The distributional impacts of residential electricity rate design

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MIT Energy Initiative

Harvard Electricity Policy Group
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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

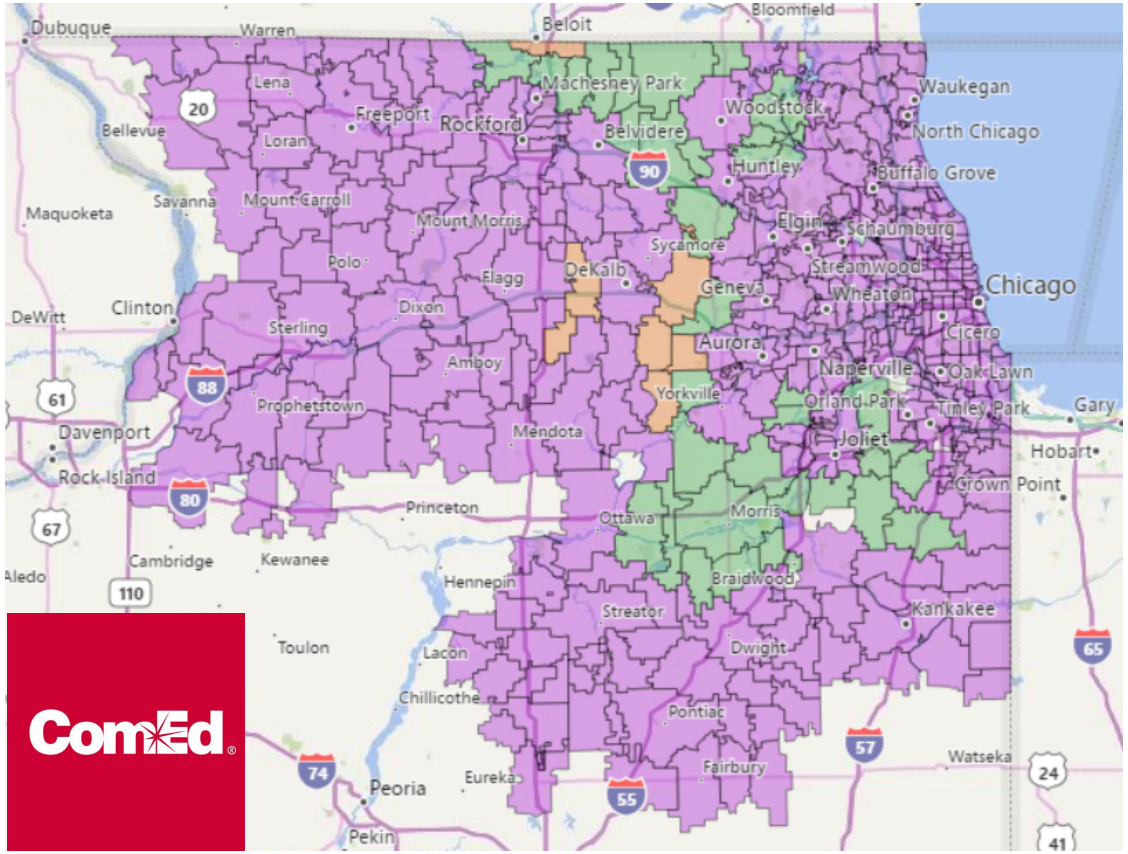
Consumption January-December 2016

30-minute smart meter readings

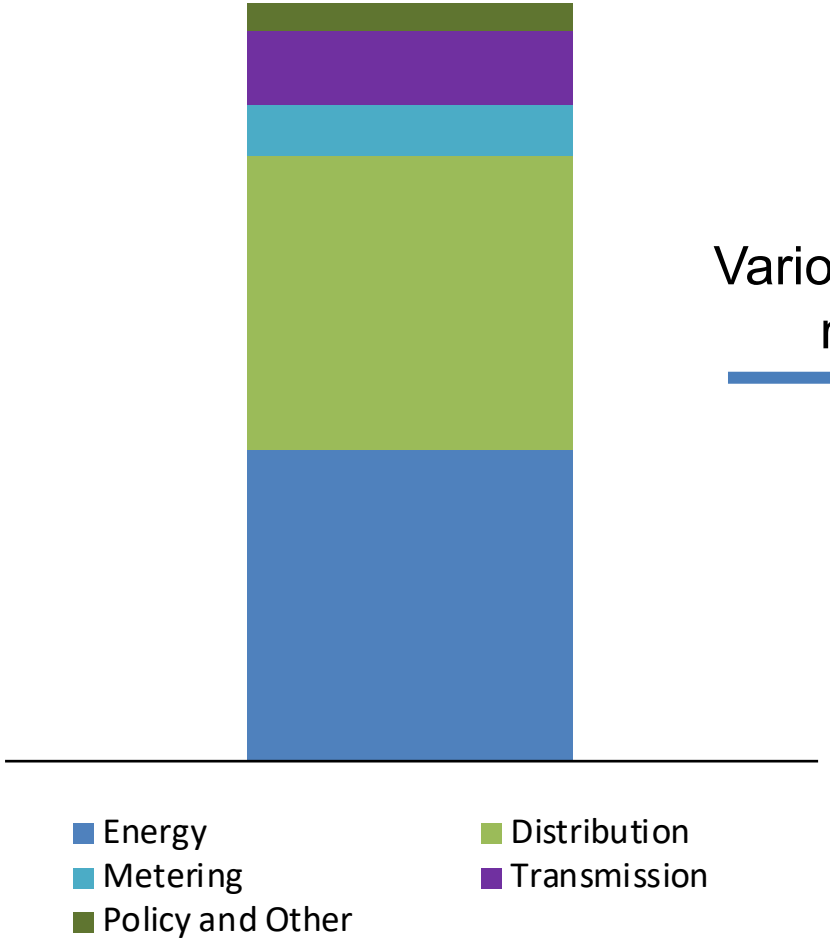
Housing type

Heating type

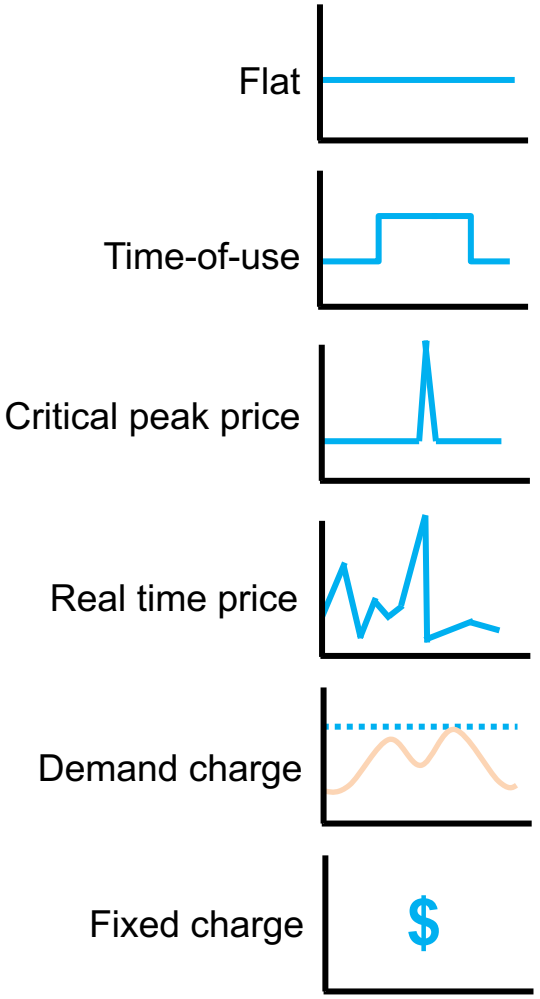
Geographic data: *9-digit zip code*



We developed and analyzed five innovative rate designs – all rates were designed to ensure ComEd recovered all network and policy costs



Various allocation methods

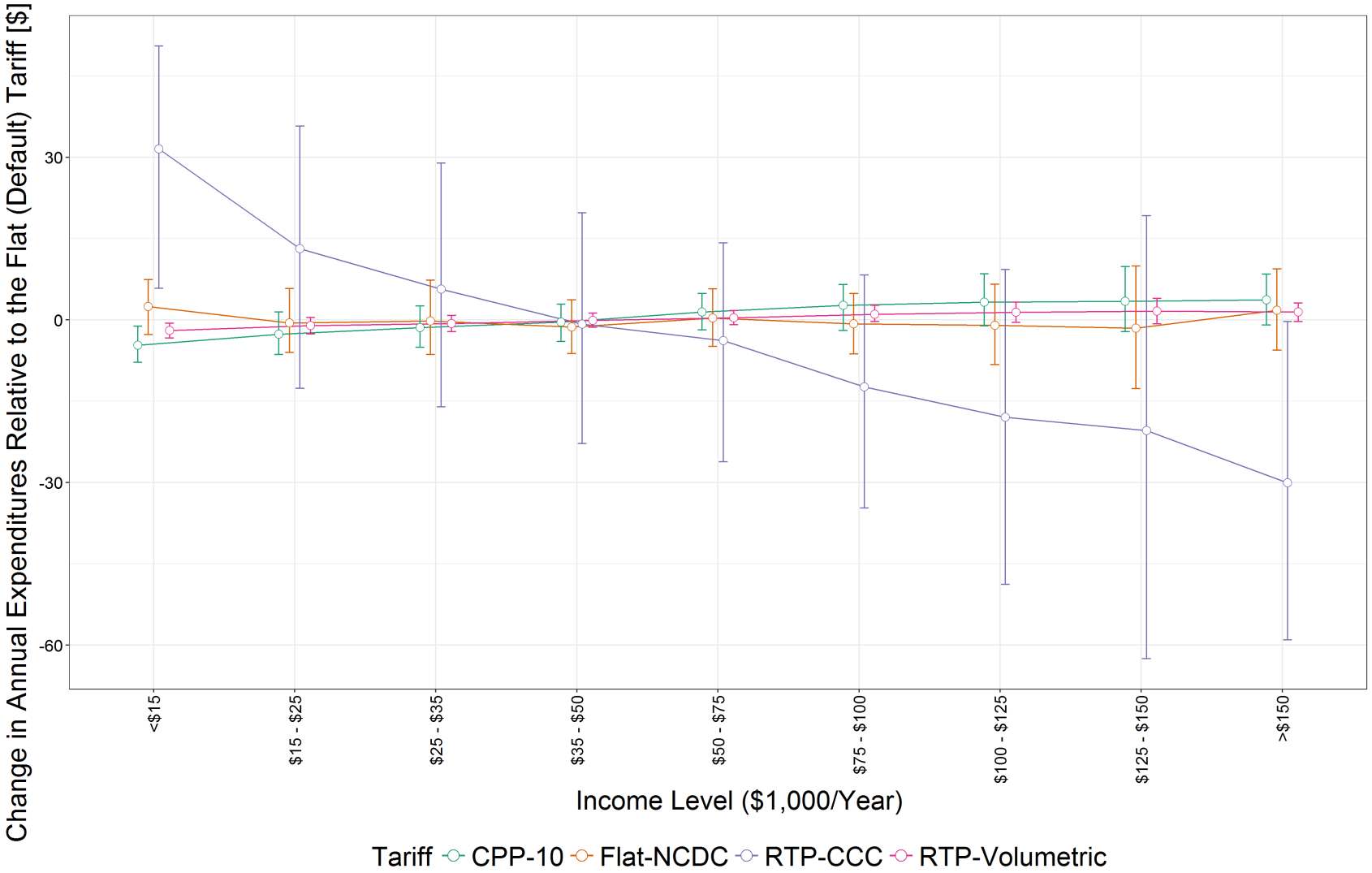


We map consumption data to Census data on income and other key socioeconomic variables

- 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

Tariff changes	Effects on bills for low-income customers
Increased granularity	↘
Reducing volumetric & increasing fixed network charges	↑
Demand charges	~



Source: Burger et al., 2019. The Efficiency and Distributional Effects of Alternative Residential Electricity Rate Designs. *The Energy Journal.* Forthcoming.

Progressive fixed charges can mitigate undesirable distributional outcomes while maintain consumer surplus benefits of efficient rates

- 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

Many customer demand characteristics correlate more strongly with income than does total consumption

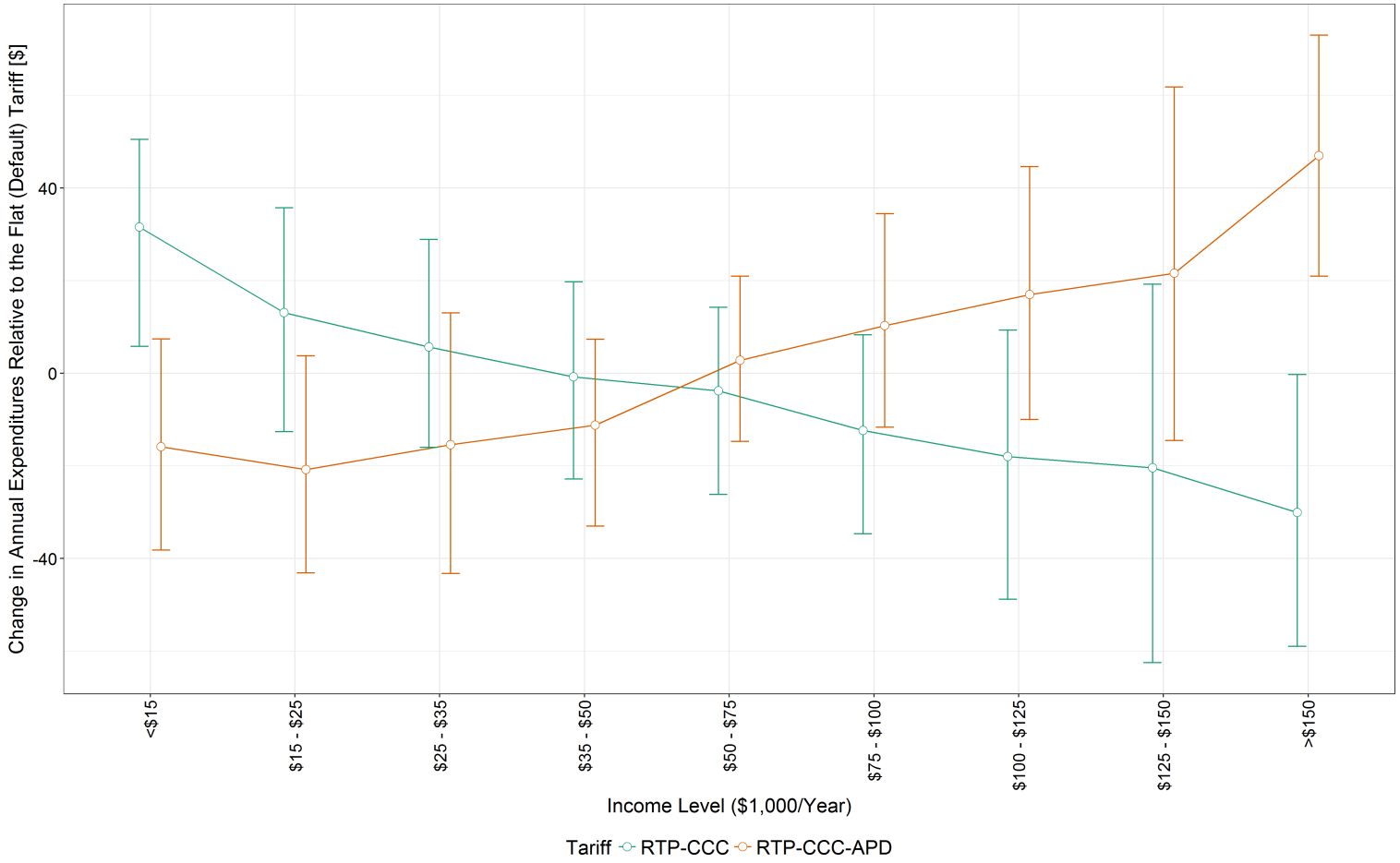
Customer demand characterstics by income, indexed to low-income customers

