank order of predicted and mean (actual) consumption

Considerable heterogeneity in electricity consumption by income bracket



Semi-log demand specification in order to incorporate zero prices

- Indirect utility function (corresponding to semi-log demand) given by:

$$V_i = \frac{1}{\delta}\exp(-\delta y_i) - \frac{1}{\beta}\exp(-\beta p_i + \eta_i)$$

- Assume value for δ
- Estimate β using within-household variation in prices (including switching from unmetered to metered)