2014.6.19
スマートコミュニティサミット2014

米国ロスアラモスにおける変動型電力料金のフィールド実験

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May 24th, 2014

日本語要旨

実験設計

住民約1,700名中実験参加者約900名を無作為比較対照実験(Randomized Control Trial, RCT)で、Opt-in CPP、Opt-out CPP、Opt-out PTR、Controlの4グループに分割。

グループ	初期値	Opt-in	Opt-out	選択確率予測
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グループはオプトインするとCPPを受ける。**オプトインしない場合は、定額料金を受ける。
- **Opt-out CPP/PTRグループはオプトアウトすると定額料金を受ける。**オプトアウトしない場合は、CPP/PTRを受ける。
- **Control**グループは定額料金を受ける。

選択確率

Opt-in CPPのCPP選択確率は64%、Opt-out CPPのCPP選択確率は98%、Opt-out PTRのPTR選択確率は97%。

グループ	定額料金	CPP	PTR	選択確率
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

- 住民1,700世帯のうち、実験参加900世帯の特徴は、①平均電力消費量が大きいこと、②負荷平準が低いこと。
- Opt-in CPPグループ363世帯のうち、CPPを選んだ232世帯の特徴は、①負荷平準が低いこと。
- いずれも、デマンドレスポンスで節電に成功すれば、経済的な便益が期待できる。

2013年夏　分析結果

グループ	ITT効果 ＝　選択確率×TOT効果	TOT効果
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)

ITT (Intention to Treat)
トリートメントの勧誘を受けたグロス・ピークカット効果　＝　選択確率　×　TOT効果
Opt-in CPP　＞　Opt-out CPP　＞　Opt-out PTR

TOT (Treatment on the Treated)
トリートメントを受けた場合のネット・ピークカット効果
Opt-in CPP　＞　Opt-out CPP　＞　Opt-out PTR

2014年冬　分析結果

グループ	ITT効果 ＝　選択確率×TOT効果	TOT効果
Opt-in CPP	-4.78%*** (0.013)	-7.12%*** (0.022)
Opt-out CPP	-4.27%*** (0.016)	-4.41%*** (0.016)
Opt-out PTR	-3.26%** (0.015)	-3.37%** (0.016)

ITT (Intention to Treat)

Opt-in CPP ＞ Opt-out CPP ＞ Opt-out PTR

TOT (Treatment on the Treated)

Opt-in CPP ＞ Opt-out CPP ＞ Opt-out PTR

2014年冬は、2013年夏よりも、ピークカット効果が落ちている。

Field Experiment of Dynamic Electricity Pricing in Los Alamos

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May 24th, 2014

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 group 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.

Experimental Design

Demand Response Experiment in Los Alamos

- The experiment is sponsored by NEDO (New Energy and Industrial Technology Development Organization). 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**

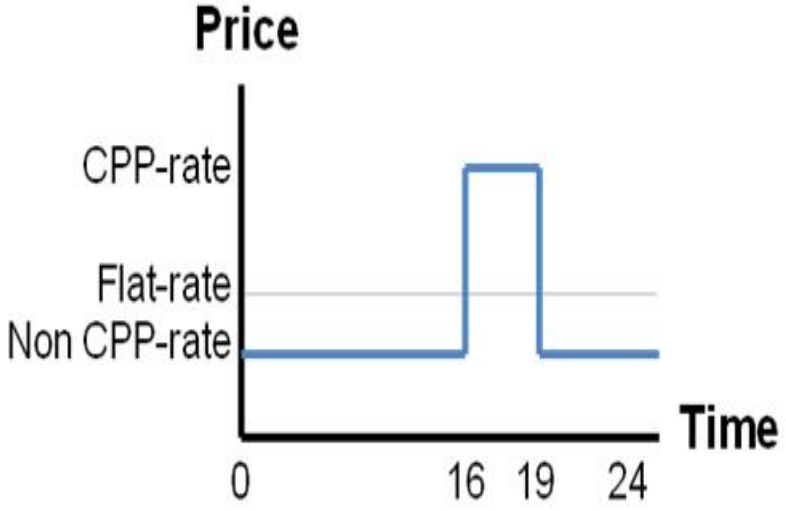
- **DR Event Days:** 15 days for summer, 15 days for winter.

- **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.