Income ($1,000 USD)	Average Monthly Consumption	Annual Peak Demand	Peak-To-Off-Peak Ratio	May Peak Demand	June Peak Demand	July Peak Demand	August Peak Demand	Consumption: 5:30PM-6:00PM	Consumption: 6:00PM-6:30PM	Consumption: 6:30PM-7:00PM
<$15	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
$15 – $25	1.07	1.03	0.95	1.05	1.06	1.05	1.05	1.08	1.08	1.08
$25 – $35	1.10	1.06	0.95	1.09	1.09	1.09	1.09	1.12	1.12	1.11
$35 – $50	1.12	1.09	0.95	1.12	1.13	1.13	1.12	1.15	1.15	1.15
$50 – $75	1.14	1.13	0.97	1.17	1.17	1.17	1.16	1.18	1.18	1.18
$75 – $100	1.18	1.17	0.97	1.22	1.22	1.22	1.21	1.23	1.23	1.23
$100 – $125	1.20	1.19	0.97	1.25	1.26	1.25	1.25	1.26	1.26	1.26
$125 – $150	1.21	1.21	0.98	1.27	1.28	1.27	1.27	1.28	1.28	1.27
>$150	1.25	1.29	1.02	1.36	1.35	1.34	1.33	1.32	1.33	1.32

Source: Burger et al., 2019. The Efficiency and Distributional Effects of Alternative Residential Electricity Rate Designs. *The Energy Journal.* Forthcoming.

Fixed charges based on customer demand characteristics that correlate strongly with income can be far more progressive than uniform fixed charges

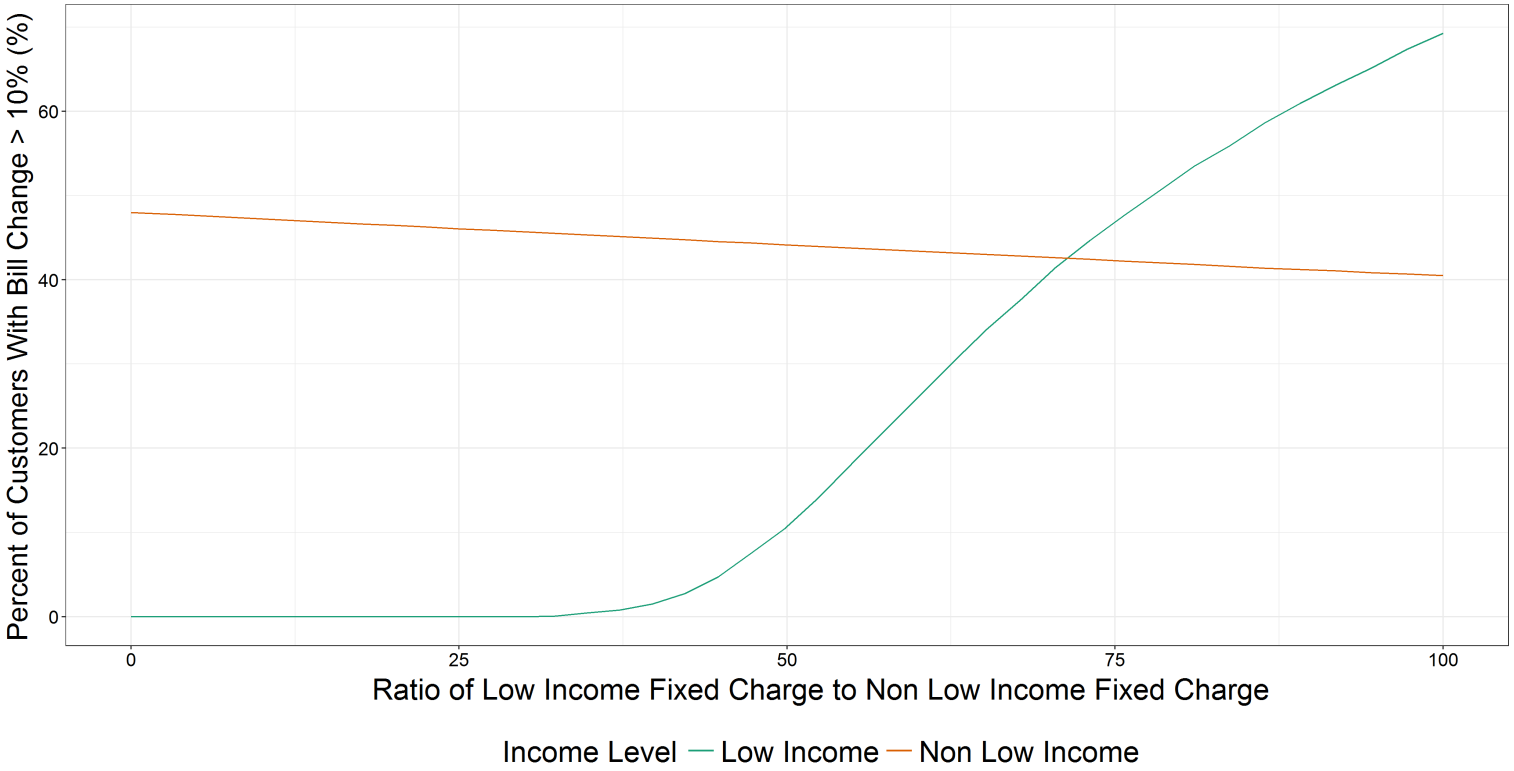
- Feasible with existing and available data
- Risk of Type 1 and Type 2 errors
- Inefficient incentives when changed frequently



Source: Burger et al., 2019. The Efficiency and Distributional Effects of Alternative Residential Electricity Rate Designs. *The Energy Journal.* Forthcoming.

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

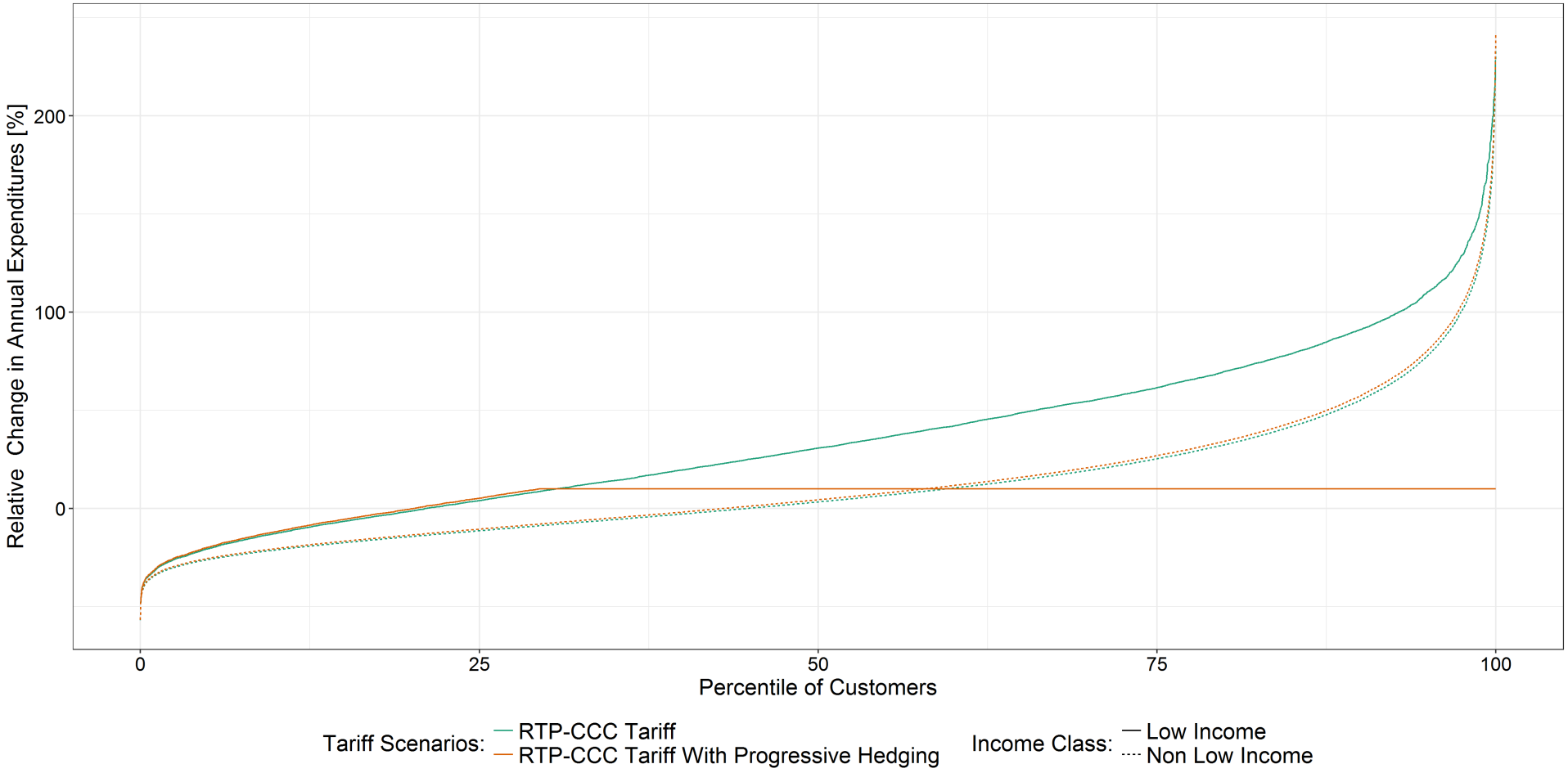
- No Type 1 and Type 2 errors
- Granular control over distributional effects
- Additional sensitive customer data required



Source: Burger et al., 2019. The Efficiency and Distributional Effects of Alternative Residential Electricity Rate Designs. *The Energy Journal.* Forthcoming.

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

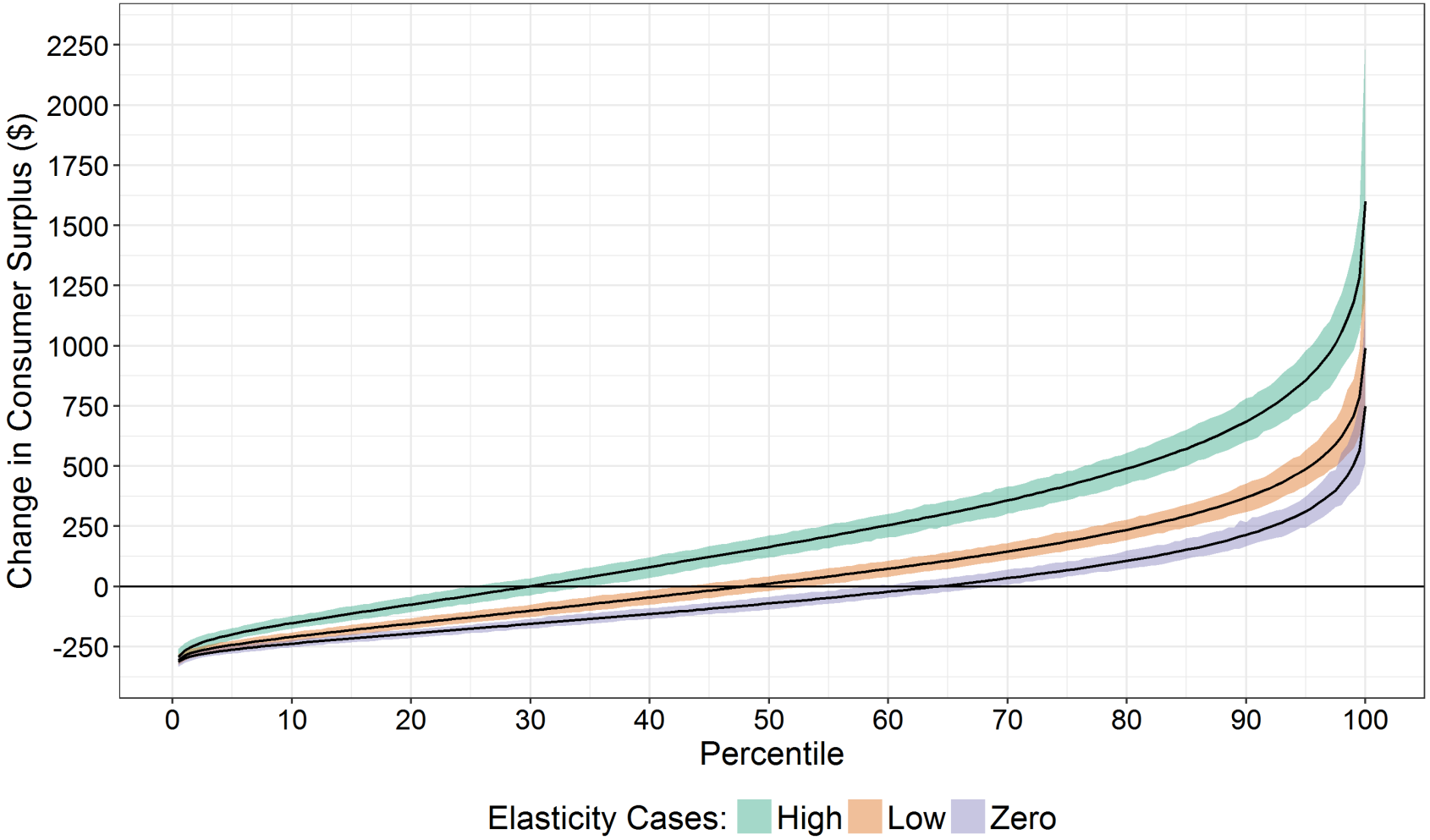
Progressive hedges protect low-income customers at minimal cost to non-low-income customers



What is the cost of inaction?

