The distributional impacts of residential electricity rate design

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What we will talk about today:

1. Do fixed charges harm low income customers?
   • *Distributional outcomes are a design choice, not a fact of efficient charges*

2. What is the cost of inaction?
   • *Efficient tariffs create substantial consumer surplus benefits*
   • *Rooftop solar may dramatically increase rates for low-income customers, making flat tariffs worse than efficient tariffs*
Do fixed charges harm low income customers?
To evaluate alternative tariffs we use metering data from Chicago, USA

- 100,170 anonymized households
- Consumption January-December 2016
- 30-minute smart meter readings
- Housing type
- Heating type
- Geographic data: 9-digit zip code
We developed and analyzed five innovative rate designs – all rates were designed to ensure ComEd recovered all network and policy costs.
We map consumption data to Census data on income and other key socioeconomic variables

- Geographically distinguished at Census Block Group (CBG) level
- Distribution of household incomes and other socioeconomic variables by CBG
  - Nine discrete income classes
  - Other socioeconomic variables on race, employment, education, etc.
Increasing fixed charges in a uniform fashion increases expenditures for low-income customers, but moving to real-time prices does not.

<table>
<thead>
<tr>
<th>Tariff changes</th>
<th>Effects on bills for low-income customers</th>
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<tbody>
<tr>
<td>Increased granularity</td>
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<tr>
<td>Reducing volumetric &amp; increasing fixed network charges</td>
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Objective: Maintain overall system savings while avoiding undesired social effects

Idea: Differentiating fixed charges according to certain customer criteria

Two proposals for fixed charge design:
1. Customer demand characteristics
2. Observed customer income

Progressive fixed charges can mitigate undesirable distributional outcomes while maintain consumer surplus benefits of efficient rates
Many customer demand characteristics correlate more strongly with income than does total consumption


### Customer demand characteristics by income, indexed to low-income customers

<table>
<thead>
<tr>
<th>Income ($1,000 USD)</th>
<th>Average Monthly Consumption</th>
<th>Annual Peak Demand</th>
<th>Peak-To-Off Peak Ratio</th>
<th>May Peak Demand</th>
<th>June Peak Demand</th>
<th>July Peak Demand</th>
<th>August Peak Demand</th>
<th>Consumption: 5:30PM-6:00PM</th>
<th>Consumption: 6:00PM-6:30PM</th>
<th>Consumption: 6:30PM-7:00PM</th>
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<tbody>
<tr>
<td>&lt;$15</td>
<td>1.00</td>
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<td>$15 – $25</td>
<td>1.07</td>
<td>1.03</td>
<td>0.95</td>
<td>1.05</td>
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<td>1.08</td>
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<tr>
<td>$25 – $35</td>
<td>1.10</td>
<td>1.06</td>
<td>0.95</td>
<td>1.09</td>
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<tr>
<td>$35 – $50</td>
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<td>1.09</td>
<td>0.95</td>
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<td>1.13</td>
<td>1.12</td>
<td>1.15</td>
<td>1.15</td>
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<tr>
<td>$50 – $75</td>
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<td>1.13</td>
<td>0.97</td>
<td>1.17</td>
<td>1.17</td>
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<td>0.97</td>
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<td>1.23</td>
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<td>0.97</td>
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<td>1.26</td>
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<tr>
<td>$125 – $150</td>
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<td>&gt;$150</td>
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<td>1.32</td>
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<td>1.32</td>
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Fixed charges based on customer demand characteristics that correlate strongly with income can be far more progressive than uniform fixed charges.

- Feasible with existing and available data
- Risk of Type 1 and Type 2 errors
- Inefficient incentives when changed frequently

With smart meter data and available customer demographic data, it is possible to target rebates or incentives to those who need them most.

- ✔ No Type 1 and Type 2 errors
- ✔ Granular control over distributional effects
-❗ Additional sensitive customer data required

Protections provided to low-income customers can be designed to have minimal bill impacts on other customers.

