Retail Electricity Pricing in Colombia and the Efficient Deployment of Distributed Generation

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We study the structure of residential electricity tariffs in Colombia and explore the potential for tariff reform.

1. What is the design of the existing regulated tariff structure for residential electricity users in Colombia?

2. How large are the short-term and long-term inefficiencies of the existing residential tariffs?
   - Short-term: electricity consumption
   - Long-term: adoption of EVs, solar, energy efficiency, storage

3. What would be an alternative pricing mechanism that limits incentives for inefficient behavior, while still protecting low-income households?
Structure of Existing Electricity Tariffs
Energy regulator CREG sets base tariffs for each distribution company, comprising six individual components.
Colombia uses a targeted increasing block tariff to reduce the cost of electricity for low-income households

- Increasing Block Tariff targeted to low-income neighborhoods
  - Level of subsidy for first block depends on neighborhood classification
- Funded by 20% surcharge on businesses and high-income neighborhoods, topped up by government
- Utility firms reimbursed for subsidy component of bills
Variation across firms in subsidy amount: discount on first block in 50 to 60% for Stratum 1, 40 to 50% for Stratum 2
Number of households classified in Strata 1 and 2 has increased from 4.5 million to more than 8 million over past 15 years.
Aggregate billed consumption has stayed fairly flat for Strata 5 and 6, in contrast to large increase for subsidized households.
Deficit in the cross-subsidy program for electricity tariffs has widened to about 0.15% of GDP.
Inefficiency in the existing tariff structure
Summary of the approach used in the analysis

- Data comes from the National Household Income and Expenditure Survey, conducted between July 2016 and July 2017
- Match households to distributors and the corresponding tariff for the previous month
- Impute consumption in kWh from the reported expenditure on most recent bill
- Calibrate household-level demand function for electricity based on assumed elasticity (-0.15 or -0.3)
- Use this demand to (i) calculate welfare loss and (ii) simulate alternative tariffs
Most households in Colombia consume less than 250 kWh per month.
Marginal price for electricity consumption varies between 6 US cents and 22 US cents per kWh
How does the marginal price faced by households compare to the marginal cost of providing electricity?

- We consider four components of marginal cost:
  - Generation cost (from wholesale market price)
  - Average cost of transmission restrictions
  - Marginal transmission and distribution losses
  - Value of average carbon dioxide emissions from generation

- Note that we do not include local pollution costs
Difference of more than US$20/MWh in the mean price between peak hours and off-peak hours
Weekly average generation prices were highest at the start of the sample period and declined to US$25/MWh by mid-2017.
Marginal (not average) transmission and distribution losses can reach 20% in some hours.
Higher distribution and transmission losses during peak hours widen difference between peak and off-peak marginal costs.
Marginal costs decline over the year that we study, reflecting the lower generation costs in the wholesale market.
Most households face a marginal price above marginal cost, though a minority face a price that is too low.
We calculate, for each household, the welfare loss that results from setting a price that is higher or lower than marginal cost.
Deadweight loss from non-marginal cost pricing is largest for Strata 5 and 6 households, who face a price that is too high.

<table>
<thead>
<tr>
<th>Stratum</th>
<th>DWL (US$/month)</th>
<th>DWL (% of bill)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$0.50</td>
<td>4.1%</td>
</tr>
<tr>
<td>2</td>
<td>$0.53</td>
<td>3.5%</td>
</tr>
<tr>
<td>3</td>
<td>$0.73</td>
<td>3.3%</td>
</tr>
<tr>
<td>4</td>
<td>$1.09</td>
<td>3.4%</td>
</tr>
<tr>
<td>5</td>
<td>$1.77</td>
<td>5.0%</td>
</tr>
<tr>
<td>6</td>
<td>$2.62</td>
<td>4.7%</td>
</tr>
</tbody>
</table>

Note: results assume linear electricity demand with a price elasticity of -0.30.
Incentives for Installation of Residential Solar
We study the interaction of the existing tariffs with the new 2018 regulations for distributed generation

- High marginal prices create an incentive for households to install their own generation (rooftop solar) as a substitute
- Users who contribute the most to fixed cost recovery will leave first... the utility death spiral
- CREG Resolution 30/2018 specifies how to calculate bills for households with rooftop solar
  - Generation can offset consumption during the billing cycle ("net metering")
  - BUT generation sent back to the grid will be charged the retail charge component of the tariff
  - Excess generation will be paid the mean wholesale price
Combine household data with information on solar potential, load and generation profiles, and tariff design

- Geographic data on solar resource
- Electricity tariffs in each distribution area
- Household survey data with imputed electricity usage
Solar radiation (and potential solar generation) peaks just after midday with limited variation across locations.
Electricity demand by regulated users peaks in early evening for most distribution networks
We combine the generation and consumption data to simulate the electricity bills for households who install rooftop solar.
How do we simulate the potential adoption of rooftop solar, for the existing and counterfactual efficient tariffs?