Efficient rate designs increase consumer surplus for nearly all customer segments at very low levels of price elasticity

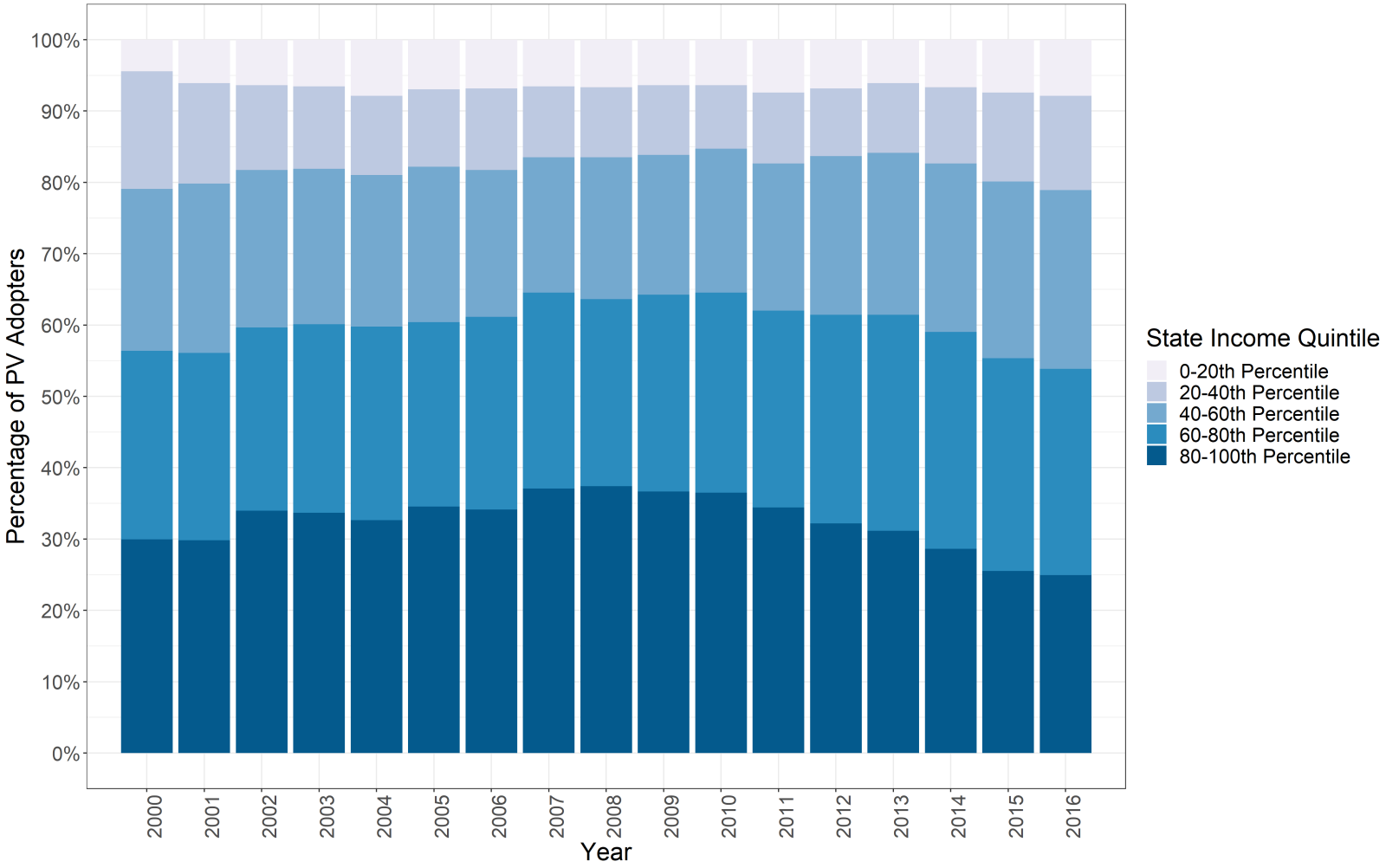
Changes in consumer surplus relative to the flat (default) tariff for customers with <$15,000 per year in income



Source: Burger et al., 2019. The Efficiency and Distributional Effects of Alternative Residential Electricity Rate Designs. *The Energy Journal.* Forthcoming.

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

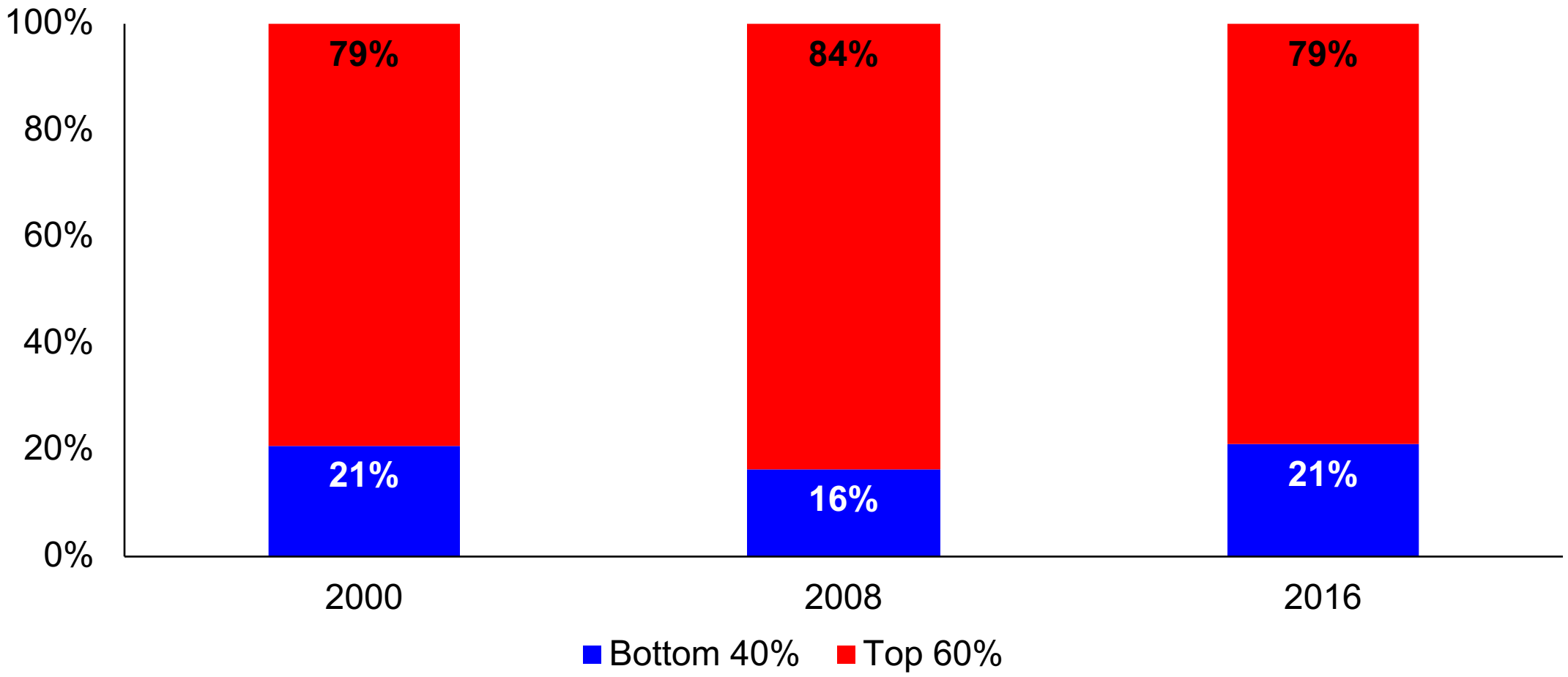
Income trends of PV adopters, 2000 - 2016



Data source: Barbose et al., 2018. Income Trends of Residential PV Adopters An analysis of household-level income estimates. Graphic source: Scott Burger, 2019. Tariff Design for the 21st Century: Designing Efficient Electricity Tariffs Within Socio-Political Constraints. Forthcoming.

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

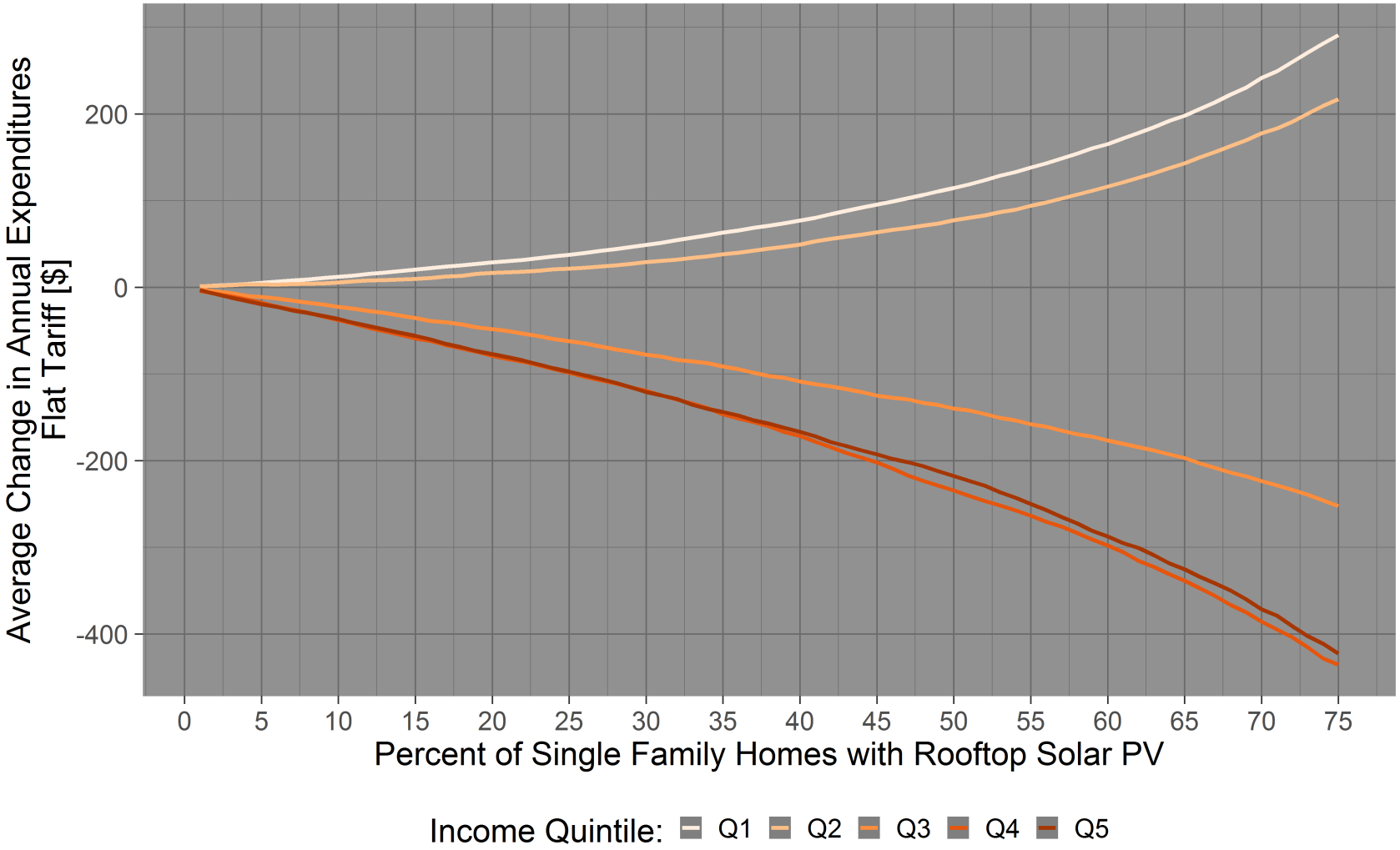


Data source: Barbose et al., 2018. Income Trends of Residential PV Adopters An analysis of household-level income estimates. MIT graphic.

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

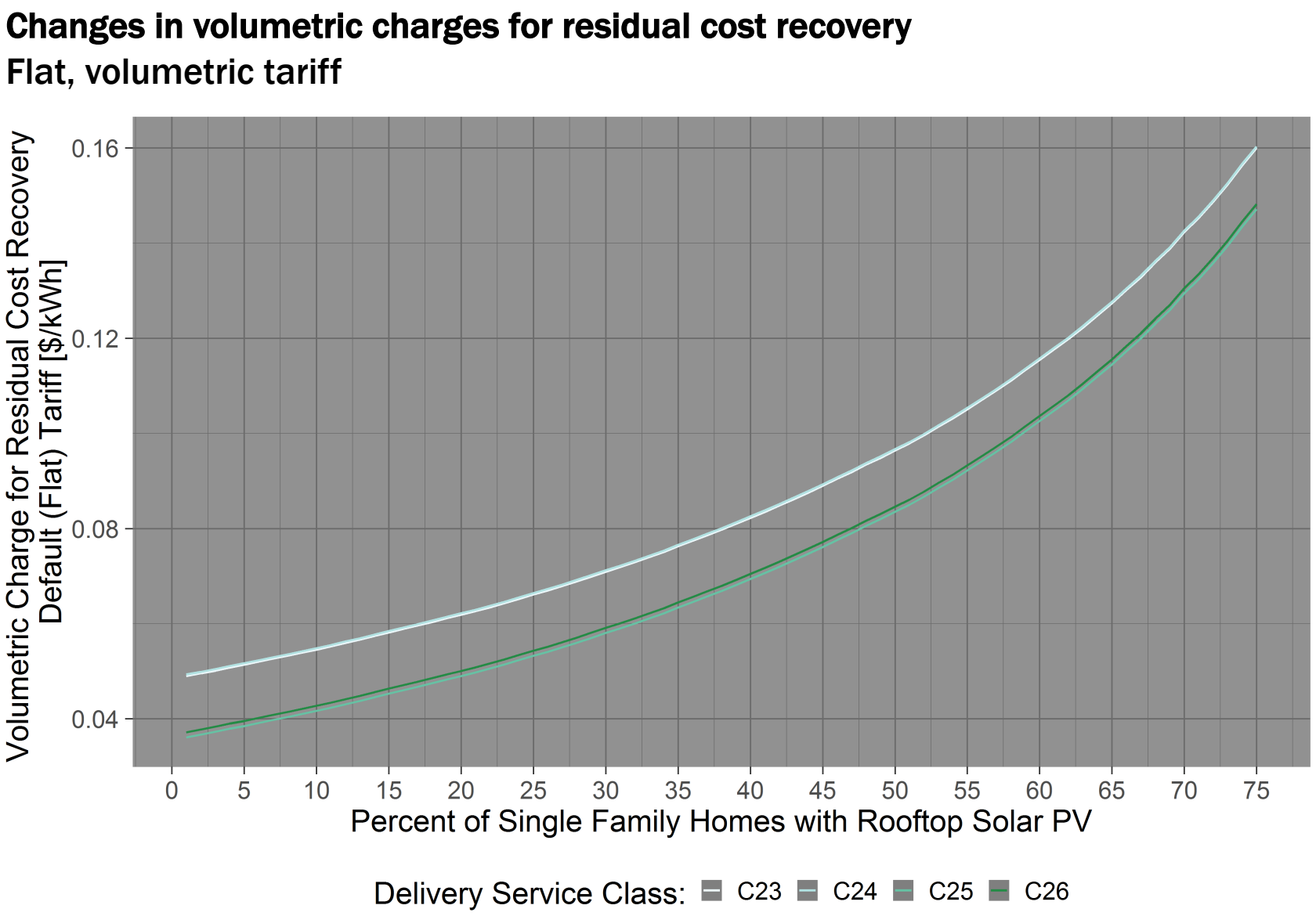
Changes in expenditures by income quintile