Progressive hedges protect low-income customers at minimal cost to non-low-income customers.
What is the cost of inaction?
Efficient rate designs increase consumer surplus for nearly all customer segments at very low levels of price elasticity.

Changes in consumer surplus relative to the flat (default) tariff for customers with <$15,000 per year in income.

Solar PV adopters tend to be wealthy – Median solar adopters are >50% wealthier than the average household, and more than 80% of solar adopters are in the top three income quintiles.

Income trends of PV adopters, 2000 - 2016

Low-income solar installations have grown since 2008, but are the same as in the year 2000 – The demographics are changing over time... sort of...

Solar installations in the top three income quintiles (“top 60%”) versus the bottom two income quintiles (“bottom 40%”), in 2000, 2008, and 2016

Under tariffs with volumetric residual cost recovery, distributed solar is likely to lower bills for high income customers at the expense of low income customers.

Changes in expenditures by income quintile
Flat, volumetric tariff

Holding fixed charges constant, the volumetric charge for residual cost recovery roughly triples as solar PV penetration increases.

Changes in volumetric charges for residual cost recovery
Flat, volumetric tariff

Within and across income classes, solar adopters benefit at the expense of non-adopters.

Changes in annual expenditures by income: Adopters vs. Non-Adopters

Flat, volumetric tariff

Efficient tariffs eliminate cost shifts, enabling energy cost savings and average savings across income quintiles

Changes in expenditures by income quintile
Real-time price tariff with fixed residual cost recovery

Efficient tariffs eliminate cost shifts, enabling energy cost savings and average savings across income quintiles

Changes in annual expenditures by income: Adopters vs. Non-Adopters
Real-time price tariff with fixed residual cost recovery

Low-income expenditures may be lower under a fixed-charge tariff at moderate rooftop solar penetrations – This observation contradicts common rate design logic.

Thank you
sburger@mit.edu
We create and evaluate five innovative tariffs designs – All tariffs are designed to recover all costs for the utility

<table>
<thead>
<tr>
<th>Cost Category</th>
<th>Costs</th>
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<tbody>
<tr>
<td>Energy</td>
<td></td>
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<tr>
<td>Network</td>
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<td>Policy</td>
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<tr>
<th>Default Flat</th>
<th>Flat NCDC</th>
<th>CPP-10</th>
<th>RTP-Vol</th>
<th>RTP-CCC</th>
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The challenge of inefficient rates
Plenty of goods are unevenly distributed in society – Why should we care about DER ownership?

**Boat ownership rate by household income in the U.S., 2013**

- Under $50k: 5.1%
- $50k to $75k: 6.7%
- $75k to $100k: 8.3%
- Over $100k: 9.4%

Under inefficient tariffs, DER adoption reduces revenues more than it reduces system costs – as revenue for existing network assets and policies fall, the utility has to recover these “residual” costs by raising rates.
The quantity of residual costs is highly uncertain – If residual costs are high, the potential for cost shifting is also high.
Efficient prices reflect the marginal cost of using networks – If networks are constrained, network revenues rise.

Differences in marginal prices across networks result in network revenues, reducing residual costs.

$80/\text{MWh}$

$40/\text{MWh}$
The distributional impacts of PV adoption
Sensitivities bound our estimates of distributional impacts – I model a low- and high-impact case, providing a broad view of the potential distributional impacts of PV adoption

Networks have significant slack, and all networks costs are “residual”

Networks are constrained, and all distribution costs are marginal

Sensitivities bound our estimates of distributional impacts – I model a low- and high-impact case, providing a broad view of the potential distributional impacts of PV adoption

Networks have significant slack, and all networks costs are “residual”

Peak loading on the circuit is only 15% of the circuit’s rated capacity. Peak demand reduction has no immediate network cost reduction value

Source: National Grid, N.D. Available online: http://ngrid.maps.arcgis.com/apps/MapSeries/index.html?appid=4c8cf75800b469abb8febca4d5dab59&folderid=8ffa8a74b834613a04c19a68eefb43b
Sensitivities bound our estimates of distributional impacts – I model a low- and high-impact case, providing a broad view of the potential distributional impacts of PV adoption.

