

Residential Demand Response — A Case Study in California

Datong Paul Zhou, Maximilian Balandat, Claire Tomlin
UC Berkeley, CA, USA

Demand Response as an Ancillary Service

Ancillary Services

- Operations beyond generation and transmission to maintain grid stability
 - Spinning reserves
 - Non-spinning (supplemental) reserves
 - Frequency control

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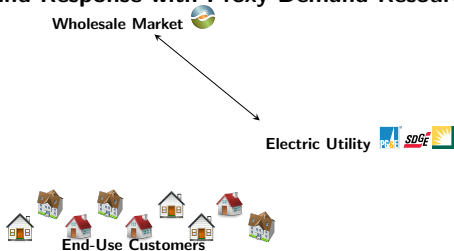
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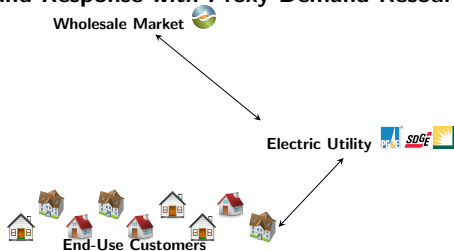
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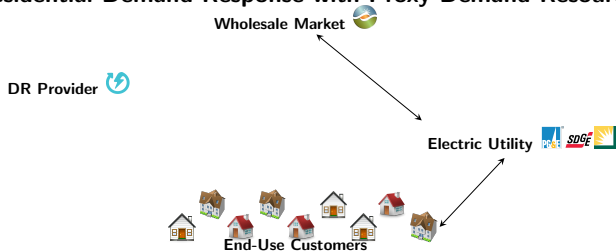
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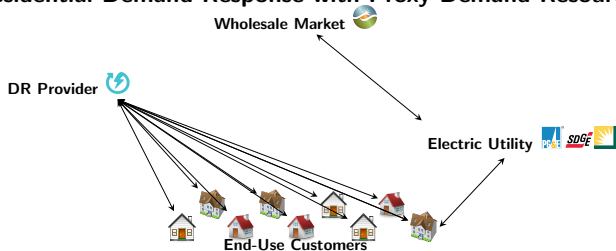
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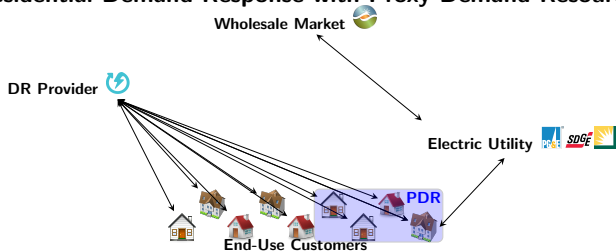
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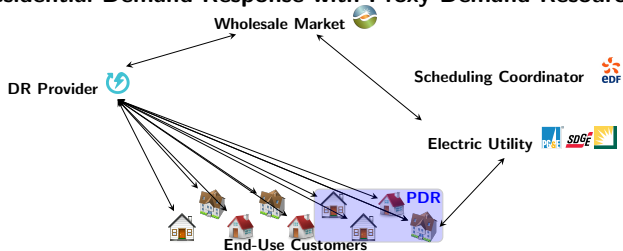
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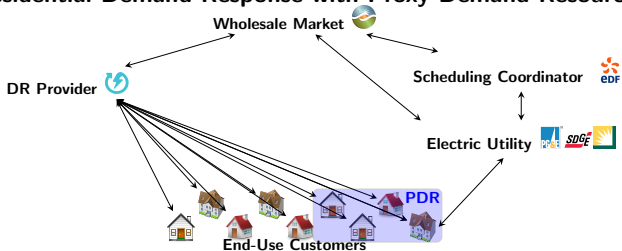
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Fundamental Problem of Causal Inference