Flat, volumetric tariff



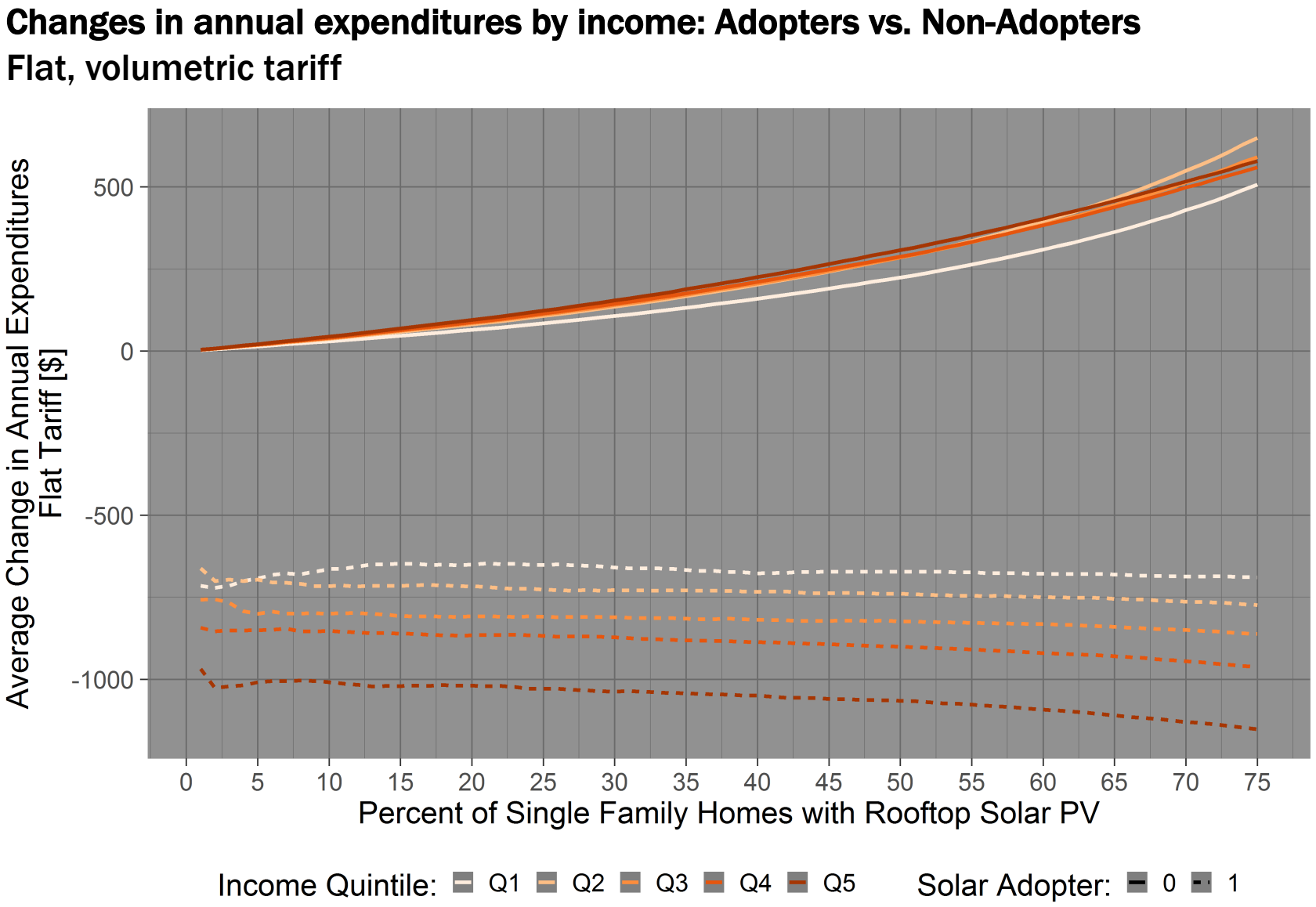
Source: Scott Burger, 2019. Tariff Design for the 21st Century: Designing Efficient Electricity Tariffs Within Socio-Political Constraints. Forthcoming.

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



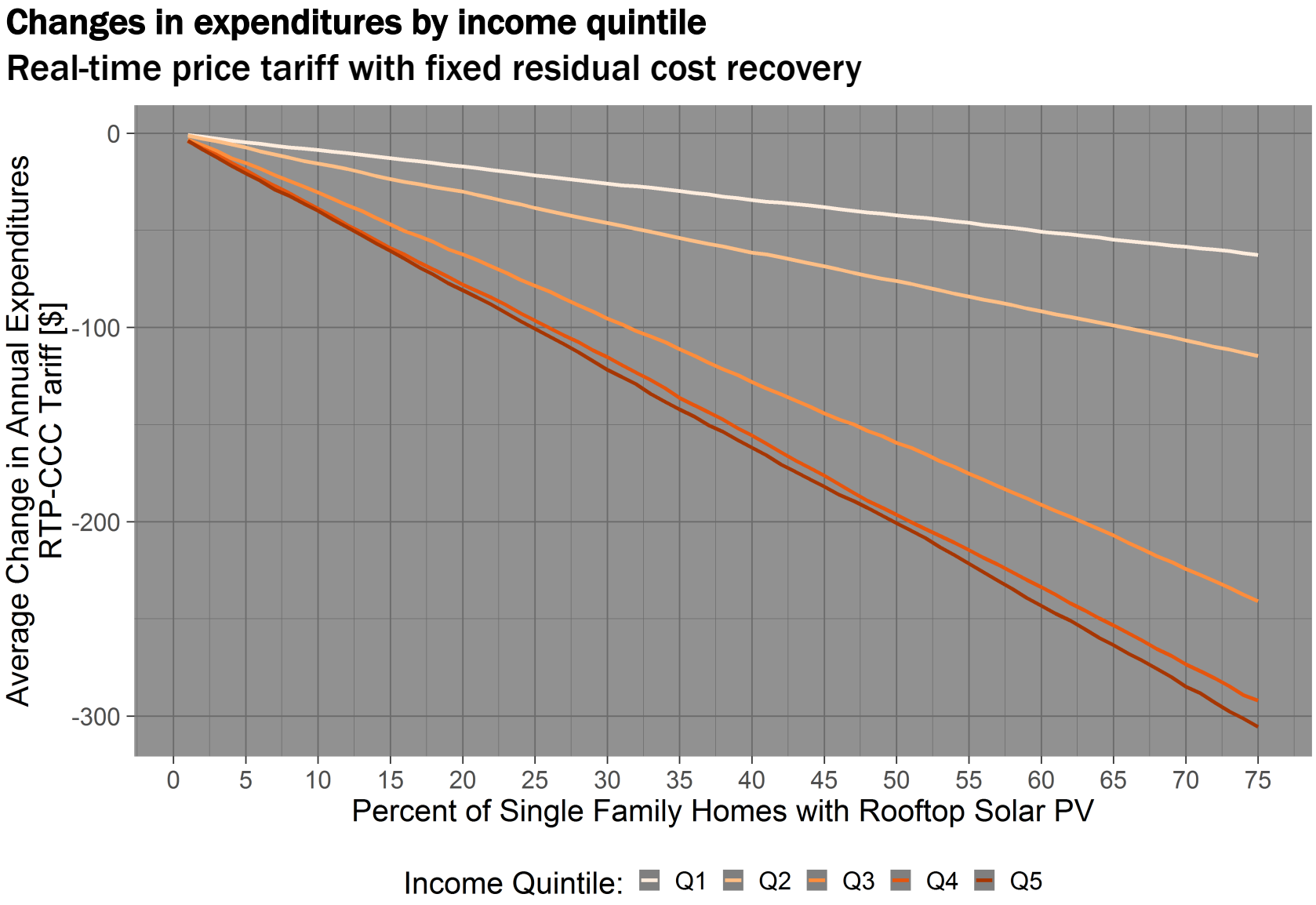
Source: Scott Burger, 2019. Tariff Design for the 21st Century: Designing Efficient Electricity Tariffs Within Socio-Political Constraints. Forthcoming.

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



Source: Scott Burger, 2019. Tariff Design for the 21st Century: Designing Efficient Electricity Tariffs Within Socio-Political Constraints. Forthcoming.

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

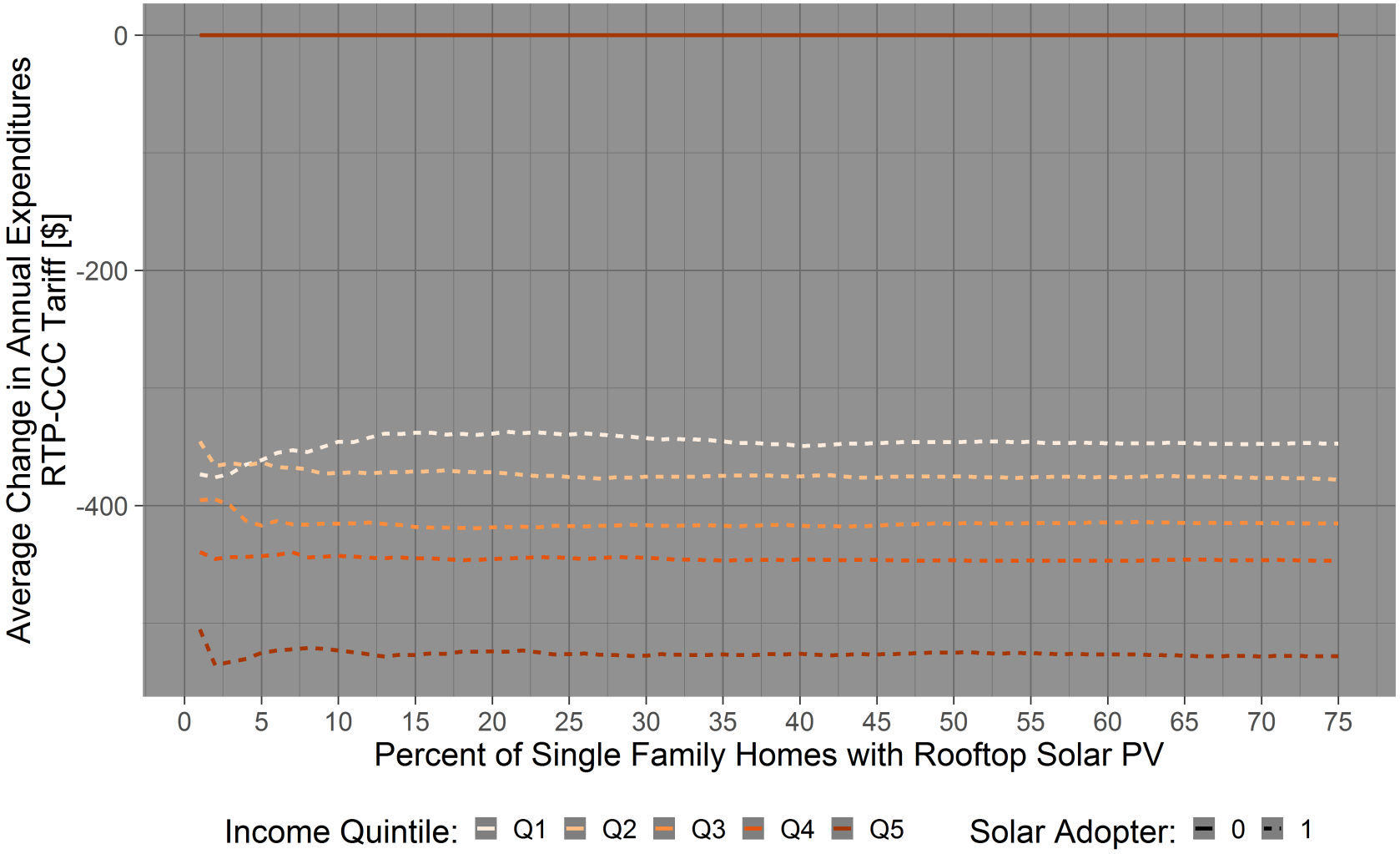


Source: Scott Burger, 2019. Tariff Design for the 21st Century: Designing Efficient Electricity Tariffs Within Socio-Political Constraints. Forthcoming.

