Can real-time pricing be progressive? Identifying cross-subsidies under fixed-rate electricity tariffs

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Monash Brown Bag Series

Retail and wholesale pricing of utility services

- Traditional pricing of electricity (and other utility services)
  - Connection fee (\$x per day)
  - Usage fee (\$y per kWh)

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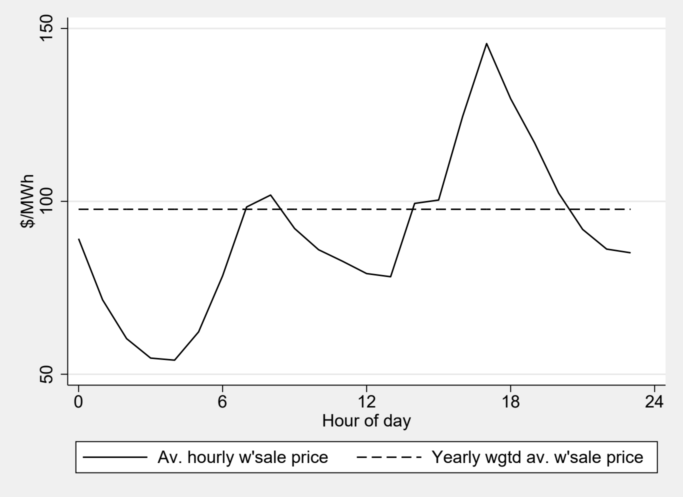
    - **This paper:** We ask, *who cross-subsidizes whom, and to what extent?*
    - **Motivation:** To better understand the distributional consequences of more cost-reflective pricing, which a) can improve economic efficiency, and b) is now technologically feasible in many jurisdictions.

Average wholesale prices, Victoria 2018



- Electricity use at the evening peak is cross-subsidised on-average by consumption overnight and during the middle of day

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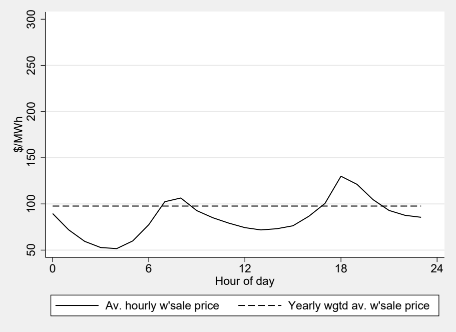
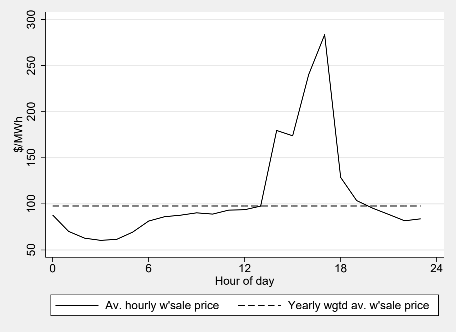


Non-summer



Summer

- If wholesale energy component of electricity bills are socialised via a year-long fixed price, then consumption at the summer peak is the largest recipient of cross-subsidies

Growing pertinence of cost-reflective electricity pricing

- Metering upgrades
  - Possible to monitor consumption at high frequency, therefore vary retail prices at high frequency
- Increasing variation in wholesale procurement costs (predictable + idiosyncratic)
  - Changes in electricity supply (eg. intermittent renewables)
  - Changes in electricity demand (eg. extreme and prolonged weather events + A/C)

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- Incentivising demand flexibility requires more cost-reflective pricing
- But what are the distributional consequences from real-time pricing?

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- Main findings:
  - Households in areas with low house prices, high levels of renters, and more elderly residents are the net **funders** of cross-subsidies from flat-rate pricing.
    - E.g, average wholesale procurement costs in high rental neighborhoods is 9.91 c/kWh, 11% less than equivalent households in high owner-occupier neighborhoods (11.15 c/kWh).
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  - Magnitude of cross-subsidies have been increasing, co-incident with solar penetration
- Results raise possibility that cost-reflective electricity pricing could *on average* benefit more vulnerable segments of the population

Roadmap

1. Introduction
2. Literature
3. Data and setting
4. Method overview
5. Results
6. Discussion

Selected Literature

Distributional impacts from electricity tariff structures:
Network tariffs: Simshauser (2014); *Net-metering + clean energy subsidies*: Borenstein (2012), Borenstein and Davis (2016), Borenstein (2017); *Energy pricing*: Simshauser and Downer (2016), Cahana et al. (mimeo)

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Empirical studies of electricity use:
High frequency data: Cicala (2020); *Disaggregated data*: Jessoe and Rapson (2014), Wolak (2015), Lynham et al. (2016), ACIL Allen (2019); *Demographic data*: Brounen et al. (2012); Lyubich (2020)

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Welfare economics of fixed rate and real-time electricity pricing:
Borenstein (2005), Borenstein and Holland (2005), Holland and Mansur (2006)
⇒ We identify population groups that would win/lose on average if they were to adopt RTP.