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- Observe *either* y_{it}^0 or y_{it}^1 : $y_{it} = y_{it}^0 + D_{it} \cdot (y_{it}^1 - y_{it}^0) \quad \forall t \in \mathbb{T}$

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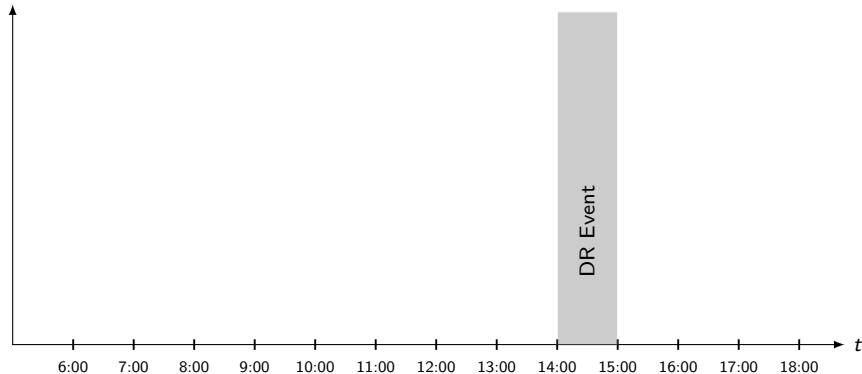
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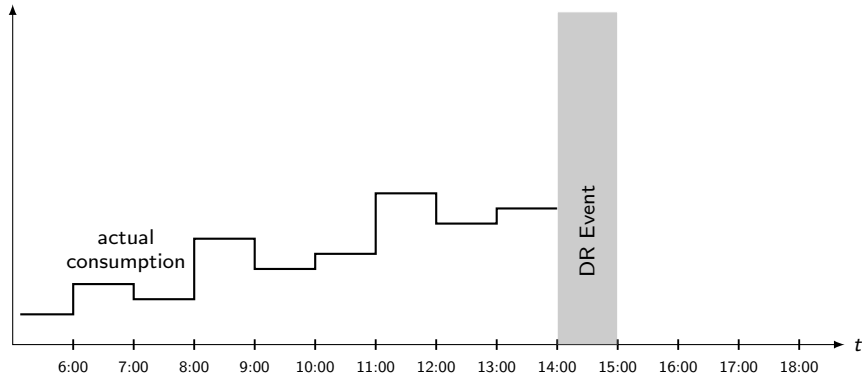


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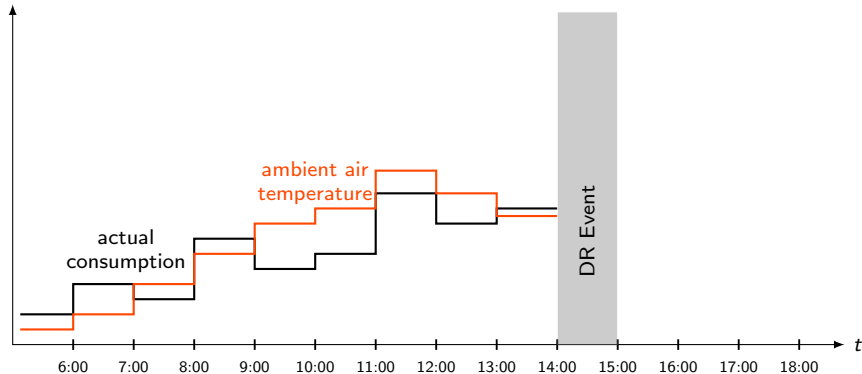


