Redistributive Electricity Pricing

with an application to California

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Redistributive Electricity Pricing

Preamble

- A theorist and an energy economist walk into a bar...

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- A theorist and an energy economist walk into ~~a bar~~ an office...

- Electricity prices have soared this last decade. Main reason: trying to recover fixed costs through volumetric pricing.

  Before: positive relationship between income and electricity consumption.

  Now: adoption of solar panels has called into question how regressive nonlinear prices are, excacerbated by increased capital needs.

Objective

How can we relate insights from the optimal redistributive pricing literature to ongoing disucussions and trends in the electricity sector?

Redistributive Electricity Pricing

Preliminary!

Current version

- Core theory paper with motivating facts and evidence

Possible version

- A more serious quantification with better (if possible) data

Any thoughts welcome!

Nonlinear pricing and its distributional impacts in CA

- Non-linear pricing is a way of redistributing or allocating the burden of fixed costs.
- It tends to be progressive in nature.
  - Even more if well measured (Borenstein, 2012).
- Solar panels are adopted by higher income households (for many reasons, see also Borenstein and Davis, 2016)
  - And non-linear pricing additional lures in *high consumption* high income (Borenstein, 2017).
- Correlation between consumption and income is not all of it, and it is evolving (Borenstein, 2024).

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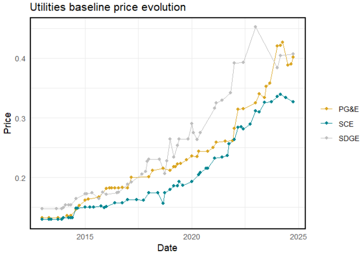
Nonlinear prices in California

Motivation

- Increasing rates and growing inequality concenrns.
- Perfect storm: death spiral meets climate adaptation.
- Number of considered or proposed changes to the rate structure.

We relate this to the theory of optimal redistributive pricing with (not great) data.



Price evolution for baseline consumption in California

Nonlinear prices in California

Key theory insights

1. Optimal non-linear prices are a function of the correlation between income and consumption with distributional utilitarian concerns.
2. As solar grows, higher fixed fees and lower prices.
3. As solar grows, flatter marginal schedules.

Nonlinear prices in California

Data

On this particular project we will focus on...

- California
- 3 main utilities: PG&E, SCE and SDGE
- Residential electric rates: tiered rate plans

Data needed for first steps...

1. IOU's territories
2. Electricity prices
3. Baseline territories
4. Census data: mean, median, quintile at a ZIP Code level

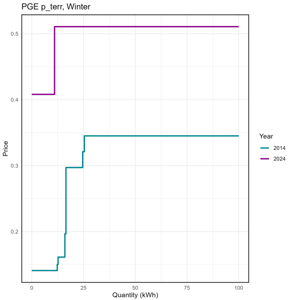
Nonlinear prices in California

Key facts

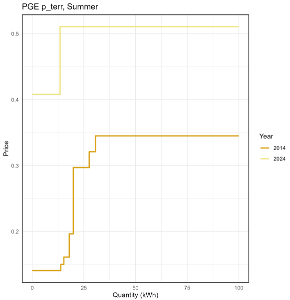
1. Increase and flattening of the rates, with fewer steps.
2. Fixed charges and public debates on how to set them.
3. Reduced correlation in electricity consumption and income.

Nonlinear prices in California

Electricity prices: PG&E



(a) Territory P, Winter

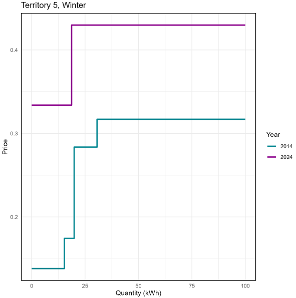


(b) Territory P, Summer

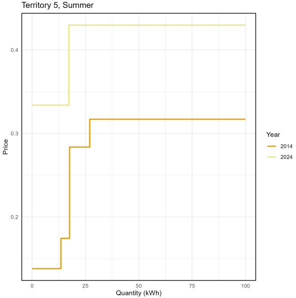
Figure: 2014 vs 2024, differences in electricity price