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

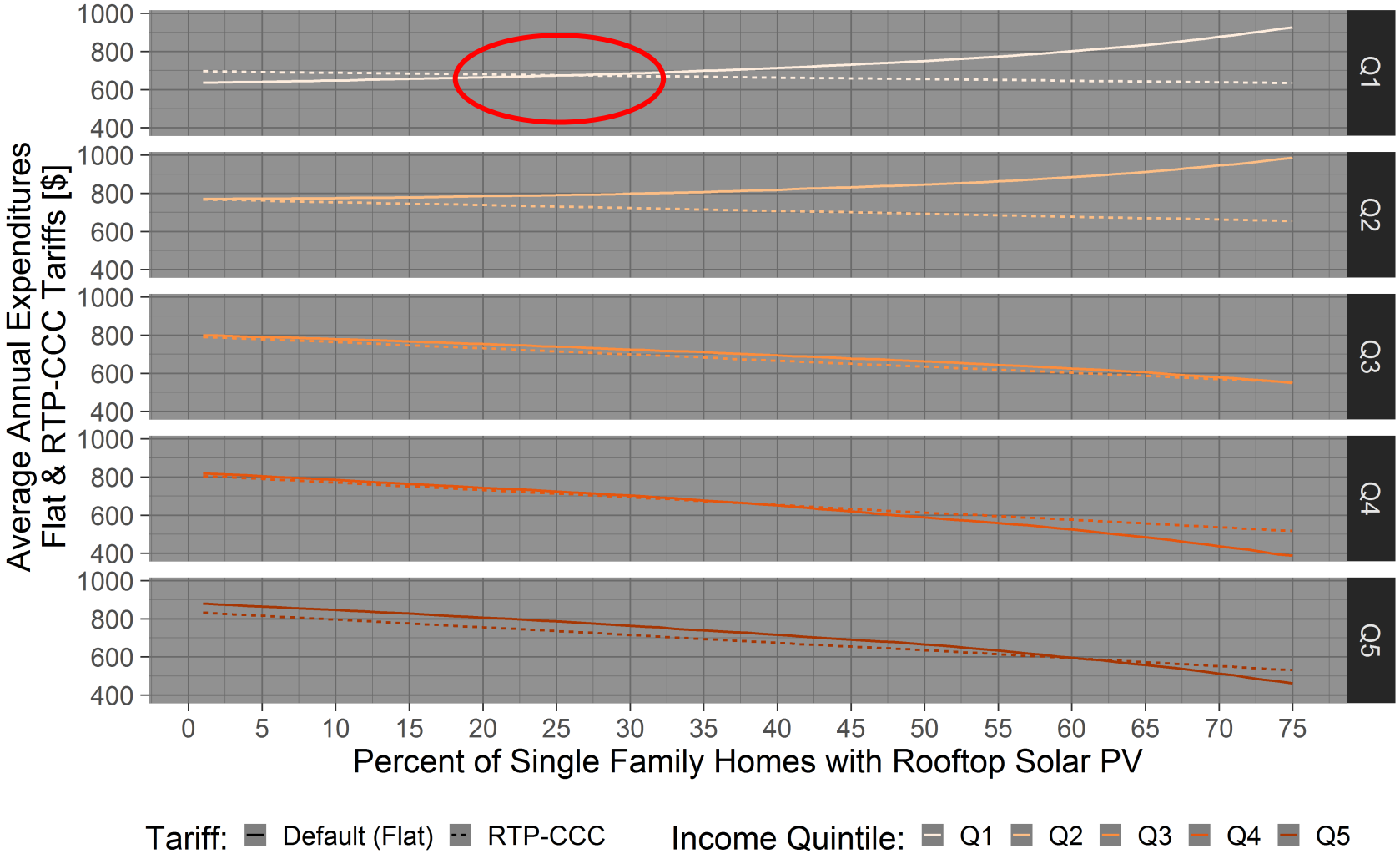


Source: Scott Burger, 2019. Tariff Design for the 21st Century: Designing Efficient Electricity Tariffs Within Socio-Political Constraints. Forthcoming.

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

Changes in expenditures by income quintile

Real-time price tariff with fixed residual cost recovery vs. Flat tariff



Source: Scott Burger, 2019. Tariff Design for the 21st Century: Designing Efficient Electricity Tariffs Within Socio-Political Constraints. Forthcoming.

Thank you

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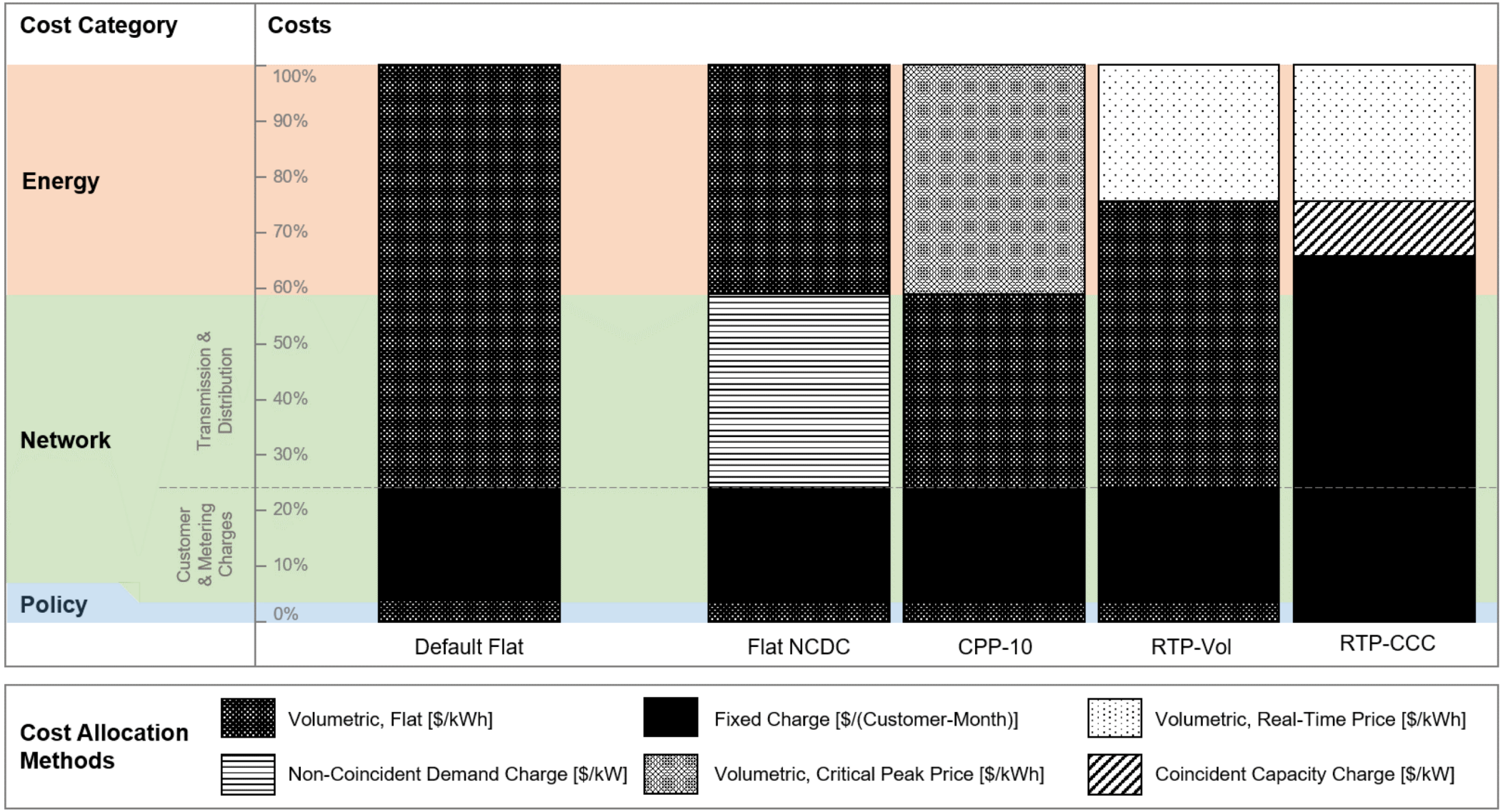
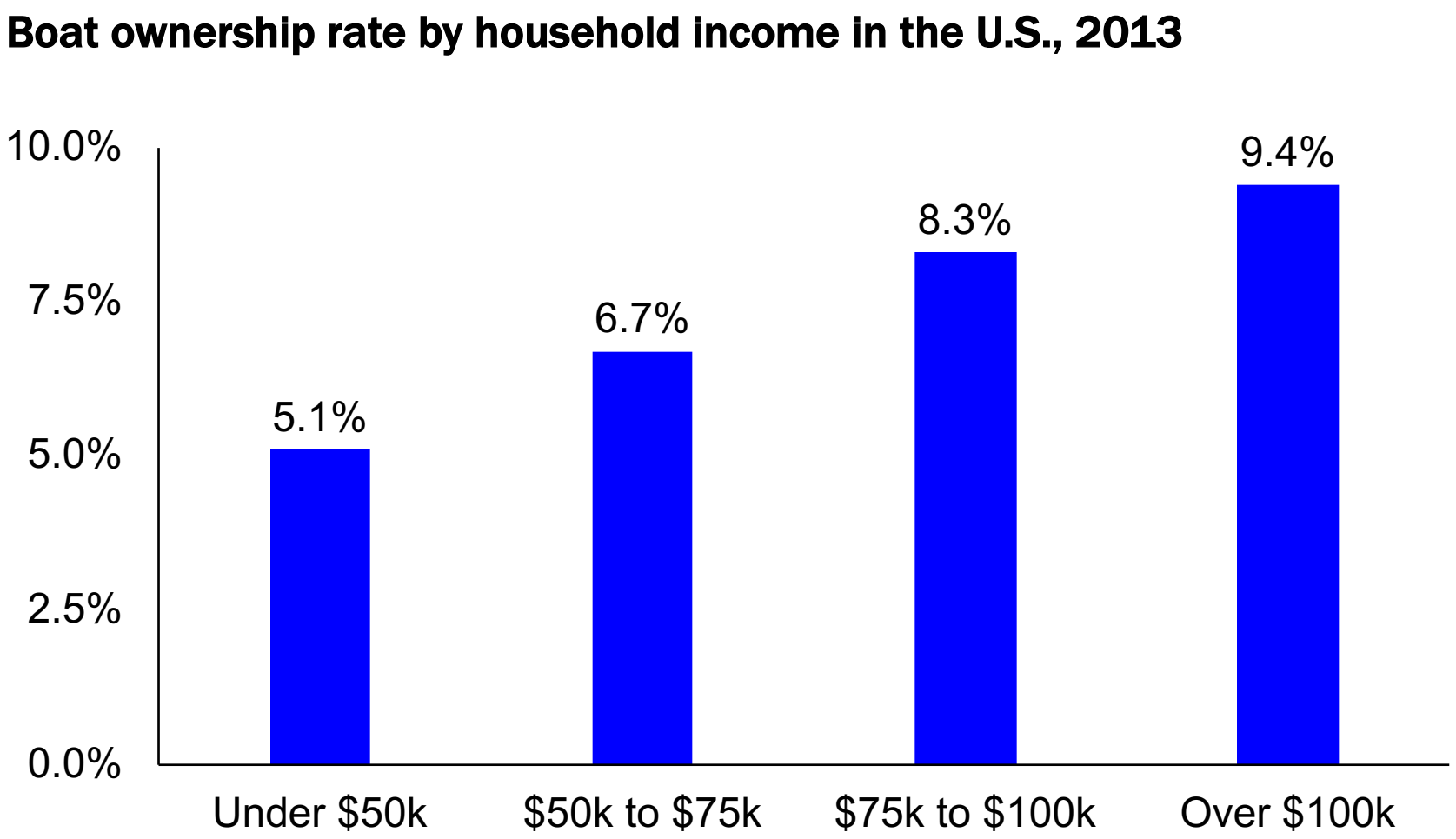
We create and evaluate five innovative tariffs designs – All tariffs are designed to recover all costs for the utility



Source: Burger et al., 2019. The Efficiency and Distributional Effects of Alternative Residential Electricity Rate Designs. *The Energy Journal.* Forthcoming.

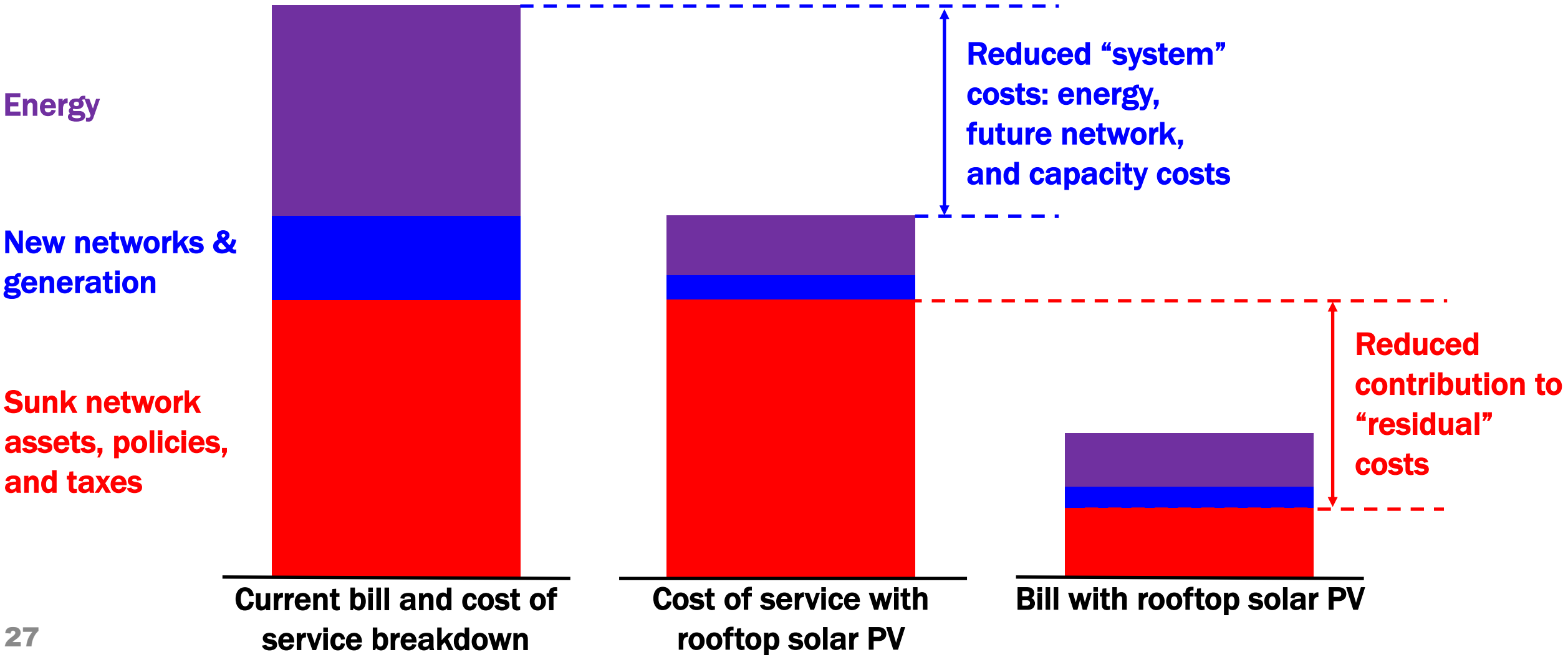
The challenge of inefficient rates

Plenty of goods are unevenly distributed in society – Why should we care about DER ownership?