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- Time: Pre-Covid; significant renewable penetration (eg. 2GW rooftop solar)

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- Climate: Summer price peak, Winter + Summer highest use periods, particularly in early evening
- Retail pricing:
  - Contestable retail markets
  - Fixed-price plans dominate ($\approx$90%), no real-time pricing, customers switch on average every 4-7 years (CME, 2017)
  - Exercise in this paper recovers average wholesale procurement costs for groups of households
    - Can relate findings to cross-subsidies given prevalence of fixed price plans

Data

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- Electricity use
  - Half-hourly, substation level, (DNSPs; see paper for public source links)

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- Electricity use
  - Half-hourly, substation level, (DNSPs; see paper for public source links)
- Electricity prices
  - Half-hourly, VIC price, AEMO
- Housing, demographics, climate
  - Postcode-level, Australian Bureau of Statistics
  - Weather-station-level, Bureau of Meteorology

Data

Final:

- Substation (s) x half-hour (t) panel
- Electricity use ($Q_{s,t}$), Wholesale procurement cost ($PC_{s,t} = Q_{s,t} * P_t^{VIC}$)
- Map each postcode + weather station to closest substation (see paper)
  - $|I_s|$: Number of households; $|J_s|$: Number of businesses
  - Z_s: Vector of housing, demographics, climate characteristics

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Coverage:

- We include substations with complete electricity and housing+demographic data
- 5,151,930 people, 1,706,786 residential dwellings and 47,530 businesses connecting to the 157 substations in our sample.
- Covers 80-90% of the total population in 2018 Victoria

Method overview

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- Extended model estimates how household load varies with demographic and housing rankings of substations
- Can measure things such as:
  - Average household load for connections to a substation that ranks in the top tercile in income across all substations
  - Average wholesale procurement cost per kWh of serving households that connect to a substation with particular characteristics

Usage profiles: Base statistical model

- 48 models indexed by h (one for each half-hour of day)

$$\underbrace{Q_{s,t}}_{\text{subs'n kW}} = \alpha_h + \beta_h \cdot \underbrace{|I_s|}_{\text{N h'hold}} + \gamma_h \cdot \underbrace{|J_s|}_{\text{N bus}} + \epsilon_{s,t}$$

- Recover average electricity use in half-hour h over 2018 for households (β_h) and businesses (γ_h), assuming $E(\epsilon_{s,t} | I_s, J_s) = 0$. (OLS)

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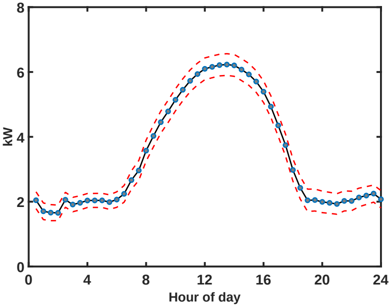
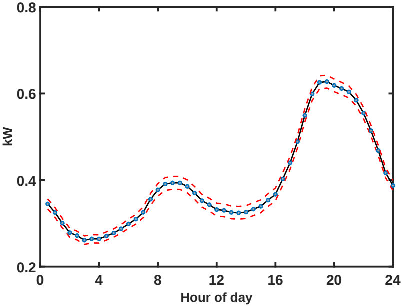


Business profiles



Household profiles

- Business use heavily concentrated between 9-5
- Households exhibit the so-called “duck-curve”

Usage profiles: Full statistical model

- Include vector of substation-level characteristics
- Each substation ranked into terciles (high, medium, low) for 12 measures
  - Demographics: prop. of people over age 65; av. h'hold size, prop. born o'seas; prop. work from home; unemployment; av. income; prop. Uni/TAFE
  - Housing: prop. rental; median house price; residential density; prop. rooftop solar
  - Climate: cooling degree days

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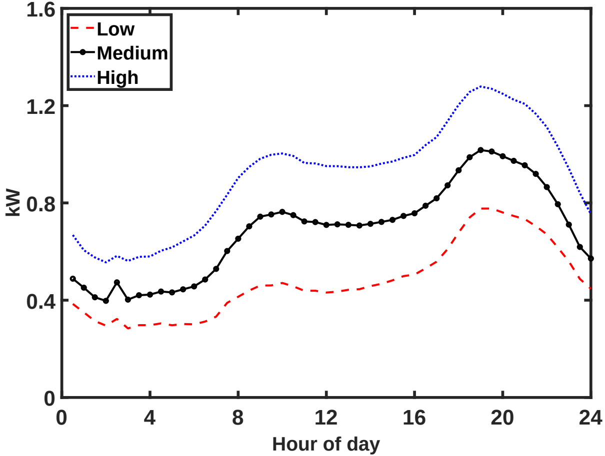
$$Q_{s,t} = \alpha_h + \boldsymbol{\beta}_h \cdot \underbrace{\boldsymbol{Z}_s}_{\text{Char's}} \cdot |I_s| + \gamma_h \cdot |J_s| + \epsilon_{s,t}$$