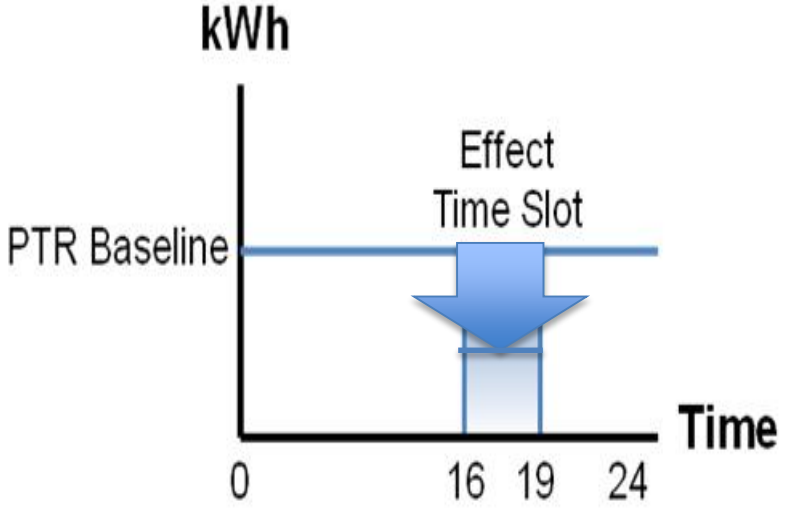
Different Pricing Scenarios

- **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**.



Incentive framed as losses (penalties)

- **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 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.

Grouping Design

Participants are assigned to the following 4 groups using Randomized 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 DR messages;

flat-rate being default rate => CPP rate

Opt-out CPP/PTR grps may actively choose to "opt-out" in order not to receive DR 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 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.

2013 Summer Results

Estimation Results (summer 2013)

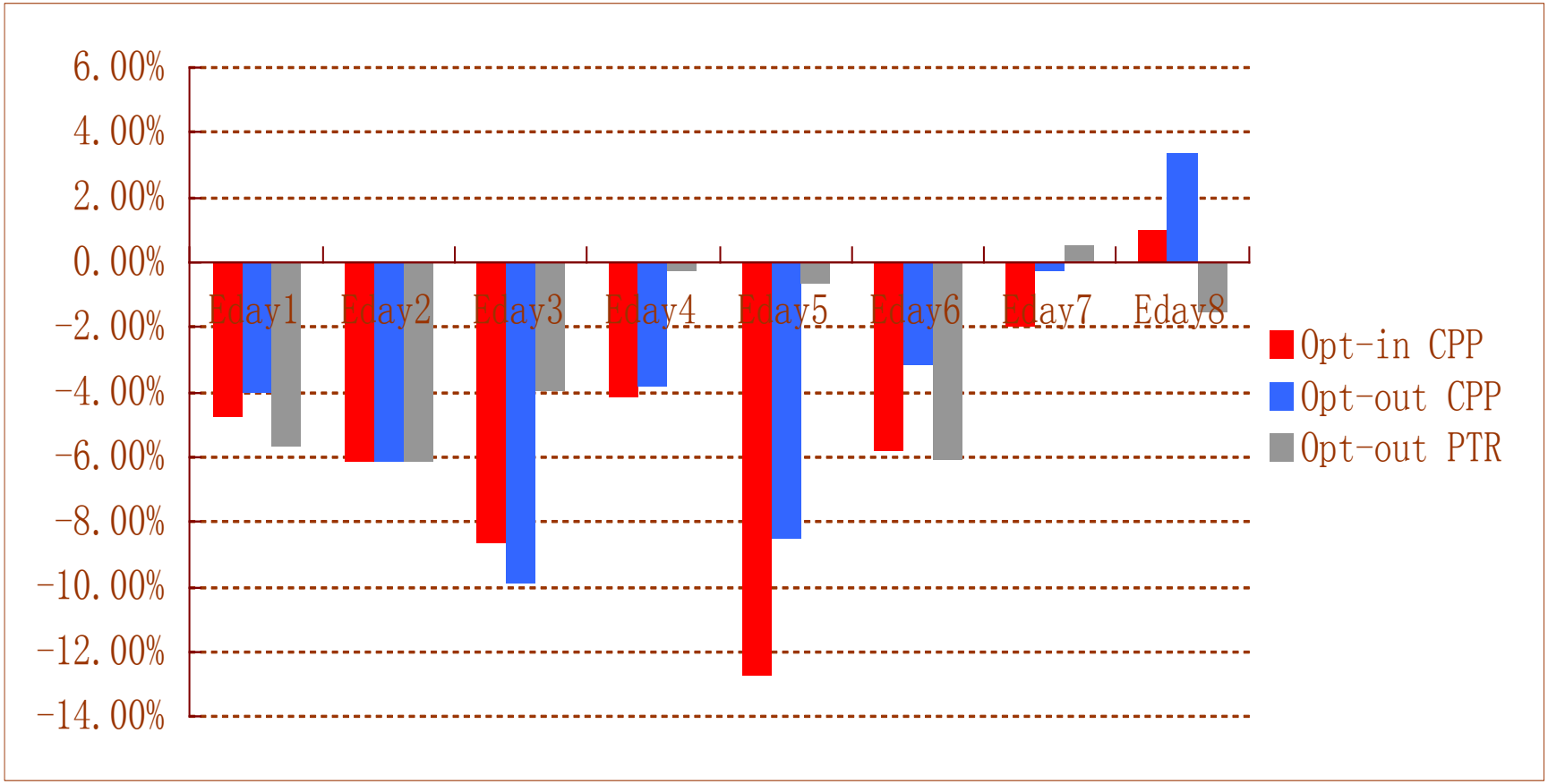
Group	Intent-to-treat (ITT)	Treatment-on-treated (TOT)
Opt-in CPP	**-6.90%*** (0.016)**	**-10.49%*** (0.025)**
Opt-out CPP	**-4.59%** (0.020)**	**-4.71%** (0.021)**
Opt-out PTR	**-4.06%** (0.019)**	**-4.17%** (0.019)**