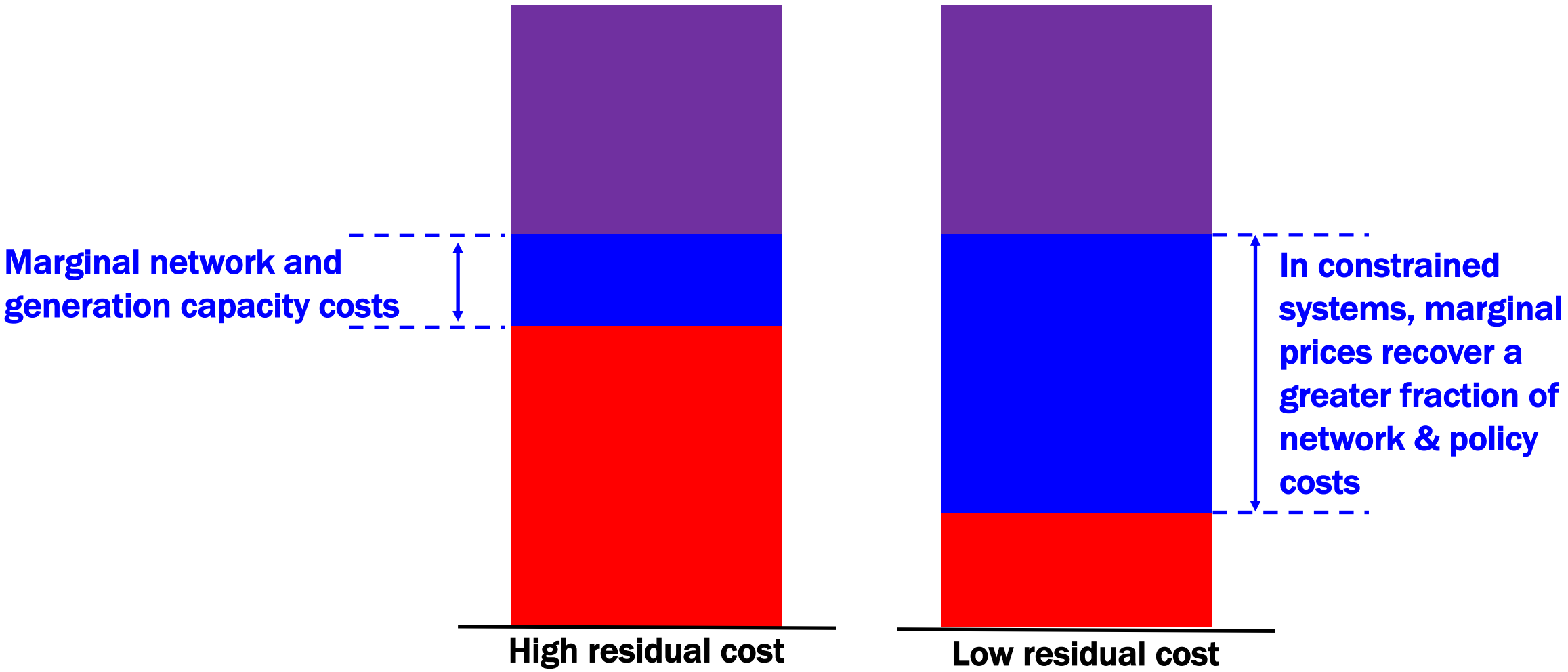


Source: Statista. Boat ownership rate by household income in the U.S. in 2013. Available online: https://www.statista.com/statistics/240543/boat-ownership-by-household-income-in-the-us/

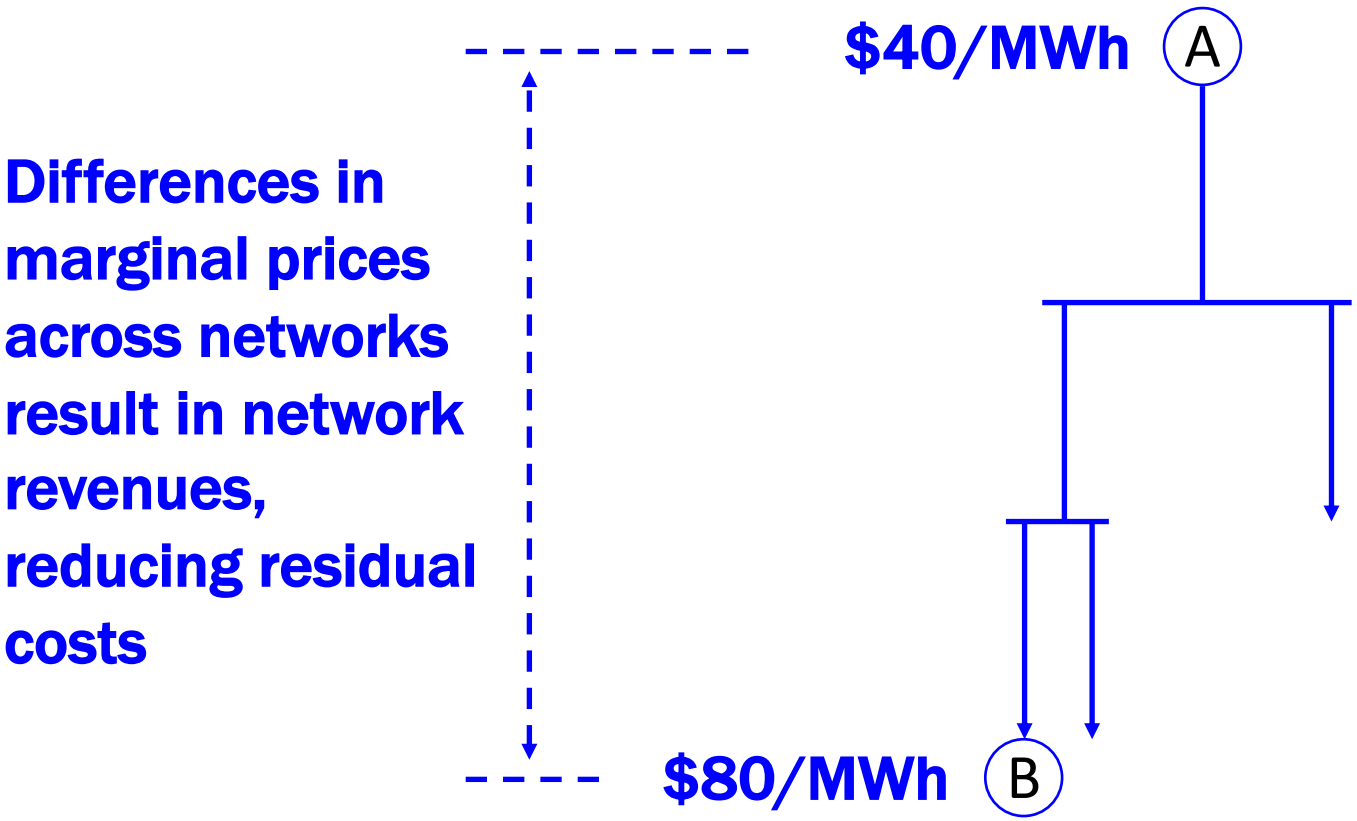
Under inefficient tariffs, DER adoption reduces revenues more than it reduces system costs – as revenue for existing network assets and policies fall, the utility has to recover these "residual" costs of by raising rates



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



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

A

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

B

Networks are constrained, and all distribution costs are marginal

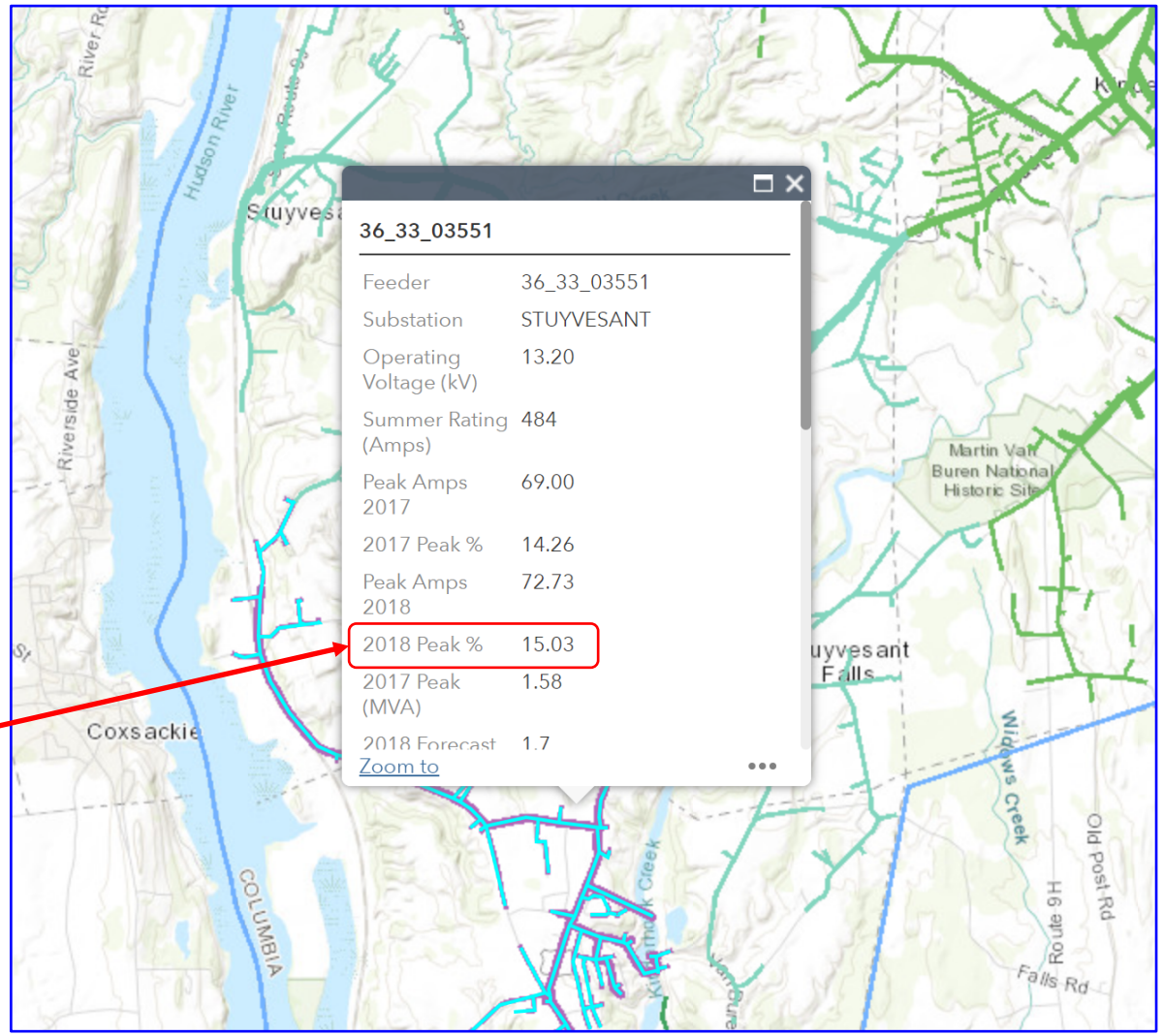
Source: Scott Burger, 2019. Tariff Design for the 21st Century: Designing Efficient Electricity Tariffs Within Socio-Political Constraints. Forthcoming.

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

A

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



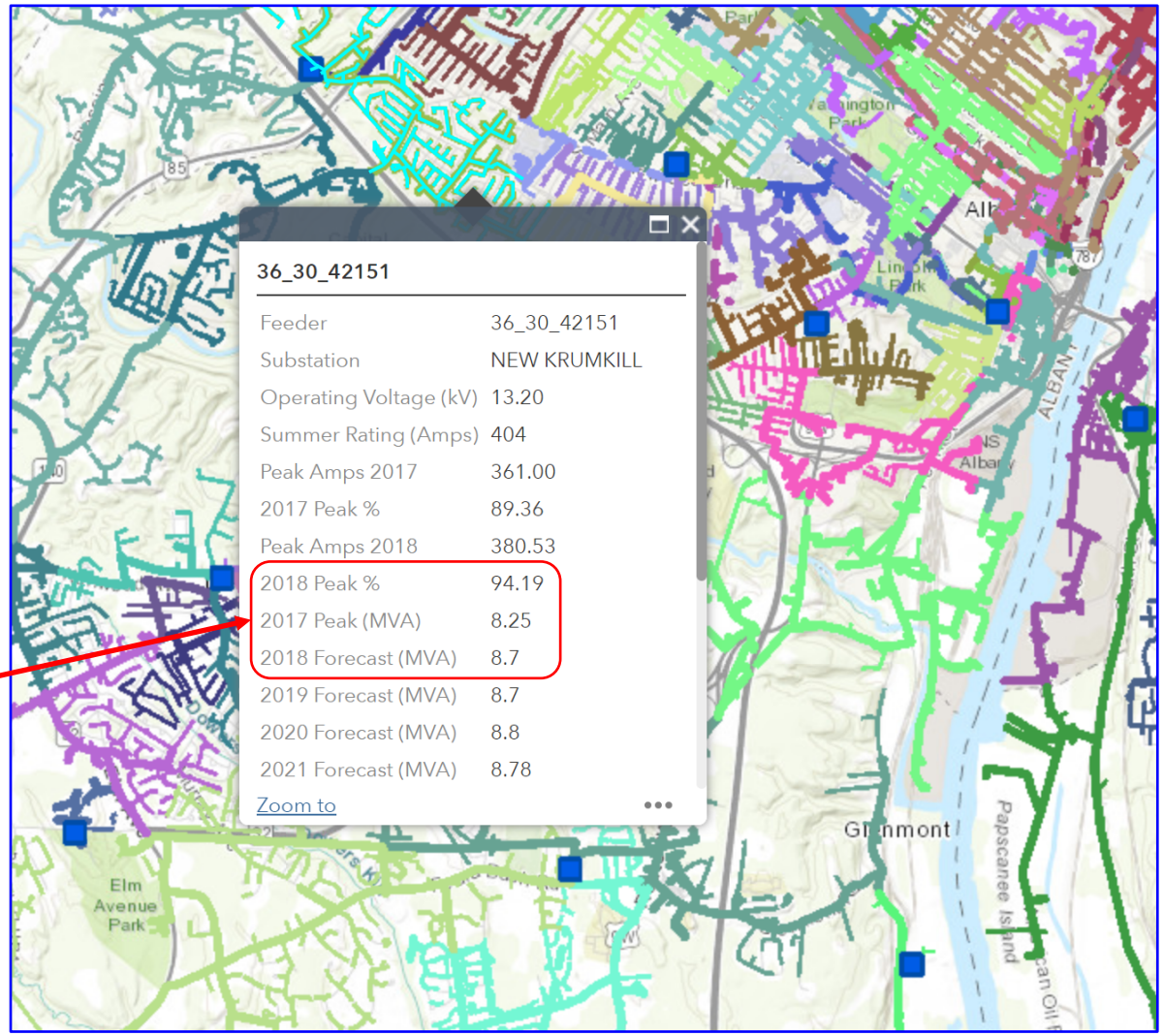
Source: National Grid, N.D. Available online: http://ngrid.maps.arcgis.com/apps/MapSeries/index.html?appid=4c8cfd75800b469abb8febca4d5dab59&folderid=8ffa8a74bf834613a04c19a68eefb43b