- $\boldsymbol{Z}_s$ a vector of binary variables
- Can use $\hat{\boldsymbol{\beta}}_h$ to estimate average usage for households in neighbourhoods with characteristics $\boldsymbol{Z}_s$

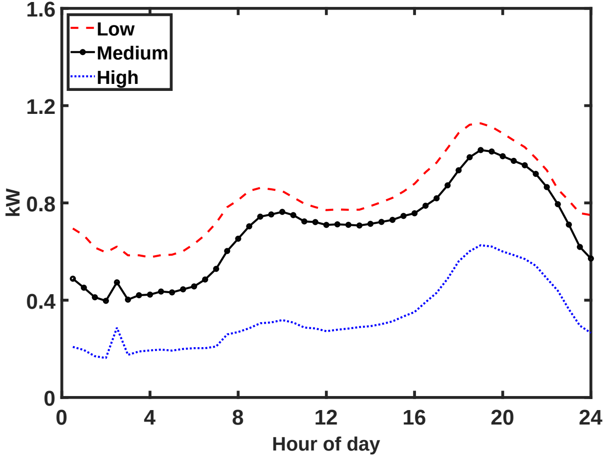
Results: Demographic characteristics + consumption



Estimated profiles by average size of household in the neighbourhood

- Electricity use is higher across all hours of day for households in areas with an older population, larger households, more overseas-born

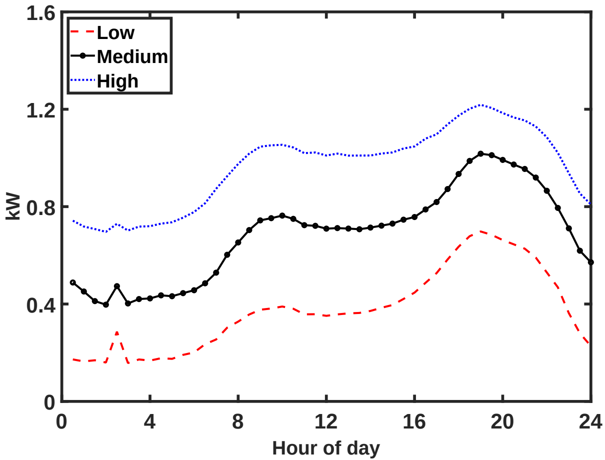
Results: Housing + consumption



Estimated profiles by median house price in the neighbourhood

- Electricity use is higher across all hours of day for households in areas with more rental properties, and lower house prices

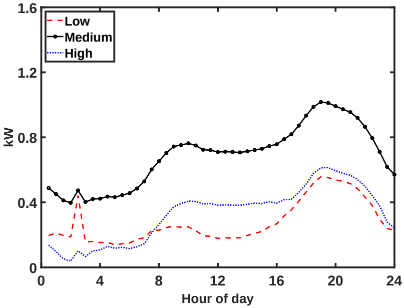
Results: Housing + consumption



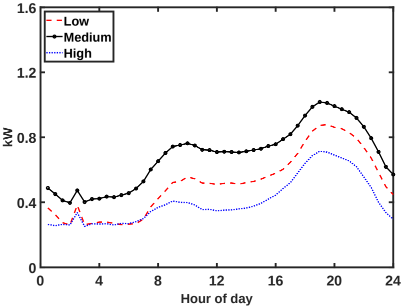
Estimated profiles by neighbourhood rental rates

- Low rental shares (high OO shares): have lower overall usage but higher weights during the evening peak

Results: Monotonicity with respect to characteristics?



Average income



Rooftop solar proportion

- Middle-income areas highest users
- Middle-solar area higher users (reminder: descriptive, not causal statistical model)

Procurement cost profiles: Base statistical model

- Wholesale procurement cost: Same framework as usage profiles, replace $Q_{s,t}$ with $PC_{s,t}$ - the procurement cost of energy delivered via substation s at wholesale spot prices at time t

$$PC_{s,t} = \alpha_h^{PC} + \beta_h^{PC} \cdot |I_s| + \gamma_h^{PC} \cdot |J_s| + \epsilon_{s,t}^{PC}$$

Results: Cross-subsidisation across population characteristics

- We construct wholesale cost per kWh for households in areas with specific characteristics from our early estimates
- Mathematically, for a given Z calculate $\frac{\sum_{h=1}^{48} \hat{\beta_h^{PC}} \cdot \mathrm{Z}}{\sum_{h=1}^{48} \hat{\beta}_h \cdot \mathrm{Z}}$