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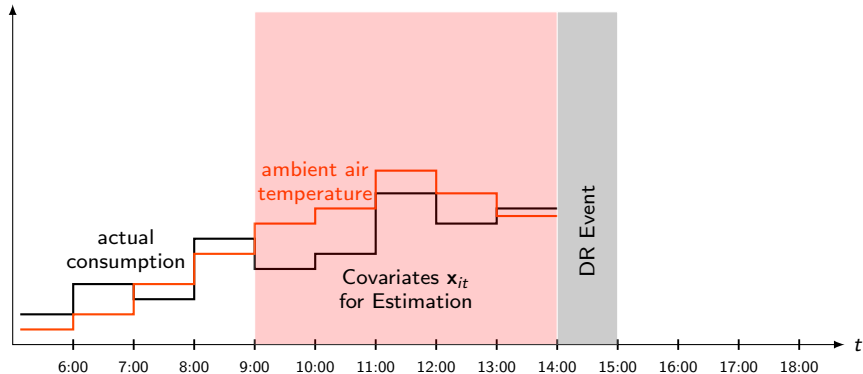


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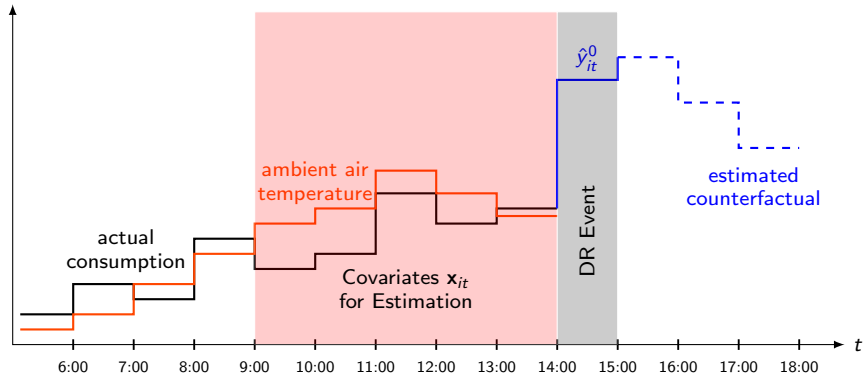


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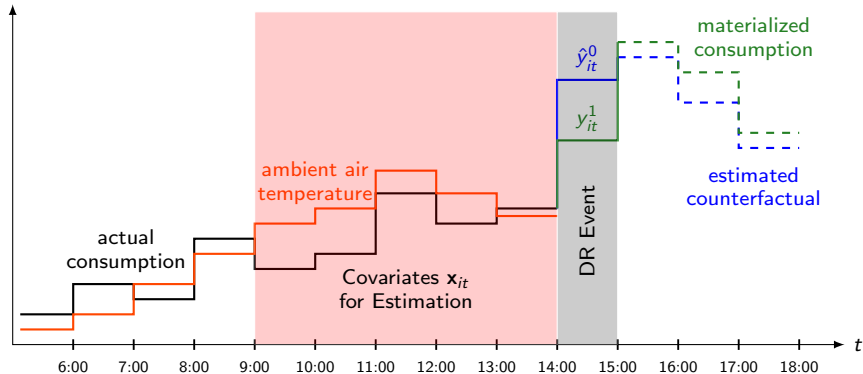


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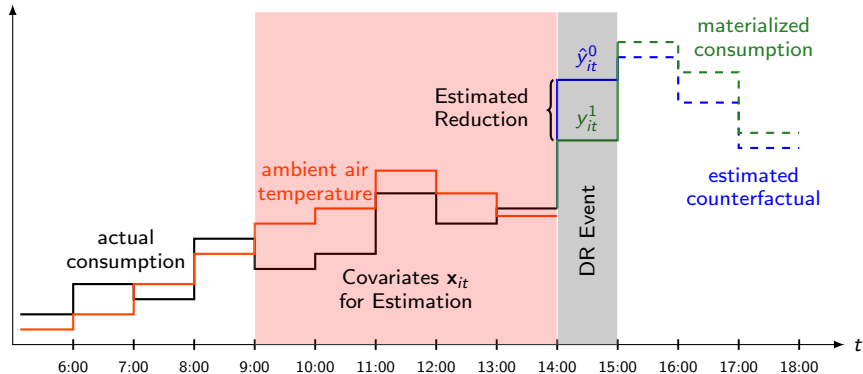


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Randomized Controlled Trial (RCT)

Why?