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

B

Networks are constrained, and all distribution costs are marginal

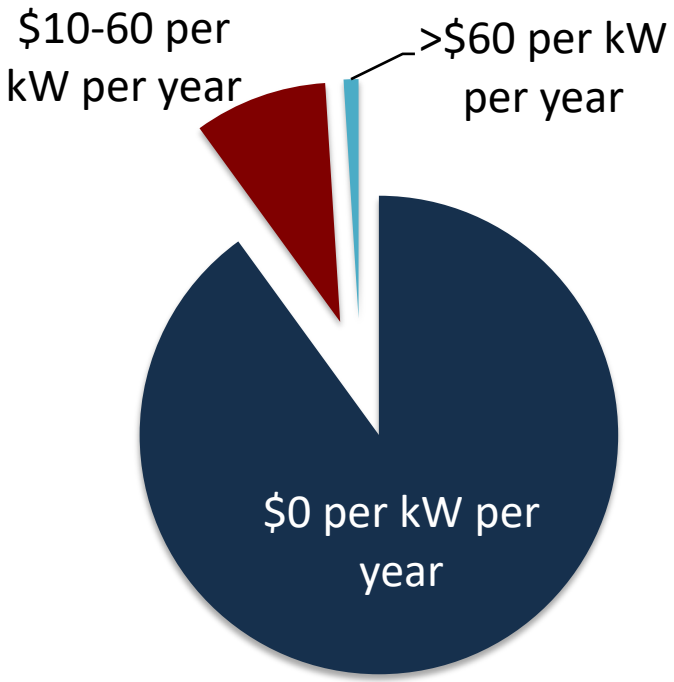
Peak loading is 95% of rated capacity & growing. Peak demand reductions could eliminate or delay the need to invest in upgrading this circuit

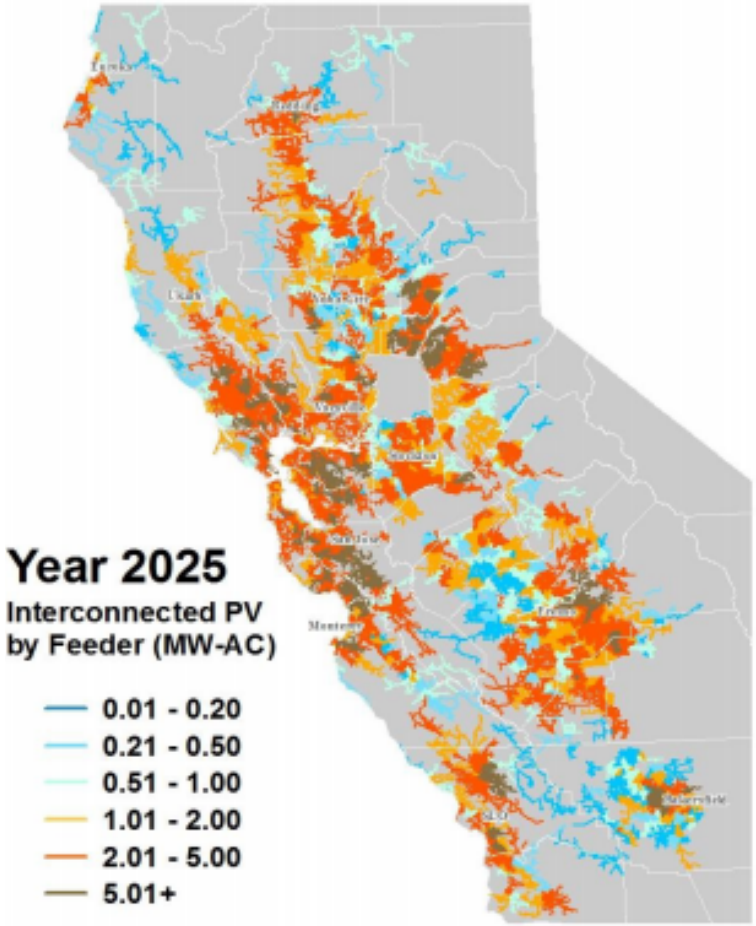


Source: National Grid, N.D. Available online: http://ngrid.maps.arcgis.com/apps/MapSeries/index.html?appid=4c8cfd75800b469abb8febca4d5dab59&folderid=8ffa8a74bf834613a04c19a68eefb43b

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





Source: M.A. Cohen, P.A. Kauzmann, D.S. Callaway, Effects of distributed PV generation on California's distribution system, part 2: Economic analysis, Solar Energy, Volume 128, 2016, 139–152

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.

$$ComEd\ Default\ Tariff = p^{e}_{i,t,\phi} + \overset{\$0/kWh}{\cancel{p^{ccc}_{i,t,\phi}}} + p^{r}_{i,t,\phi} + \overset{\$0/kWh}{\cancel{p^{cp}_{i,t,\phi}}} + F^{r}_{i,\phi}$$

Energy
~$0.05/kWh

Residual costs
~0.05/kWh

Residual costs
~$10/month

Source: Scott Burger, 2019. Tariff Design for the 21st Century: Designing Efficient Electricity Tariffs Within Socio-Political Constraints. Forthcoming.

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

$$RTP - CCC = p^{e}_{i,t,\phi} + p^{ccc}_{i,t,\phi} + \overset{\$0/\text{kWh}}{\cancel{p^{r}_{i,t,\phi}}} + \overset{\$0/\text{kWh}}{\cancel{p^{cp}_{i,t,\phi}}} + F^{r}_{i,\phi}$$

Energy
~$0.03/kWh

"Marginal" generation capacity costs
~$1/kW

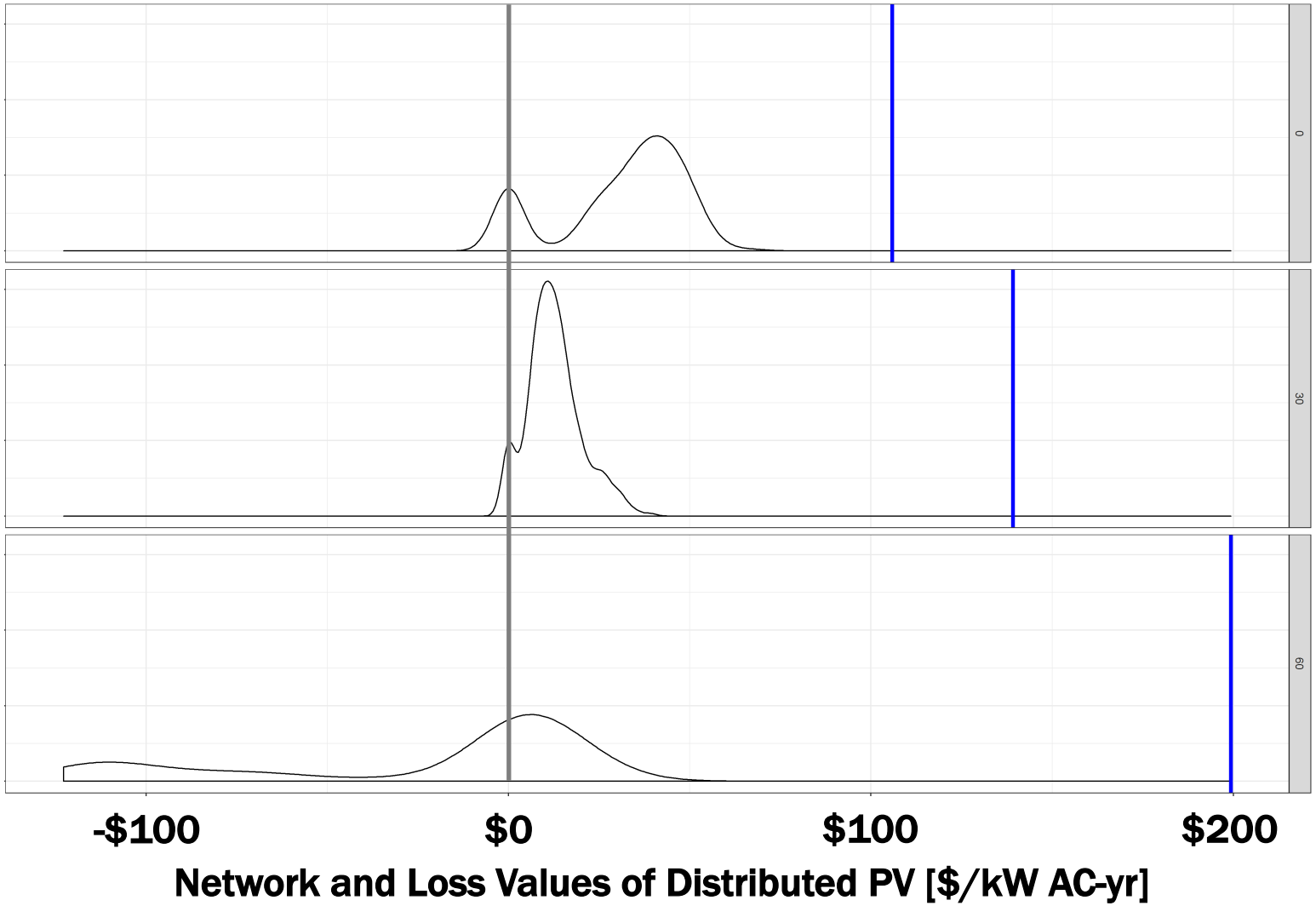
Residual costs
CCC: ~$39/month

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



0% rooftop solar penetration

30% rooftop solar penetration

60% rooftop solar penetration

Source: Scott Burger, 2019. Tariff Design for the 21st Century: Designing Efficient Electricity Tariffs Within Socio-Political Constraints. Forthcoming.

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

$0/kWh

$$RTP - CCC - CP = p^{e}_{i,t,\phi} + p^{ccc}_{i,t,\phi} + \cancel{p^{n}_{i,t,\phi}} + p^{cp}_{i,t,\phi} + F^{r}_{i,\phi}$$

Energy ~$0.03/kWh

"Marginal" generation capacity costs ~$1/kW

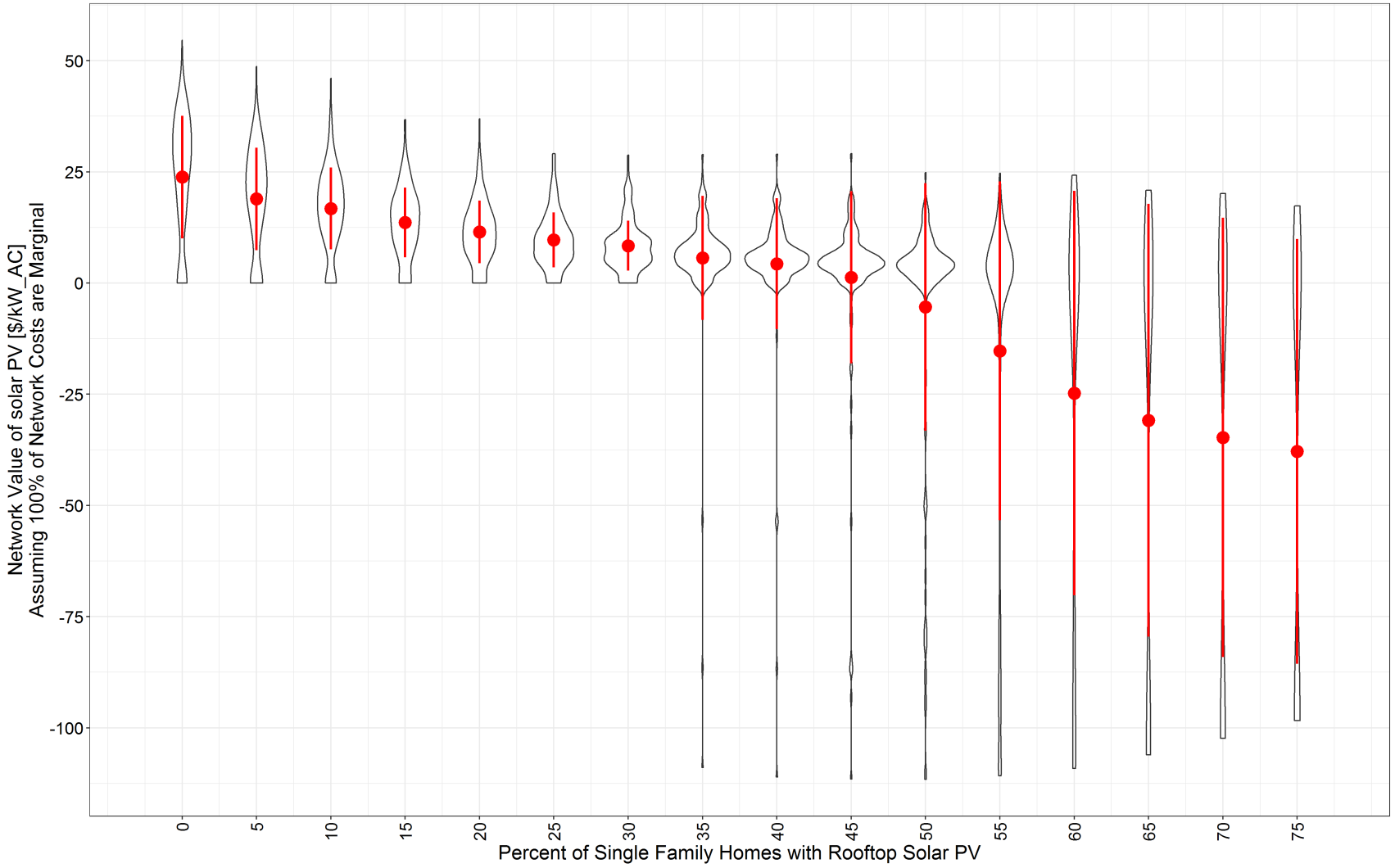
"Marginal" network costs ~$0 - 0.55/kW

Residual costs ~$15/month

Source: Scott Burger, 2019. Tariff Design for the 21st Century: Designing Efficient Electricity Tariffs Within Socio-Political Constraints. Forthcoming.