Networks are constrained, and all distribution costs are marginal.

Peak loading is 95% of rated capacity & growing. Peak demand reductions could eliminate or delay the need to invest in upgrading this circuit.

Source: National Grid, N.D. Available online: http://ngrid.maps.arcgis.com/apps/MapSeries/index.html?appid=4c8cfd75800b469abb8fe6bca4d5da59&folderid=8ffa8a74b834613a04c19a68e6f6b43b
Our hypothesis is that the majority of distribution feeders are unconstrained – evidence from CA indicates that solar PV may not have ubiquitous distribution value.

Capacity benefit of distributed solar PV in PG&E’s network

- $0 per kW per year
- $10-60 per kW per year
- >$60 per kW per year

The distributional impacts of PV adoption: Zero marginal network cost cases
ComEd’s default tariff is volumetric, and time- and location-invariant – such “flat” tariffs are common across the U.S.

$$ComEd\ Default\ Tariff = p_{i,t,\phi}^e + p_{i,t,\phi}^{ce} + p_{i,t,\phi}^r + p_{i,t,\phi}^{cp} + F_{i,\phi}$$

- Energy: ~$0.05/kWh
- Residual costs: ~$0/kWh
- Residual costs: ~$0/kWh
- Residual costs: ~$10/month

I construct an “efficient” tariff with a real-time price, a “coincident capacity charge” for “marginal” generation capacity costs, and a fixed charge for residual cost recovery.

\[
RTP - CCC = p_{i,t,\phi}^e + p_{i,t,\phi}^{ccc} + p_{i,t,\phi}^r + p_{i,t,\phi}^{cp} + F_{i,\phi}
\]

- Energy: \(~\$0.03/kWh\)
- “Marginal” generation capacity costs: \(~\$1/kW\)
- Residual costs CCC: \(~\$39/month\)
- $0/kWh
- $0/kWh

Note: I model the possibility of a non-zero marginal network charges in the next section.
The distributional impacts of PV adoption: Marginal network cost cases
The potential “value of D” is smaller than the average residual cost shift – Flat tariffs are likely creating a cost shift with today’s rates.

Value of distribution network deferral and distribution network loss reduction versus the volumetric tariff residual cost shift

I construct an “efficient” tariff with a real-time price, a “coincident capacity charge” for “marginal” generation capacity costs, a “coincident peak” charge for “marginal” network costs, and a fixed charge for residual cost recovery.

\[ RTP - CCC - CP = p^e_{i,t,\phi} + p^{ccc}_{i,t,\phi} + p^r_{i,t,\phi} + p^{cp}_{i,t,\phi} + F^r_{i,\phi} \]

- **Energy**: $0.03/kWh
- **“Marginal” generation capacity costs**: $1/kW
- **“Marginal” network costs**: $0 - 0.55/kW
- **Residual costs**: $15/month

At low penetrations, rooftop PV may decrease future network costs, but at high penetrations, rooftop PV increases network costs.

Estimation of network capacity value of distributed PV

Similarly, rooftop solar likely reduces marginal losses at low penetrations, but drives losses at high penetrations.

Efficient tariffs eliminate cost shifts, enabling energy cost savings and average savings across income quintiles

Changes in expenditures by income quintile
Real-time price tariff, fixed residual cost recovery, and marginal network costs

Efficient tariffs eliminate cost shifts, enabling energy cost savings and average savings across income quintiles

Changes in annual expenditures by income: Adopters vs. Non-Adopters
Real-time price tariff, fixed residual cost recovery, and marginal network costs

Low-income expenditures are on average lower under an efficient tariff with marginal network costs – efficiency and equity need not be in conflict.

Changes in expenditures by income quintile
Real-time price tariff, fixed residual cost recovery, marginal network cost vs. Flat tariff