- RCT as experimental gold standard
- Goal: Estimate treatment effects of DR in *non-experimental* fashion
- Idea: Benchmark non-experimental estimates against ground truth RCT

Experiment funded by CEC and carried out by OhmConnect, Inc.

- $\approx 10,000$ users, November 2016 - December 2017.
- Reward levels randomly chosen from $\{0.05, 0.25, 0.50, 1.00, 3.00\} \frac{\text{USD}}{\text{kWh}}$

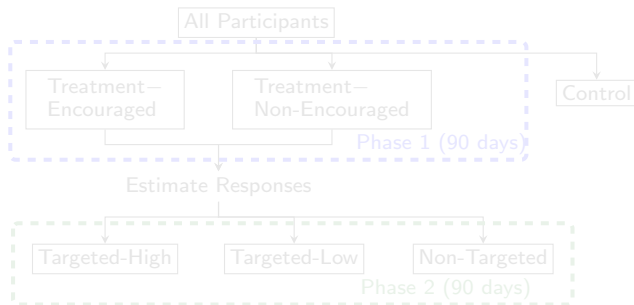


Figure: Setup of Experiment

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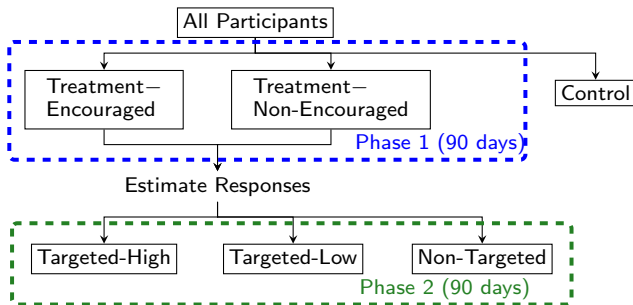


Figure: Setup of Experiment

Summary Statistics

Historical Smart Meter Data Availability by Group

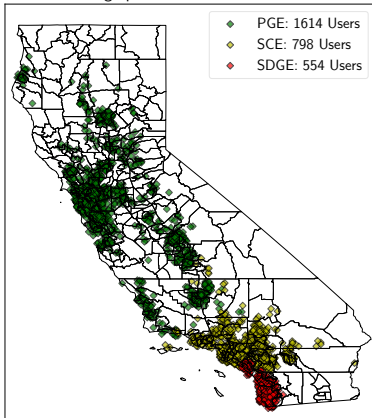
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Treatment—Enc.	4,626	1,802	39.0
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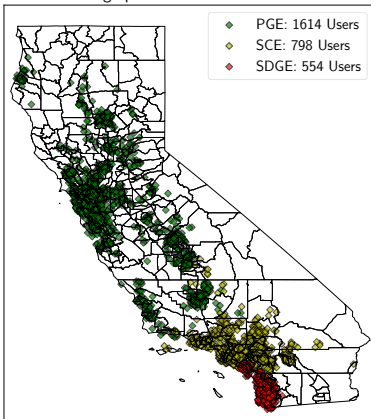


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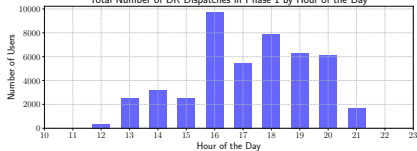
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Total Number of DR Dispatches in Phase 1 by Hour of the Day