ITT (gross peak-cut effects): the effects of those who are offered certain treatment (Opt-in CPP, Opt-out CPP, Opt-out PTR).
TOT (net peak-cut effects): the effects of those who actually accepted the treatment, thus excluding customers who were offered the treatment but did not accepted it.

Remark: 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,

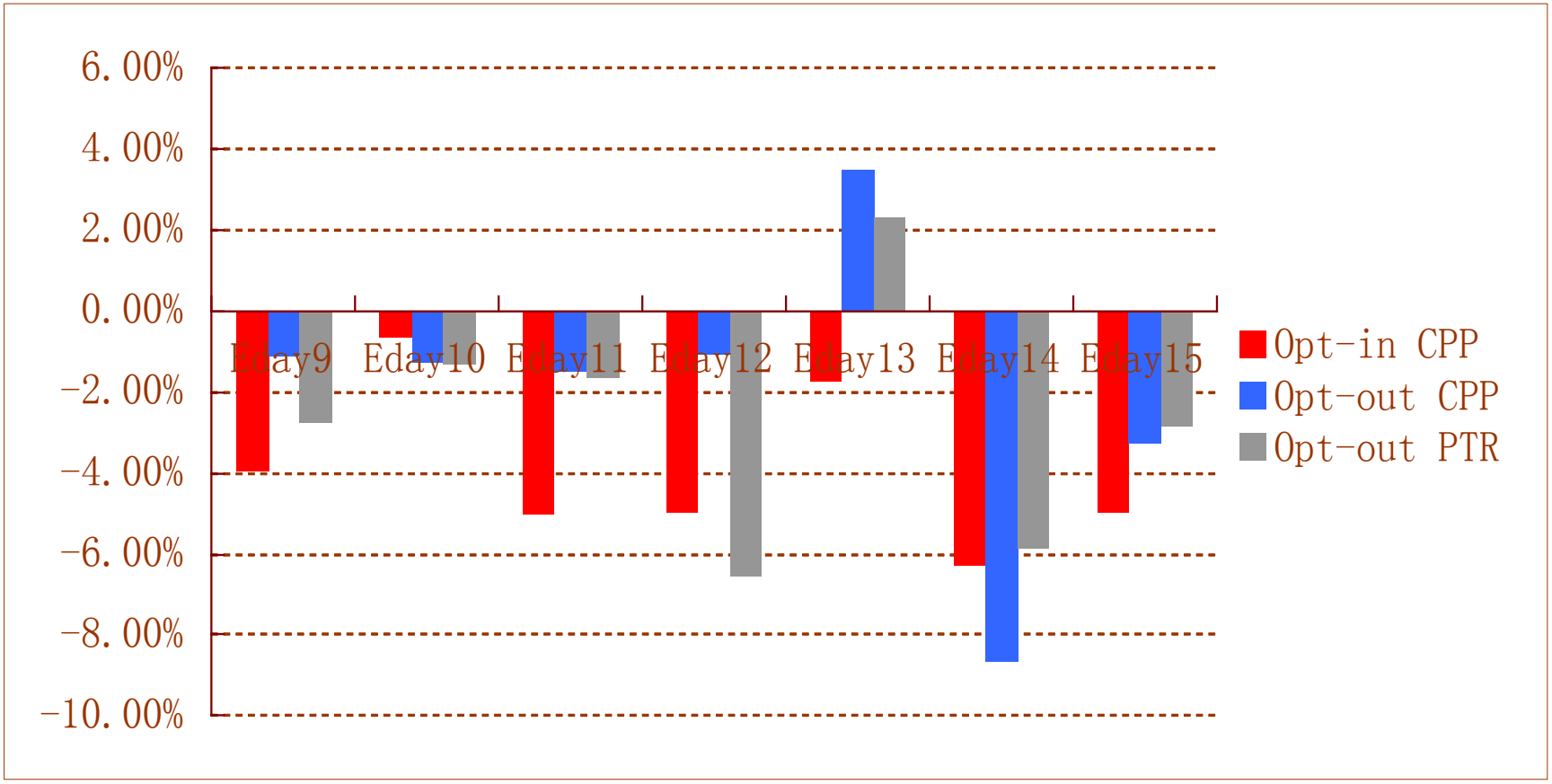
Estimate of ITT ≈ Estimate of TOT x Selection Probability (63.9%)