Nonlinear prices in California

Electricity prices: SCE



(a) Territory 5, Winter

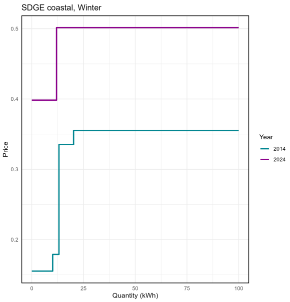


(b) Territory 5, Summer

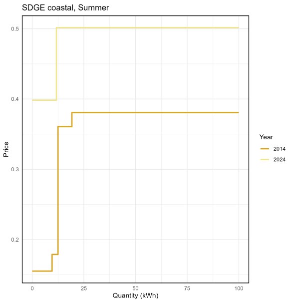
Figure: 2014 vs 2024, differences in electricity price

Nonlinear prices in California

Electricity prices: SDGE



(a) Coastal, Winter



(b) Coastal, Summer

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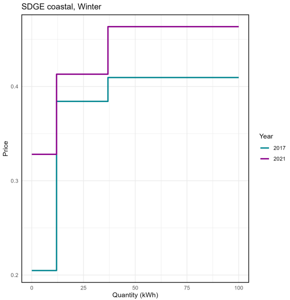
Nonlinear pricing in California

Problematic observations electricity consumption: SDGE Electricity prices 2017 vs 2021



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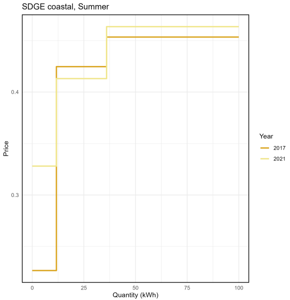

(b) Coastal, Summer

Figure: 2017 vs 2021, differences in electricity price.

PG&E

Income and zip code electricity consumption

2 different analysis:

- Correlation electricity consumption and zip code income
- Correlation price paid for electricity consumption and zip code income

SDGE 2014 and 2022

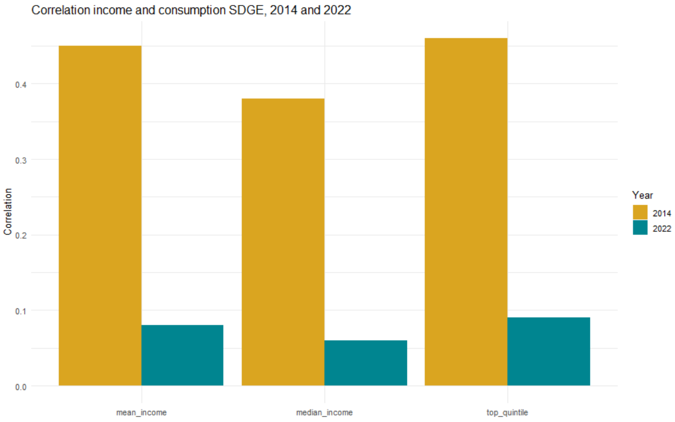

Figure: Correlation between income and zip code electricity consumption

Correlation income and daily electricity price paid

SDGE 2014 and 2022

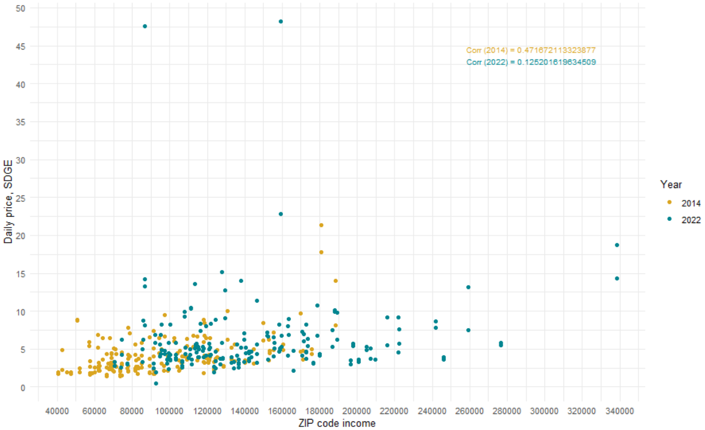

Figure: Correlation between income and zip code electricity price, SDGE 2014 and 2022

Theoretical framework: setup

- Electricity is priced according to a convex schedule $P[q]$
- Measure μ of agents i with incomes y_i and utility functions:

$$u^i\left(q,\ y_i - P[q]\right)$$

  - u^i satisfies Inada conditions
  - q is the agent's total electricity use
  - q_i^* will denote agent i's chosen q
- Planner chooses price schedule $P[q]$ to maximize welfare...