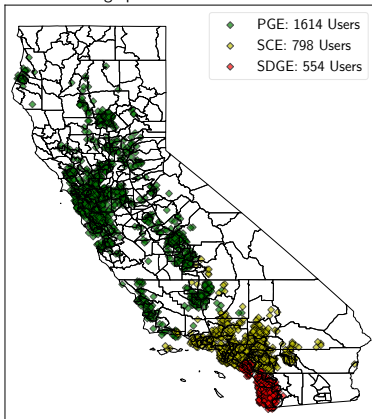


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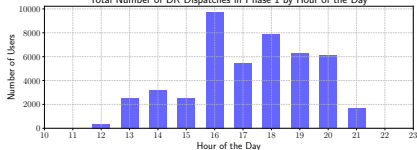
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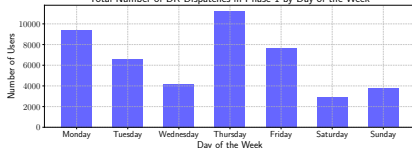
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Total Number of DR Dispatches in Phase 1 by Day of the Week

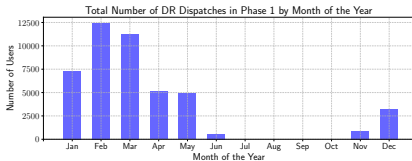
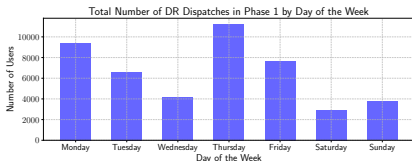
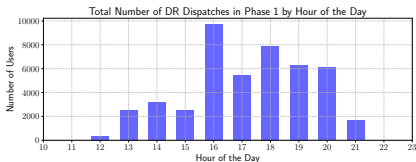
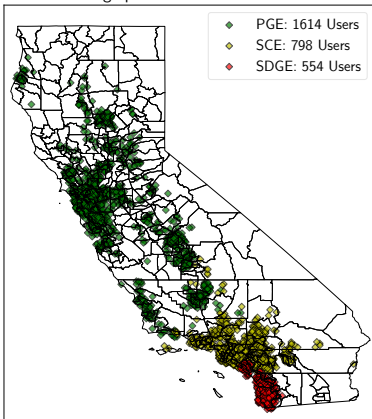


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Results for Nonexperimental Estimators

Treatment Effects

- Nonexperimental Estimation admits *Individual Treatment Effects* (ITEs)
- Aggregation of ITEs yields *Average Treatment Effect* (ATE)
- Use bootstrapping to construct unit-level confidence intervals

Results (Nov 2016 - April 2017)

- ATE is -0.033kWh (-4.7%)
- 95% confidence interval: $[-0.048, -0.019]\text{kWh}$
- Automated vs. non-automated users: -9.9% vs. -4.3% .

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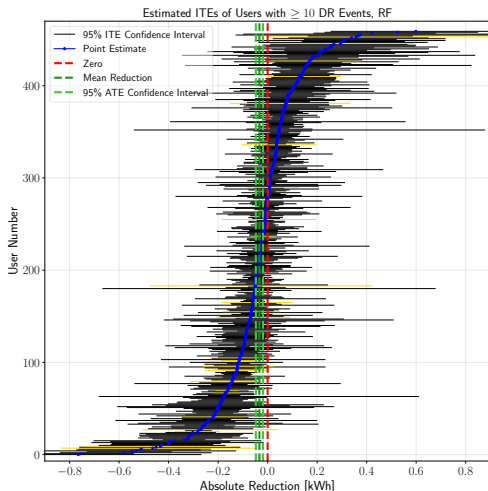
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Results for Fixed-Effects Estimation

Fixed Effect Model

- Regression specification:

$$\text{kWh}_{it} = \mathbf{X}_{it}\beta + \alpha_{it} + u_{it}. \quad (1)$$

- Fixed effects term α_{it} removes persistent differences across users:

$$\alpha_{it} \sim C(\text{HoD}_{it}) : C(\text{is_Bday}_{it}) + C(\text{MoY}_{it}). \quad (2)$$

