Field Experiment of Dynamic Electricity Pricing in Los Alamos

Takanori Ida and Wenjie Wang

Graduate School of Economics,

Kyoto University

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Outline

- Introduction of the **Demand Response experiment** in Los Alamos, US.
- Different dynamic pricing scenarios: **Critical Peak Pricing** (CPP) and **Peak Time Rebate** (PTR).
- Grouping design for our **Randomized Control Trial** (RCT): Opt-in CPP, Opt-out CPP, Opt-out PTR, Control.
- What kind of households participate into the program; what kind of households choose opt-in CPP.
- We estimate **Peak-cut effects** of each treatment groups using Panel Fixed Effects model.
- For welfare analysis, we calculate **Actual/Counterfactual Monthly Bills** for treatment groups.

Research Objectives: Opt-in/Opt-out for CPP&PTR

- Tokyo Electricity Power Company (TEPCO) will deploy smart meters across **27 million customers** until 2020. We must consider how to migrate from the present flat rate to dynamic pricing systems.
- Till date, the **SMUD** (Sacramento Municipal Utility District) experiment in California was the only study to have investigated the opt-in/opt-out CPP framework.
- Ida, Ito and Tanaka (2013) studied **variable-CPP (VCPP)** using field experiment in Kitakyusyu, Kyoto, Toyota and Yokohama.
- However, CPP can be perceived as **punishing customers** when they need the power most.
- And there were no investigation to study the **opt-in/opt-out choices of both CPP and PTR**. The Los Alamos experiment becomes the first trial to address the opt-in/opt-out choice of both pricing scenarios.

Demand Response Experiment in Los Alamos

- The experiment is sponsored by NEDO. It is implemented **from July to September** in summer and **from December to February** in winter in **Los Alamos, New Mexico.** Also be implemented in summer/winter 2014.
- The main objective is to evaluate **peak-cut effects** of different dynamic electricity pricing scenarios.
- On-peak time is set to be **4pm – 7pm of weekdays**.
- Toshiba's Micro EMS decides the dates of **Demand Response (DR)** events based on prediction of temperature and on-peak power usage.
- The number of DR days is **15 max.** for summer/winter, respectively.
- Participants will **get incentive points** according to amount of conservation.
- DR message is sent to participants one day ahead of the DR day as well as in the morning of the DR day. The third message is sent to the participant the day after the DR day to convey the incentive points total.

Demand Response Experiment in Los Alamos

- We collaborate closely with the **Department of Public Utilities in Los Alamos County**, New Mexico.
- www.losalamosnm.us/utilities/Pages/LosAlamosSmartGrid.aspx

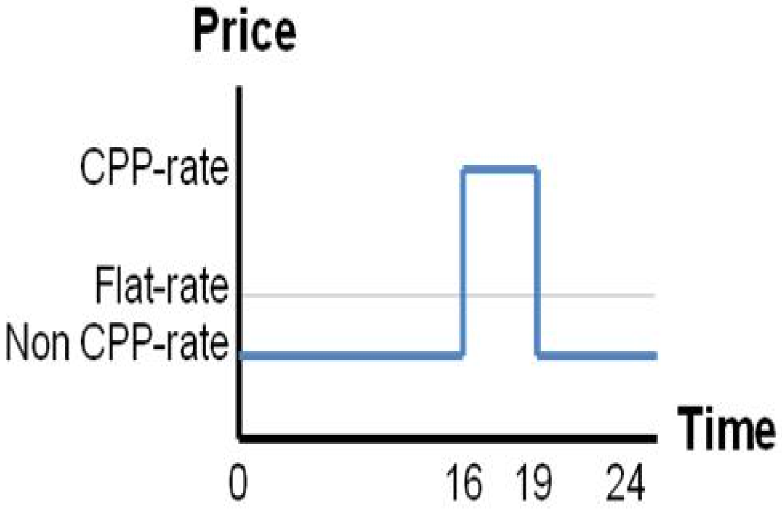
- **DR Event Days:**
- **7/29, 30, 31; 8/1, 2, 9, 13, 14, 15, 19, 20, 21, 26, 28, 29.**

- **Prior to the experiment:**
- DPU flat rate (**9.52cents/kWh**) used for all participants.