Estimation Results (ITT) for Each DR Days (summer 2013)



DR days: 7/29, 7/30, 7/31, 8/1, 8/2, 8/9, 8/13, 8/14.

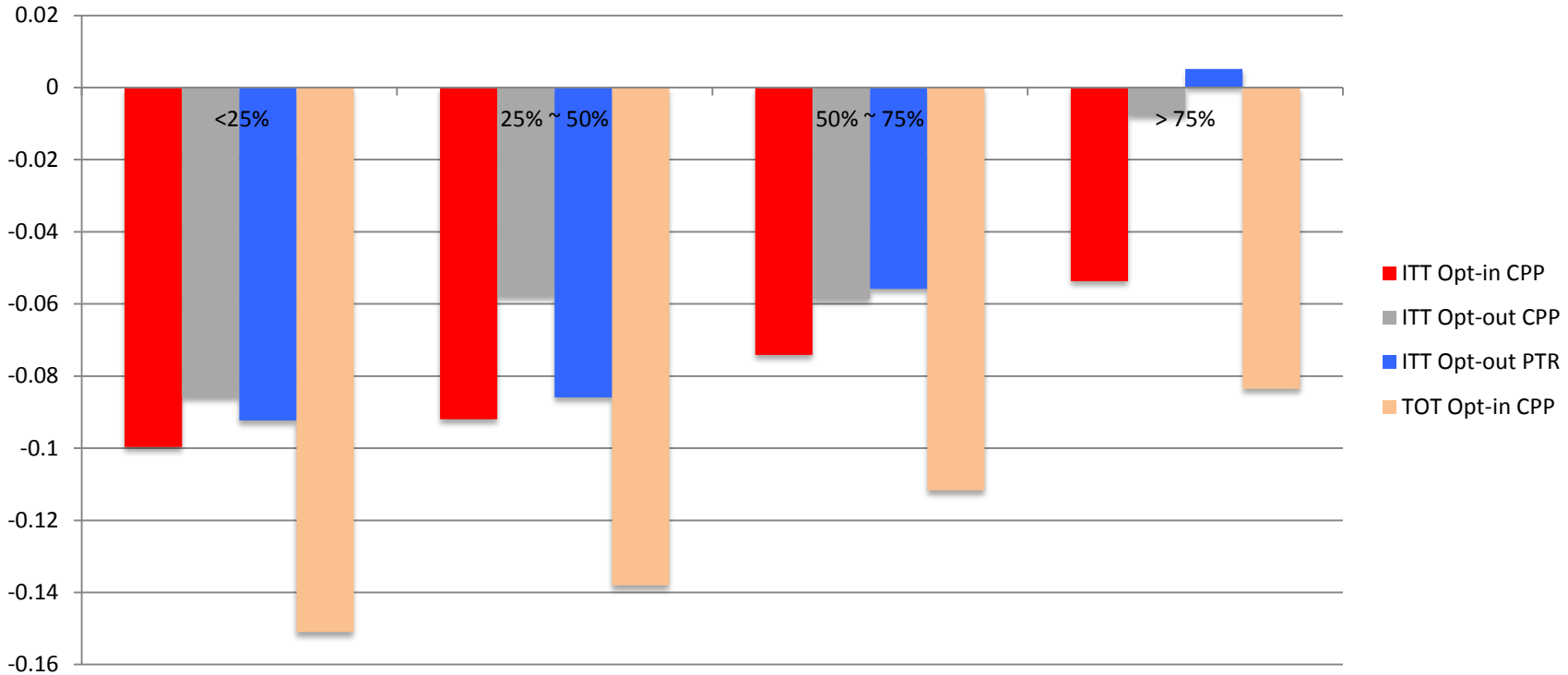
Estimation Results (ITT) for Each DR Day (summer 2013)



DR days: 8/15, 8/19, 8/20, 8/21, 8/26, 8/28, 8/29.