- Estimation by Incentive Level:

$$\mathbf{X}_{it} = [\text{is_treat}_{it} \quad \text{BL}_{it} \quad T_{it} \quad R_{it}] \quad (3a)$$

$$R_{it} = [\mathbb{1}(r_{it} = 0.05) \quad \cdots \quad \mathbb{1}(r_{it} = 3.00)] \quad (3b)$$

- Estimation by hour of the day:

$$\mathbf{X}_{it} = [\text{is_treat}_{it} \quad \text{BL}_{it} \quad T_{it} \quad C(\text{HoD}) : \text{is_DR}_{it}] \quad (4)$$

- Estimation by month of the year:

$$\mathbf{X}_{it} = [\text{is_treat}_{it} \quad \text{BL}_{it} \quad T_{it} \quad C(\text{MoY}) : \text{is_DR}_{it}]. \quad (5)$$

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- Estimation by hour of the day:

$$X_{it} = [\text{is_treat}_{it} \quad \text{BL}_{it} \quad T_{it} \quad C(\text{HoD}) : \text{is_DR}_{it}] \quad (4)$$

- Estimation by month of the year:

$$X_{it} = [\text{is_treat}_{it} \quad \text{BL}_{it} \quad T_{it} \quad C(\text{MoY}) : \text{is_DR}_{it}]. \quad (5)$$

Results for Fixed-Effects Estimation

Fixed Effect Model

- Regression specification:

$$\text{kWh}_{it} = X_{it}\beta + \alpha_{it} + u_{it}. \quad (1)$$

- Fixed effects term α_{it} removes persistent differences across users:

$$\alpha_{it} \sim C(\text{HoD}_{it}) : C(\text{is_Bday}_{it}) + C(\text{MoY}_{it}). \quad (2)$$

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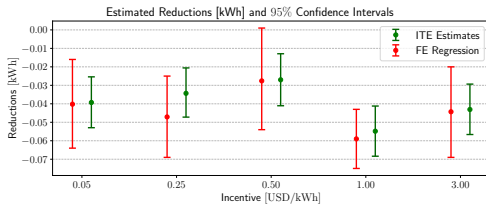
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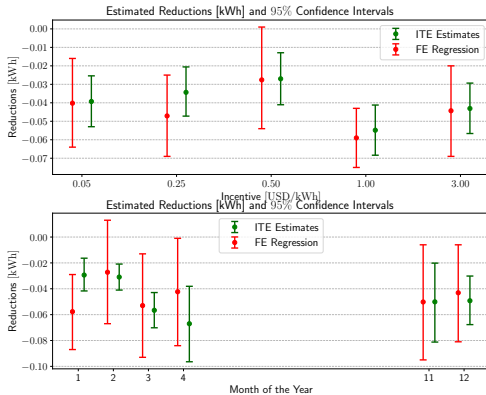
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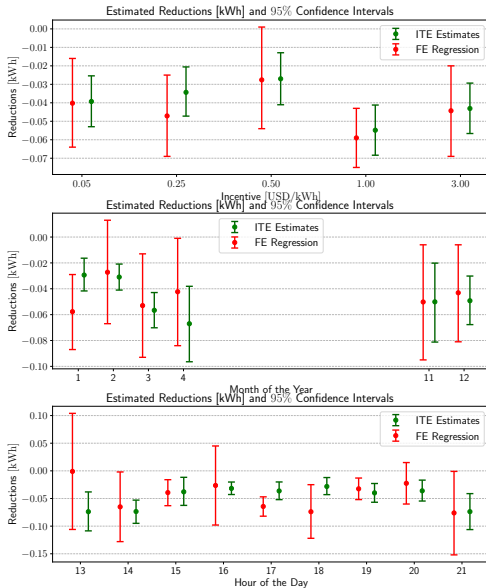
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Next Steps

- Evaluate effect of *adaptive targeting* on payout to users
- Idea: Utilize heterogeneity of users to make “better decisions”

THANK YOU!
QUESTIONS?