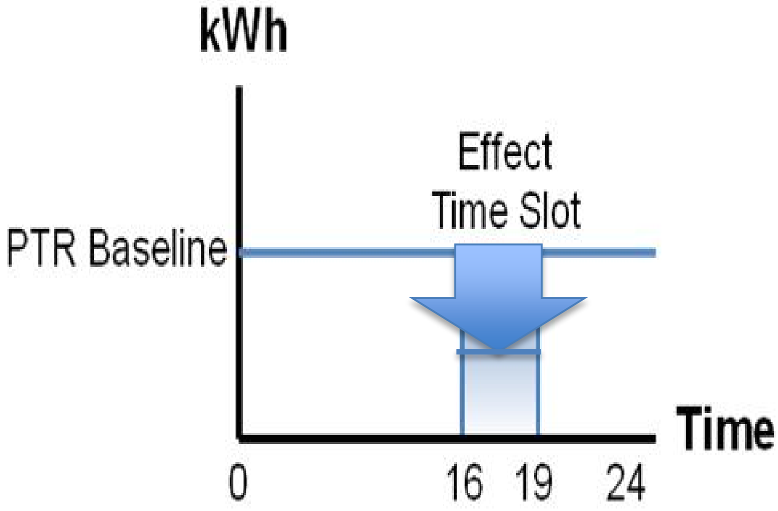
- **During the experiment:**
- **CPP participants**: premium rate (**75 cents/kWh**) during **DR peak times** (4pm-7pm on DR event days listed above) & discounted rate (**7.77 cents/kWh**) during off-peak times (every day, hour of the summer season that is not designated as the DR peak times)
- **PTR participants:** earn PTR rebate (**75 cents/kwh**) x (PTR baseline – power usage) during **DR peak times**. PTR baseline: average of three highest use (4pm-7pm) days in previous week.
- **Control group:** flat rate (**9.52cents/kWh**).
- * Flat rate is used to customers who were assigned to CPP/PTR groups but decided not to take the offer.

Different Pricing Scenarios

- **Critical Peak Pricing (CPP):** very high price during peak period **(lose points)** and low price during off-peak period **(earn points)**; reduce on-peak consumption to **prevent from losing points**.
- **Peak Time Rebate (PTR):** baseline is from consumption in previous week; customers with peak-time consumption less than baseline will **receive points (PTR rate x kWh saved)**.



Incentive framed as losses (penalties)



Incentive framed as gains (rebates)

Incentive Rules for Different Groups

- **CPP on-peak:** Usage x (Flat Rate – CPP Peak Rate) = **Points Lost**
- **CPP off-peak:** Usage x (Flat Rate – CPP Off-peak Rate) = **Points Earned**

Example: on Aug. 2nd , participant "X" used 2 kWh on-peak & 8 kWh off-peak.

2 kWh x ($0.0952 - $0.75) = -$1.31, 8kWh x ($0.0952 - $0.0777) = $0.14

Thus, "X" lost $1.27 on this DR day.