Results: Cross-subsidisation

Characteristic	Low	Medium	High	Socialized price
Proportion older than 65	**10.71**	**10.40**	**10.18**	**10.42**
Average household size	10.38	10.40	10.26	10.42
Proportion that are born overseas	10.27	10.40	10.20	10.42
Proportion that work from home	10.40	10.40	10.20	10.42
Unemployment rate	11.07	10.40	10.56	10.42
Average income	11.27	10.40	11.29	10.42
Prop. with post-school qualifications	10.24	10.40	10.08	10.42
Proportion of dwellings rented	**11.15**	**10.40**	**9.91**	**10.42**
Median house price	**10.04**	**10.40**	**10.98**	**10.42**
Residential density	10.33	10.40	11.07	10.42
Prop. of dwellings with rooftop solar	10.76	10.40	10.77	10.42
Cooling degree days	10.42	10.40	10.27	10.42

Average cents per kWh if procuring energy at spot prices, assuming all other characteristics of the residence location are ranked in the middle tercile.

Results: Cross-subsidisation summary

- Neighbourhood characteristics with lower wholesale procurement costs per kWh
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⇒ Cross-subsidies from fixed-rate electricity tariffs, *on-average*, are funded by groups usually considered more vulnerable, with recipients that are usually considered more affluent.

⇒ Magnitudes matter: For example, average annual implicit transfer of $43 away from each household in high rental neighbourhoods, or approximately $25 million collectively (all other characteristics held equal).

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Distributional considerations

- At observed levels of consumption, it appears that more vulnerable groups would pay *less* under RTP than fixed-rate pricing
- It is possible that RTP could have pro-social redistributive properties

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Distributional considerations

- At observed levels of consumption, it appears that more vulnerable groups would pay *less* under RTP than fixed-rate pricing
- It is possible that RTP could have pro-social redistributive properties
- CAVEATS:
  - RTP substantially changes risk profiles and attention costs of end-users
    - See *Griddy* customers in Texas Feb 2021 blackouts...
  - Certain to be household-specific winners and losers

Discussion - real-time pricing (RTP)

Efficiency considerations

- Clear economic argument for benefits from RTP
  - Incentivise consumption when costs of generation are low (also likely to be "green")
  - Disincentivise consumption when costs of generation are high (also likely to be "brown")

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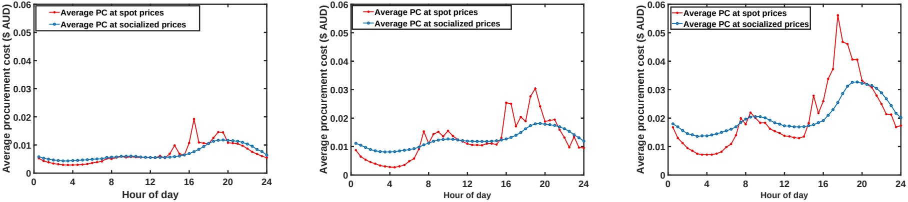
  - We found higher wholesale procurement cost in areas with more owner-occupiers and more expensive homes
  - Are these households best equipped to install smart appliances and offer automated demand flexibility?
- Optimistic interpretation: Jurisdictions with fixed, socialized electricity prices may be able to both improve economic efficiency and redistribute payment shares away from more vulnerable populations with RTP

Discussion - renewable penetration and RTP



2014
734MW of
rooftop solar

2016
1,152MW of
rooftop solar

2018
2,039MW of
rooftop solar

- Average procurement cost per half-hour at w'sale spot ($, red)
- Average procurement cost per half-hour at socialised prices ($, blue)
- Extent of cross-subsidies has been increasing, coincident with solar penetration
- Could renewable penetration reinforce efficiency *and* pro-social distributional outcomes from RTP?

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  - Areas with low house prices
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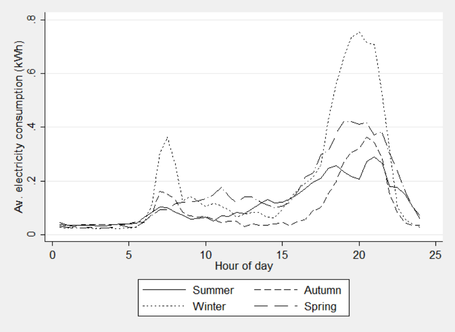
- Results raise possibility that RTP plan offerings can have positive pro-efficiency *and* pro-social distributional outcomes
  - Further work: Risk preferences, attention costs, automation costs, consumer protection.



The Leslie household contributes to the duck curve and feels the cold in Winter...

(This project would have been a lot easier if Victoria's smart meter data was readily available to researchers!)

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https://sites.google.com/site/gwleslie/