- Focus on owner-occupied houses with concrete or brick walls (about 31% of all households)
- Impute annual electricity consumption from survey data
- Estimate solar generation based on geographical location, assuming 2 kW solar installation
- Calculate new electricity bill for rooftop solar, based on CREG 30/2018 regulation
- Compare discounted value of bill savings to initial price of solar
  - Assume alternative values for discount rate and panel price
What proportion of households in Colombia would find it optimal to install solar, under the existing electricity tariffs?
Under counterfactual efficient electricity tariff, rooftop solar adoption would be lower for high panel costs.
What will be the effect of the adoption of rooftop solar on the net revenue of distribution companies in Colombia?

- For any discount rate and panel price, we know the share of households served by each utility for which adopting rooftop solar will be optimal.
- Assuming the tariffs do not change, we calculate the change in the net revenue (sales less wholesale generation purchases) of each utility.
  - Utility revenue for the customers with rooftop solar is based on CREG 30/2018 resolution.
- Under an efficient tariff, there would be no change in utility revenue from customer adoption of rooftop solar.
Under existing tariffs, with 5% discount rate and $2000/kW panel price, the “revenue-at-risk” from solar is about 11%
There is a lot of heterogeneity across distribution companies: areas with better solar potential are most at risk.
There is a lot of heterogeneity across distribution companies: areas with higher existing tariffs are most at risk.
Analysis of Alternative Retail Pricing Schemes
What would be an economically efficient retail electricity tariff look like?

- Efficient tariff would charge each consumer the hourly marginal cost of their consumption
  - This price would differ from hour-to-hour and year-to-year based on demand and supply conditions
  - Such a price would eliminate the deadweight loss from mispricing
  - For this exercise: we assume that consumers pay a price that varies monthly, based on the mean of the hourly marginal costs

- Remaining cost shortfall would be recovered through a monthly fixed charge

- Fixed charge could vary by customer type to protect low-income households from high bills (fixed charge may even be negative)
What is the total amount that we need to recover through the fixed charge on households?

- Assume that existing base tariff has been set correctly to recover each distribution firm’s total costs
  - This will include variable, fixed, and capital costs
  - Keep existing cost allocation between residential and non-residential
- Calculate total revenue from each firm’s customers under the existing tariff
- Deduct variable cost of generation (including losses and restrictions)
- Remaining amount is the amount that needs to be recovered from households under the new tariff
Fixed and capital costs to be recovered from households vary from $10 to $25 per household per month.
Some fixed costs can be recovered through the carbon tax, others through the existing subsidy transfer.
First counterfactual tariff: keep existing subsidy transfers and set the same fixed charge for all households
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Second counterfactual tariff: set fixed charge to zero for households receiving government health insurance
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Final counterfactual tariff: can we use household characteristics to better target the fixed charge?

- Ideally: want to recover more fixed costs from those households with greater willingness to pay for electricity
- But: cannot set fixed charge based on the observed consumption
  - This would no longer be a fixed charge!
- Instead: use the predicted consumption of each household, based on observable characteristics, to determine allocation of fixed costs
Predict electricity consumption for a household using observable characteristics of its dwelling

- Set fixed charge to zero for households receiving the subsidized health insurance
- Regress $Q^2$ on household characteristics and use these to predict household $Q^2$
- Allocate fixed costs among remaining households based on their share of predicted $Q^2$ out of the total for that distribution utility
- Households with lower predicted consumption, based on their dwelling or household characteristics, pay a lower fixed charge
  - Net fixed charge may be negative for some households
Under this counterfactual tariff, all income deciles would be better off, on average, than under the existing tariff.
Is this a plausible way to design an electricity tariff and set charges for each household?

- Utility customer databases are already linked to catastral database
Is this a plausible way to design an electricity tariff and set charges for each household?

- Household stratification should (in theory) be based upon dwelling characteristics in the catastral database
- Quantity of first block varies based on altitude—roughly reflecting differences in consumption
- Subsidy amount on first block is set in an arbitrary fashion
- Proposed tariff would provide a consistent and non-arbitrary approach to pricing and redistribution
  - Based on data that has already been collected and is available to distribution utilities
What about the fiscal sustainability of this type of tariff structure?

- Under current tariff, subsidy cost has increased over time
  - More and more subsidized households, higher and higher subsidized consumption
- Potential for new tariff to break this cycle
  - Explicit link between transfer amount and predicted consumption
  - As households become richer, and consumption increases, subsidy transfers will automatically fall instead of rise
Conclusion
Inefficiencies in the existing electricity prices in Colombia could be reduced by a tariff reform

- Some households pay less than marginal cost, some households pay more than three times marginal cost
- Using a two-part tariff with a fixed charge could eliminate the welfare loss from this mispricing
- This tariff would provide economically efficient incentives for adoption of solar, electric vehicles, and energy efficiency
- Varying the fixed charge across households, based on predicted consumption, could leave low-income households better off on average after the tariff reform