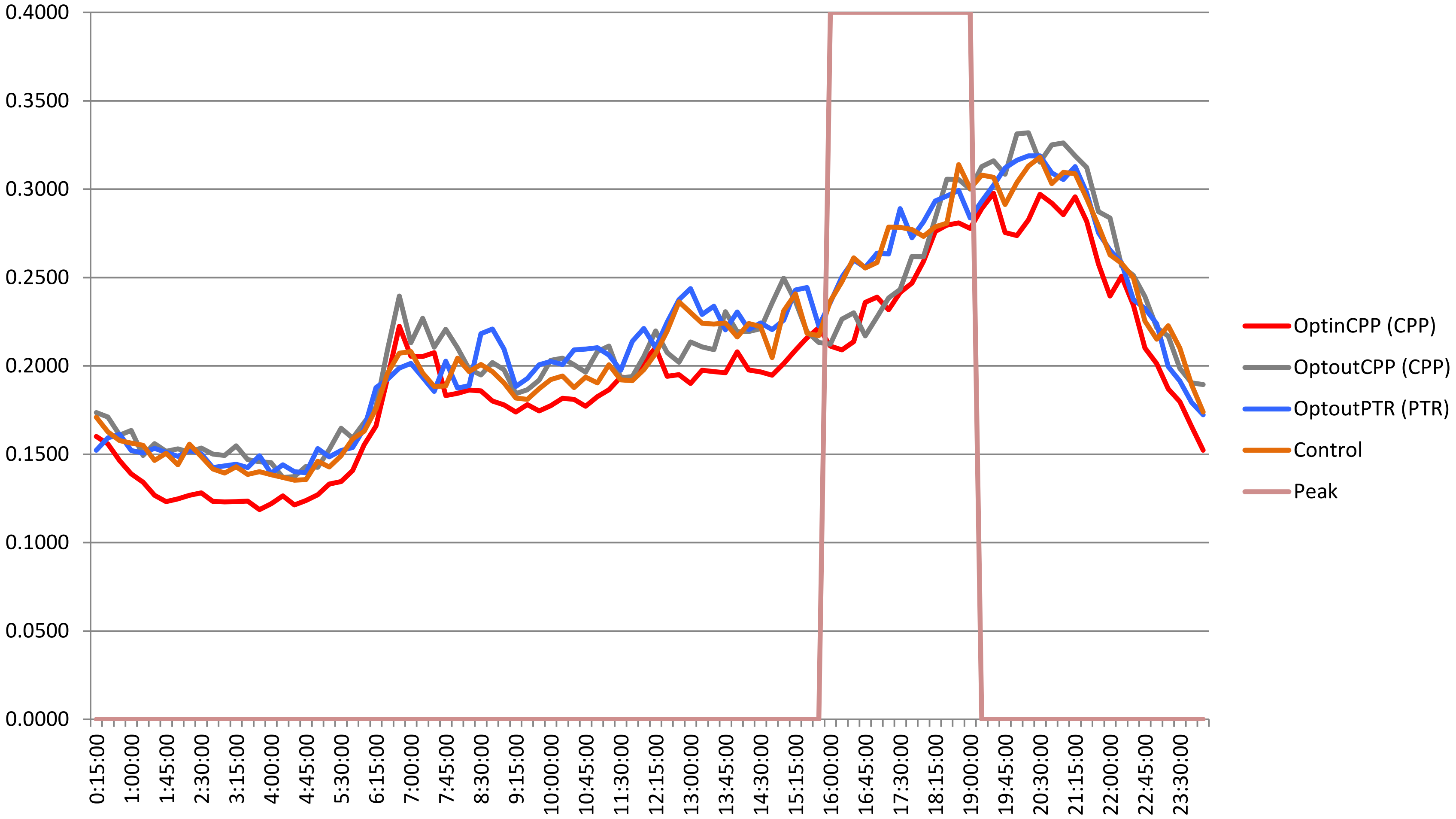
- **PTR:** Baseline* – On-peak Usage = Baseline Difference

PTR Rebate ($0.75 per kWh) x Baseline Difference = **Total Rebate Earned.**

* Baseline = (on-peak) average of **three highest use days in previous week.**

Example: on Aug. 2nd, participant "Y" used 2 kWh during on-peak period, the Baseline = 3.66 kWh based on "Y"'s power usage in previous week. Thus, "Y" earns: (3.66 kWh - 2 kWh) x $0.75 = $1.245 on this DR day.

Average Electricity Consumption of Each Group on a Demand-Response Event Day



e.g., **CPP message (by SMS or E-mail):** Price Event, Peak 4p-7p. Rate $0.75/kWh Peak, $0.0777/kWh Non-peak. PTR grp receives similar msg but with different rate.

Grouping Design

Participants are assigned to the following 4 groups using Randomize Control Trial (RCT).