$$\int u_i\left(q_i^*,\ y_i - P[q_i^*]\right) d\mu(i) \tag{W}$$

- ...subject to revenue covering the fixed and marginal costs:

$$\int P[q_i^*] d\mu(i) \ \geq\ F + \int c \cdot q_i^* d\mu(i) \tag{B}$$

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Local optimality conditions

- We find local optimality conditions for the price schedule P
- We express them in terms of the following:
  - Multiplier on the budget constraint: α
  - Average MU of income among those using q of electricity:

$$\lambda(q) := \mathbb{E}\left[u_2^i\left(q_i^*,\ y_i - P[q_i^*]\right)\ \middle|\ q_i^* = q\right]$$

  - Average income effects among those using q of electricity:

$$d_I(q) := \mathbb{E}\left[\frac{\partial}{\partial y_i} q_i^*\ \middle|\ q_i^* = q\right]$$

  - Average compensated price effect among those using q of electricity:

$$d_P(q) := \mathbb{E}\left[\frac{\partial}{\partial p} q_i^* + q_i^* \cdot \frac{\partial}{\partial y_i} q_i^*\ \middle|\ q_i^* = q\right]$$

Linear price schedules

Proposition 1

Consider linear price schedules:

$$P[q] = I + p \cdot q.$$

The optimal constant marginal price p satisfies:

$$p = c - \frac{1}{\alpha} \cdot \frac{\mathrm{Cov}[\lambda(q) - \alpha, q]}{\mathrm{Cov}[d_I(q), q] - \mathbb{E}[d_P(q)]}$$

- Intuitively, we price electricity **at cost** minus a **redistributive adjustment** term
- Redistributive adjustment **moderated** by size of **behavioral response** (positive under reg. conds.)
- If cov between MU (adjusted for value of revenue) and consumption **positive** $\rightarrow$ adjust price **downwards**

Effects of solar: intuition

What if high-income (low λ) users reduce their consumption?

$$p = c - \frac{1}{\alpha} \cdot \frac{\mathrm{Cov}[\lambda(q) - \alpha, q]}{\mathrm{Cov}[d_I(q), q] - \mathbb{E}[d_P(q)]}$$

1. Cov between between λ and q grows
   - Force towards reducing the marginal price p
2. Before we were making surplus \$ on high-income consumers, so now need more \$ to cover fixed costs
   - multiplier on revenue α increases
   - Force towards charging everyone more

- When the reduction sufficiently concentrated on high-income consumers, these two forces should give:
  - A higher *lump-sum* charge
  - A lower *marginal* price p

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Two-piece price schedules

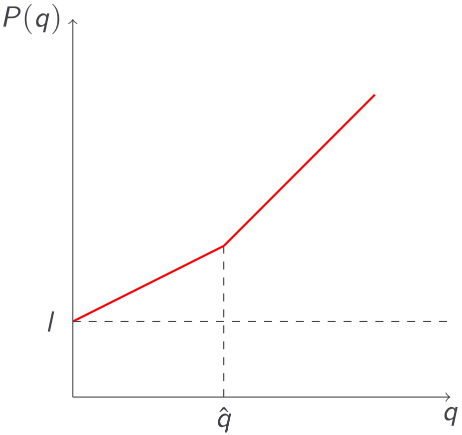

Figure: A two-piece price schedule with a kink at $\hat{q}$

Two-piece price schedules

Proposition 2

Consider two-piece price schedules. The optimal lower and higher prices, p_l and p_h, satisfy:

$$p_l = c - \frac{\mathbb{E}[(\lambda(q)-\alpha)\cdot(q-\hat{q})|\ q<\hat{q}]}{\alpha\cdot\mathbb{E}[\ d_l(q)\cdot(q-\hat{q})-d_P(q)\ |\ q<\hat{q}]},$$

$$p_h = c - \frac{\mathbb{E}[(\lambda(q)-\alpha)\cdot(q-\hat{q})|\ q>\hat{q}]}{\alpha\cdot\mathbb{E}[\ d_l(q)\cdot(q-\hat{q})-d_P(q)\ |\ q>\hat{q}]}.$$

- Similar intuition! But this time look at relations between $\lambda(q)-\alpha$ and q on each side of the kink, separately
- Under regularity conditions, leads to flattening.

Conclusions

- We relate results from state-of-the-art mechanism-design optimal pricing to the current discussions in California.
- In next iterations, maybe we can take a more structural approach to the regulator's preferences.