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

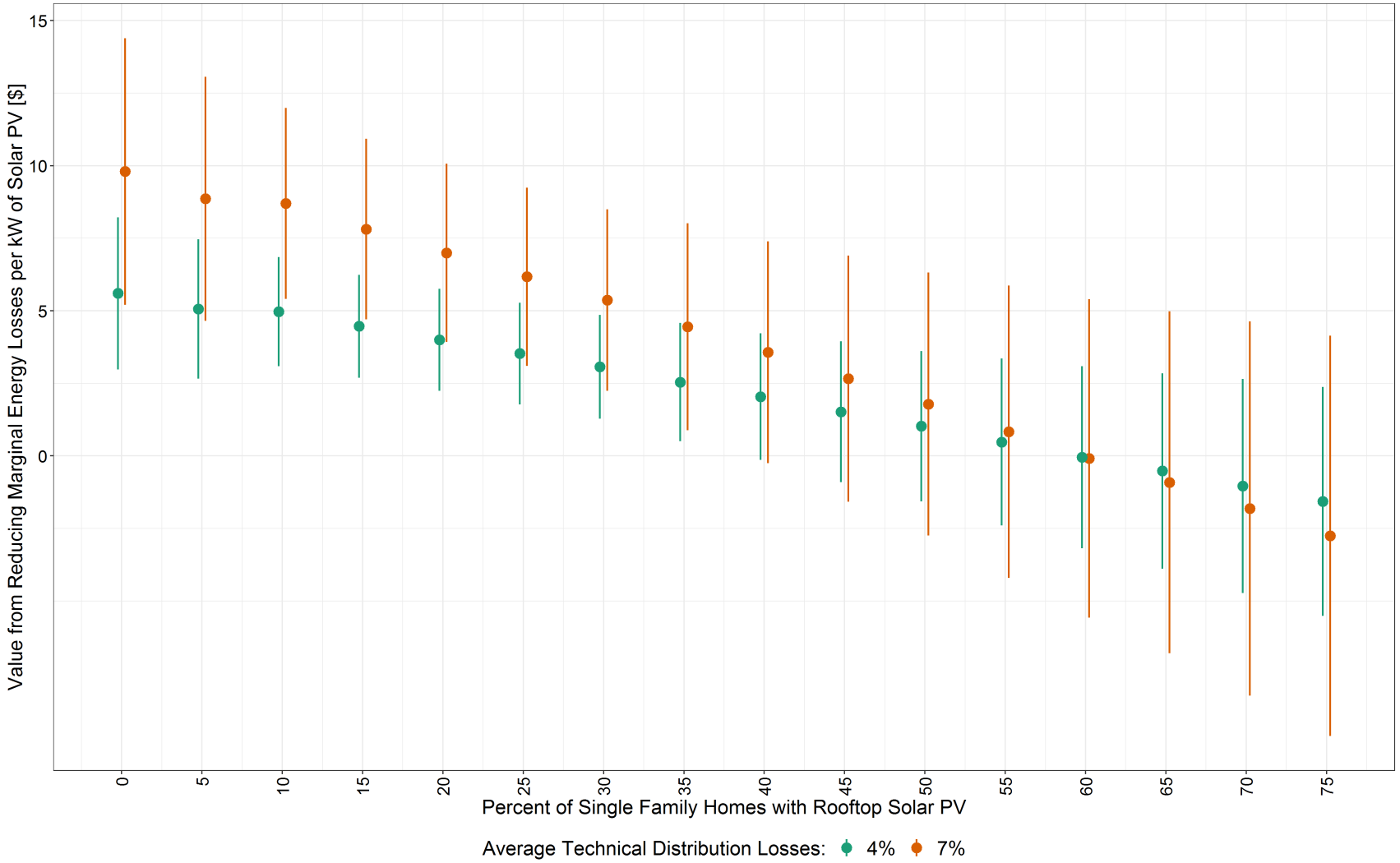
Estimation of network capacity value of distributed PV



Source: Scott Burger, 2019. Tariff Design for the 21st Century: Designing Efficient Electricity Tariffs Within Socio-Political Constraints. Forthcoming.

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

Estimation of distribution loss avoidance value of distributed PV

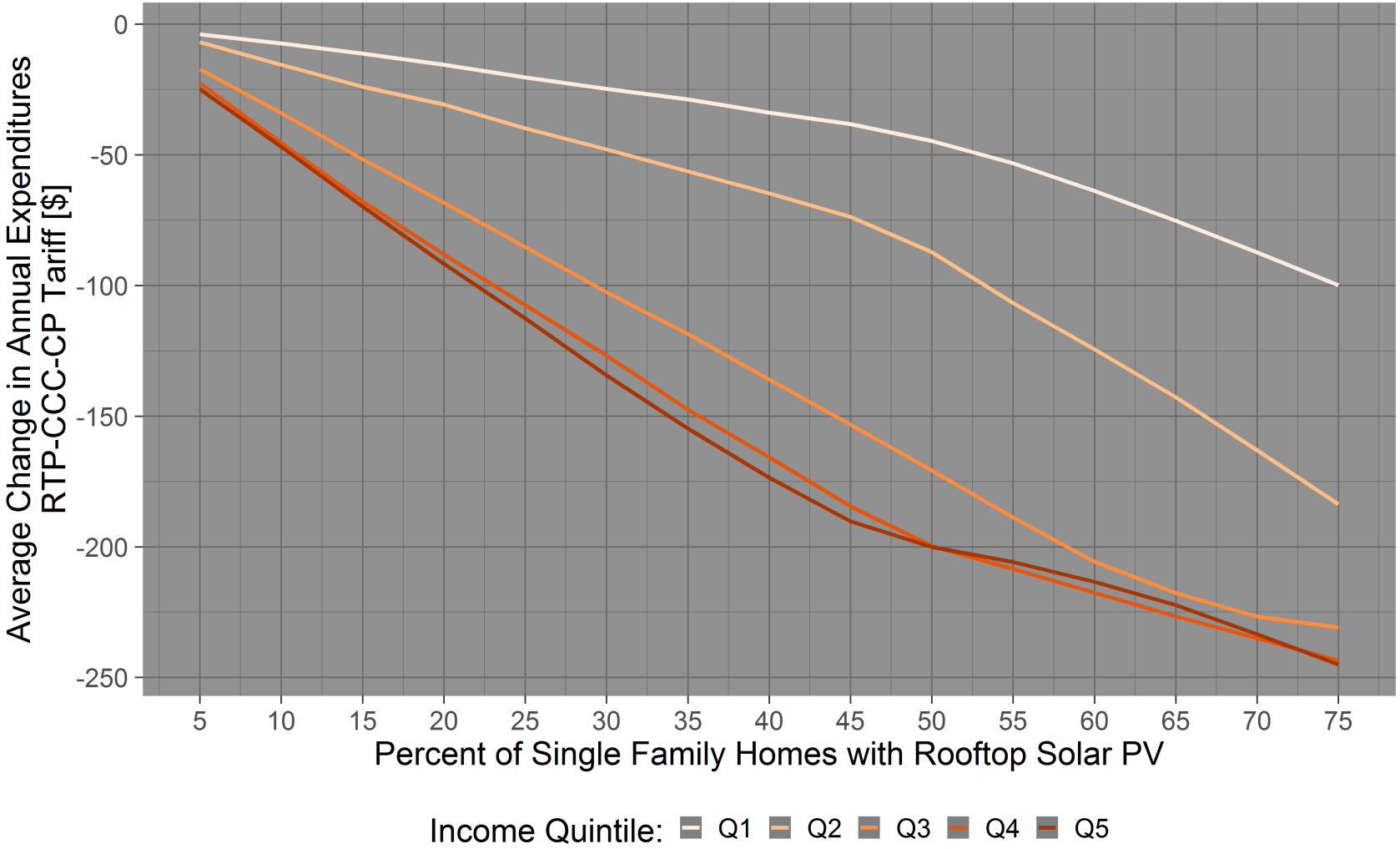


Source: Scott Burger, 2019. Tariff Design for the 21st Century: Designing Efficient Electricity Tariffs Within Socio-Political Constraints. Forthcoming.

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



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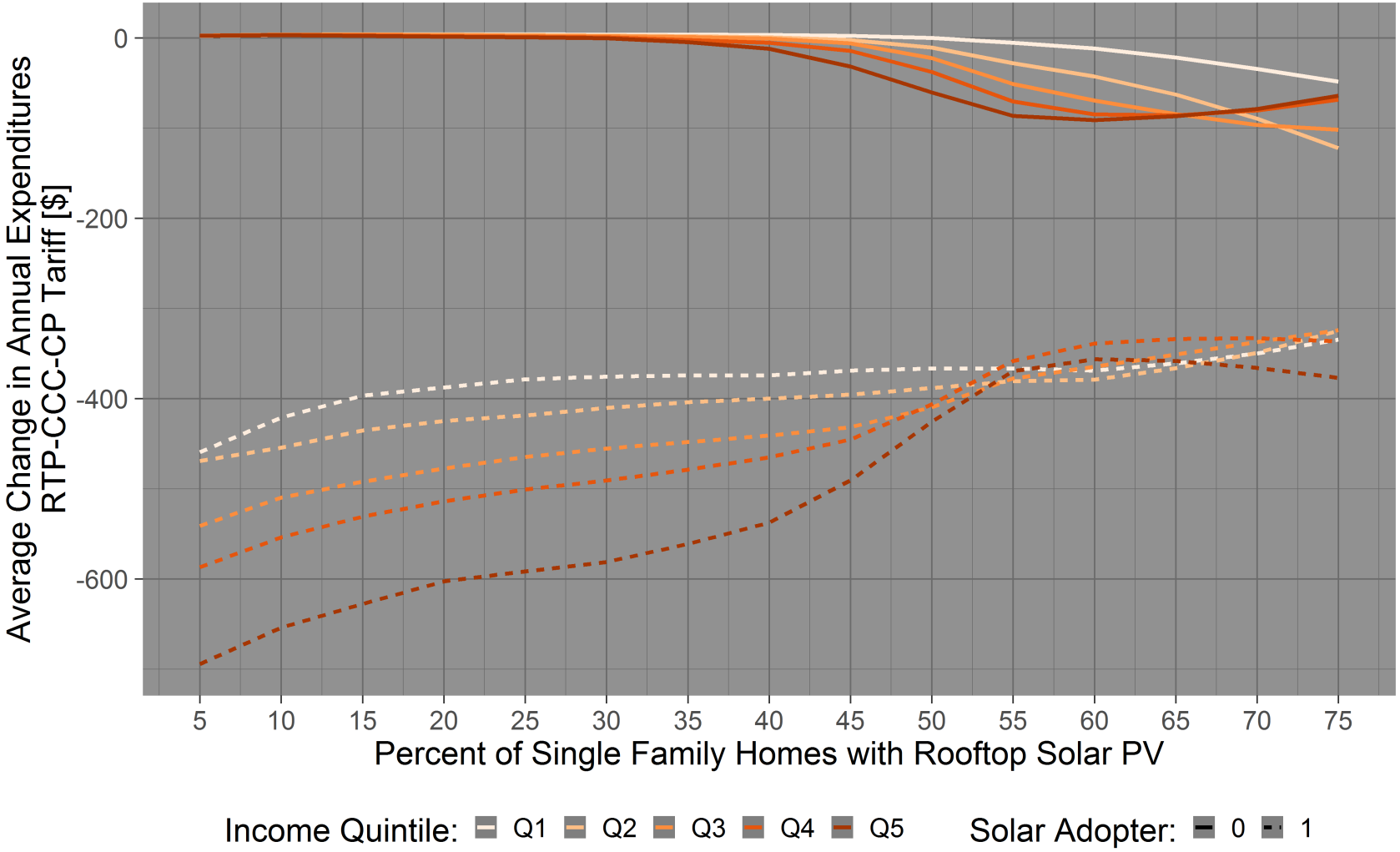
Changes in annual expenditures by income: Adopters vs. Non-Adopters

Real-time price tariff, fixed residual cost recovery, and marginal network costs

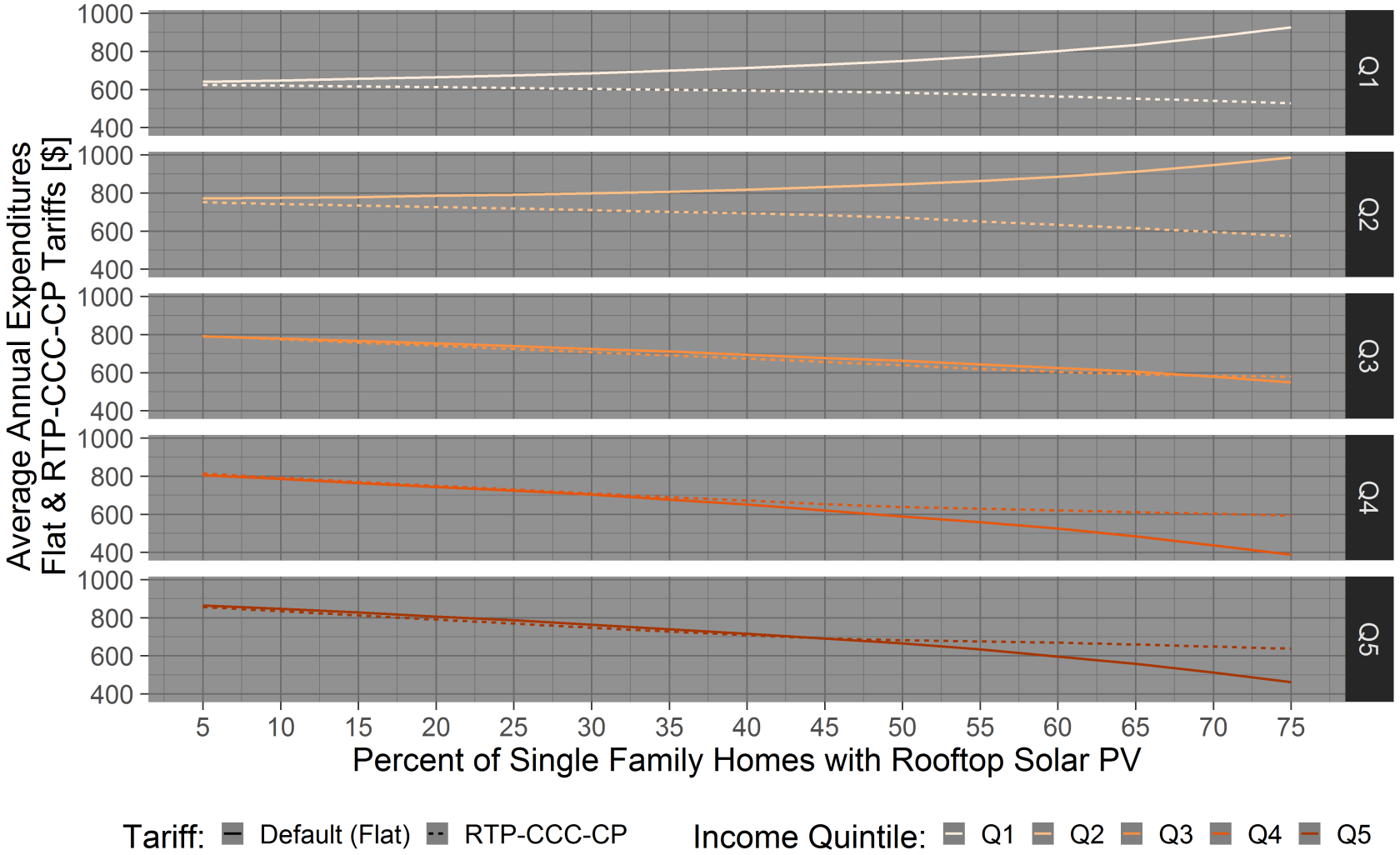


Source: Scott Burger, 2019. Tariff Design for the 21st Century: Designing Efficient Electricity Tariffs Within Socio-Political Constraints. Forthcoming.

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



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