Groups	Default	If Opt-in then	If Opt-out then	Expected Selection Probability
Opt-in CPP	Flat	CPP	N/A	Low
Opt-out CPP	CPP	N/A	Flat	
Opt-out PTR	PTR	N/A	Flat	High
Control	Flat	N/A	N/A	

Opt-in CPP grp may actively choose to “opt-in” to receive messages;

flat-rate being default rate => CPP rate

Opt-out CPP/PTR grps may actively choose to “opt-out” in order not to receive msg.;

CPP/PTR rate being default rate => flat-rate

Grouping Result

Groups	Flat	CPP	PTR	Selection Probability
Opt-in CPP	131	232	N/A	63.9%
Opt-out CPP	4	177	N/A	97.7%
Opt-out PTR	5	N/A	173	97.1%
Control	174	N/A	N/A	N/A

Number of participants:

- Totally **1,700 households** were encouraged to participate into the program and **896** actually did.

Who participate into the experiment? (external validity)

- We consider **Binary Choice model:**

$$\Pr(y_i = 1 \mid X) = F(x'_i \gamma)$$

where **y=1** if household i participates into the experiment and **y=0** otherwise. X denotes certain household characteristics, e.g., **household average consumption, the ratio between off-peak and on-peak consumption**. Other data such as **household income** will be provided soon.

Estimation Strategy: we use the data of the control group and of those who decided not to participate. These data are **"clean"** .

To avoid potential bias of not using treatment grps, we use **subsampling:**

N_1 (participants) = 896, N_0 (non-participant) = 804

N'_1 (control group) = 174, N'_0 = ?

For N'_0, subsampling about 20% households randomly from N_0, to mimic the Choice Probability of interest.

Estimation Results (Binary Choice Model)

Explanatory Variables	Model Specification	Marginal Effects
Household Average Consumption	Probit	0.47** (0.21)
Off-peak/On-peak Ratio		-0.03* (0.019)

Remark 1: to guarantee high reliability of subsampling, we implemented **blocked randomization** by blocking on **group of non-participants**, using average consumption (High & Low) and off-peak/on-peak ratio (High/Low). i.e., 4 blocks totally. Then we draw about **40 households from each block**.

Remark 2: for robustness check, we estimate the model using the data of **all the groups before the first DR day**. The estimate result is similar with the coefficient of Average Consumption being positive and that of Ratio being negative.

Who choose Opt-in CPP?

We are also interested in what kind of households tend to choose Opt-in CPP. Similar to previous one, we estimate binary choice model using **Opt-in CPP (CPP) grp. (232 households)** and **Opt-in CPP (Flat) grp. (131 households).**

Explanatory Variables	Model Specification	Marginal Effects
Household Average Consumption	**Probit**	**0.04 (0.19)**
Off-peak/On-peak Ratio		**-0.26** (0.13)**

Remark: we also plan to analyze these choice probabilities using other characteristics such as **household income**, etc. Moreover, a questionnaire survey to the participants is also scheduled.

Estimation Strategy for the Treatment Effects

Intent-to-treat (ITT) & Treatment-on-treated (TOT)

- To study peak-cut effects of different treatment groups (opt-in CPP, opt-out CPP, opt-out PTR), we are interested in both ITT and TOT.

- **ITT: Effect of those who were assigned the treatment.** Utility companies may be especially interested in ITT.

  TOT: Effect of those who were actually treated.

e.g., 363 were **assigned** to Opt-in CPP; 232 were actually **treated (63.9%).**

- For the **estimation of ITT**, we use panel fixed effects model by constructing dummy variables for each treatment groups and DR events.

- For the **estimation of TOT**, we use panel two stages least squares (TSLS) regression with dummy variable of **Treatment Assignment** as Instrument.

i.e., we can run first-stage regression:

$$TREATED_i = \alpha_0 + \alpha_1 ASSIGNED + \varepsilon_i$$

Estimation Strategy for Treatment Effects

- Let y_{it} denote household i's electricity consumption during a 30-minute period t. We estimate the ATE using **Panel Fixed Effects** model:

$$\ln y_{it} = \sum_{p \in \{CPPin, CPPout, PTRout\}} \beta_p \cdot D_{it}^p + \theta_i + \lambda_t + \eta_{it}$$

D_{it}^p equals one if household i is in group p and the pricing event occurs in interval t (i.e., 16:00-19:00 during event-days).

θ_i is a **household fixed effect** that controls for persistent differences across households;

λ_i is a **time fixed effect** for each 30-minute interval that accounts for weather/temperature and other shocks specific to t.

*Possible serial correlation in the disturbances η_{it} is taken into account by clustering the standard errors in household level.

Estimation Results (summer 2013)

Group	Intent-to-treat (ITT)	Treatment-on-treated(TOT)
Opt-in CPP	**-6.90%*** (0.016)**	**-10.49%*** (0.025)**
Opt-out CPP	**-4.59%** (0.020)**	**-4.71%** (0.021)**
Opt-out PTR	**-4.06%** (0.019)**	**-4.17%** (0.019)**

Remark 1: because of the high selection probability in Opt-out CPP & Opt-out PTR, the estimates of ITT and TOT are very close to each other. For Opt-in CPP,

Estimate of ITT ≈ Estimate of TOT x Selection Probability (63.9%)

Remark 2: As one would expect, Opt-in CPP group has the largest Peak-cut effect. It seems that Opt-out PTR group has the smallest. However, this is not yet the whole picture.

Estimation Results (summer 2013)

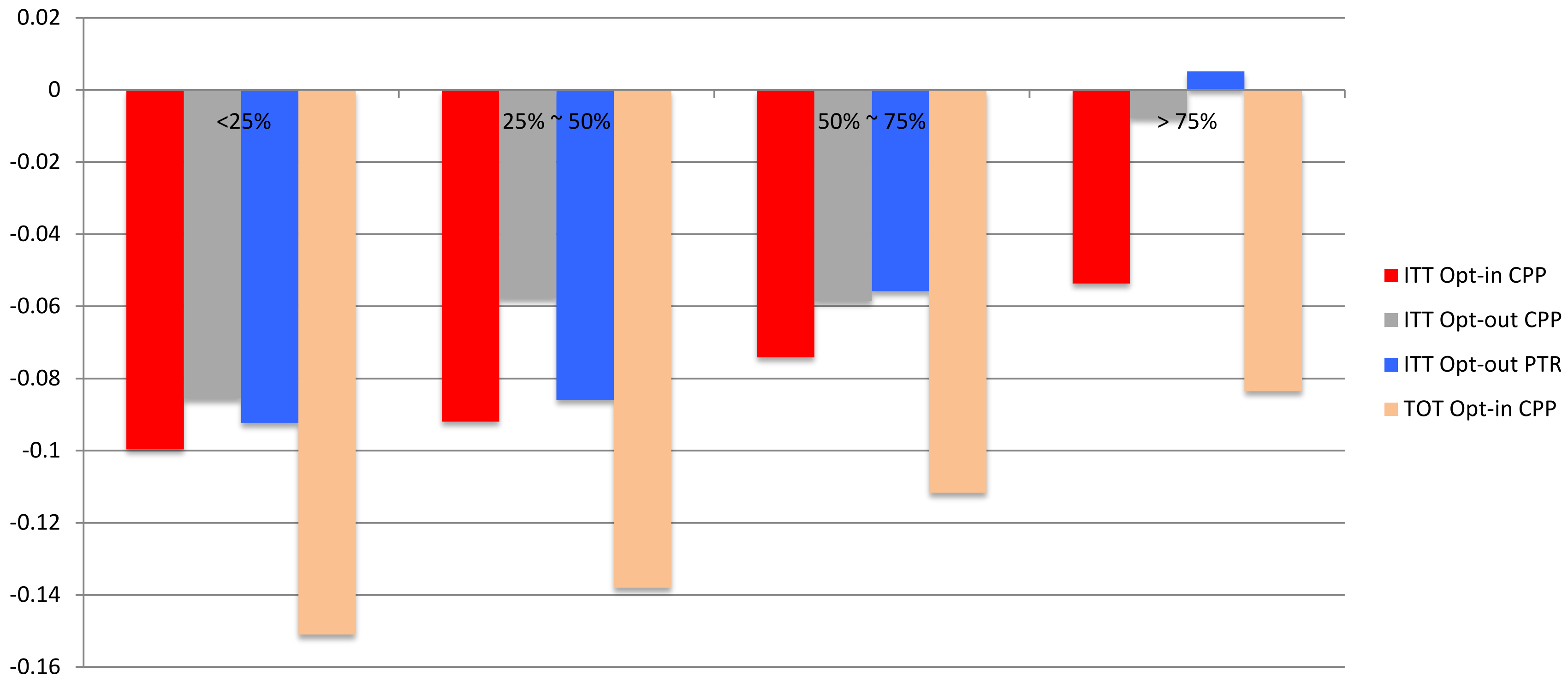
sub-groups based on household avg. consumptions

Avg. Consumption	Treatment Groups	ITT	TOT
<25%	Opt-in CPP	-9.97%*** (0.0392)	-15.10%*** (0.0527)
	Opt-out CPP	-8.55%** (0.0438)	–
	Opt-out PTR	-9.23%** (0.0423)	–
25% ~ 50%	Opt-in CPP	-9.20%*** (0.0256)	-13.80%*** (0.0368)
	Opt-out CPP	-5.77%** (0.0280)	–
	Opt-out PTR	-8.59%*** (0.0307)	–
50% ~ 75%	Opt-in CPP	-7.41%*** (0.0202)	-11.17%*** (0.0319)
	Opt-out CPP	-5.85%** (0.0241)	–
	Opt-out PTR	-5.58%** (0.0246)	–
>75%	Opt-in CPP	-5.37%** (0.0276)	-8.35%* (0.0505)
	Opt-out CPP	-0.78% (0.0354)	–
	Opt-out PTR	0.52% (0.0301)	–

Remark: e.g., for "<25%", we use the data of those who are among the lowest 25% average consumption in each group, etc.

Estimation Results

(sub-groups based on avg. consumptions)



Remark 1: interestingly, the effect of **Opt-out PTR** becomes very high for the subgroups with relatively low average electricity consumption.
(incentives framed as Gain vs. incentives framed as Loss?)

Remark 2: we construct the subgroups using 1) data **before the 1st DR day**, 2) data using **all the non-event weekdays**; the estimation results are similar.

Shadow Billing (Welfare Analysis)

Difference between Actual and Counterfactual Monthly Bills.

Opt-in CPP (CPP chosen): Actual (CPP rate) – Counterfactual (Flat rate)

Mean	p5	p10	p25	p50	p75	p90	p95
-$1.19	-$4.52	-$3.62	-$2.14	-$1.20	-$0.23	+$1.09	+$1.99

Opt-in CPP (Flat chosen): Actual (Flat rate) – Counterfactual (CPP rate)

Mean	p5	p10	p25	p50	p75	p90	p95
+$0.95	-$1.75	-$1.24	+$0.04	+$0.93	+$1.91	+$3.18	+$4.54

Opt-out CPP (CPP chosen): Actual (CPP rate) – Counterfactual (Flat rate)

Mean	p5	p10	p25	p50	p75	p90	p95
-$1.16	-$5.14	-$4.21	-$2.53	-$1.13	-$0.07	+$1.35	+$2.68

Control (Flat): Actual (Flat rate) – Counterfactual (CPP rate)

Mean	p5	p10	p25	p50	p75	p90	p95
+$0.59	-$3.14	-$1.77	-$0.45	+$0.46	+$2.02	+$3.08	+$3.97

Summary

- Field experiment of **Electricity Demand Response** in Los Alamos, New Mexico.
- We study different dynamic pricing scenarios (Opt-in CPP, Opt-out CPP, Opt-out PTR) using **RCT**.
- We investigate what kind of households will participate into the program/choose opt-in CPP.
- We estimate **Peak-cut effects** of each treatment group (& their sub-groups) using Panel Fixed Effects model.
- For welfare analysis, we calculate **shadow billing** for treatment groups.