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.

2014 Winter Results

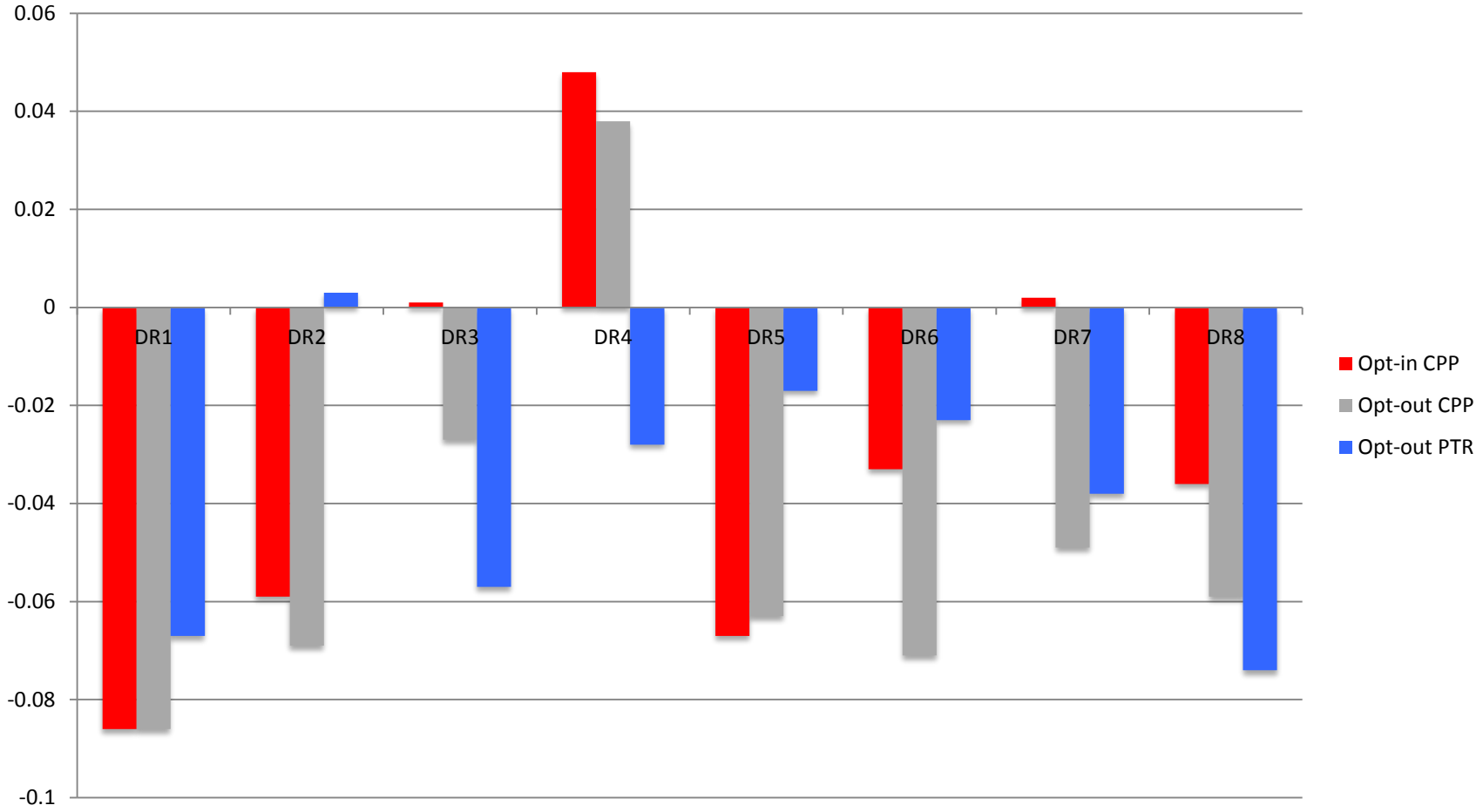
Estimation Results (winter 2013)

Group	Intent-to-treat (ITT)	Treatment-on-treated(TOT)
Opt-in CPP	**-4.78%*** (0.013)**	**-7.12%*** (0.022)**
Opt-out CPP	**-4.27%*** (0.016)**	**-4.41%*** (0.016)**
Opt-out PTR	**-3.26%** (0.015)**	**-3.37%** (0.016)**

Remark 1: the period of holidays (2013/12/23 – 2014/1/3) has been dropped out from the estimation samples.

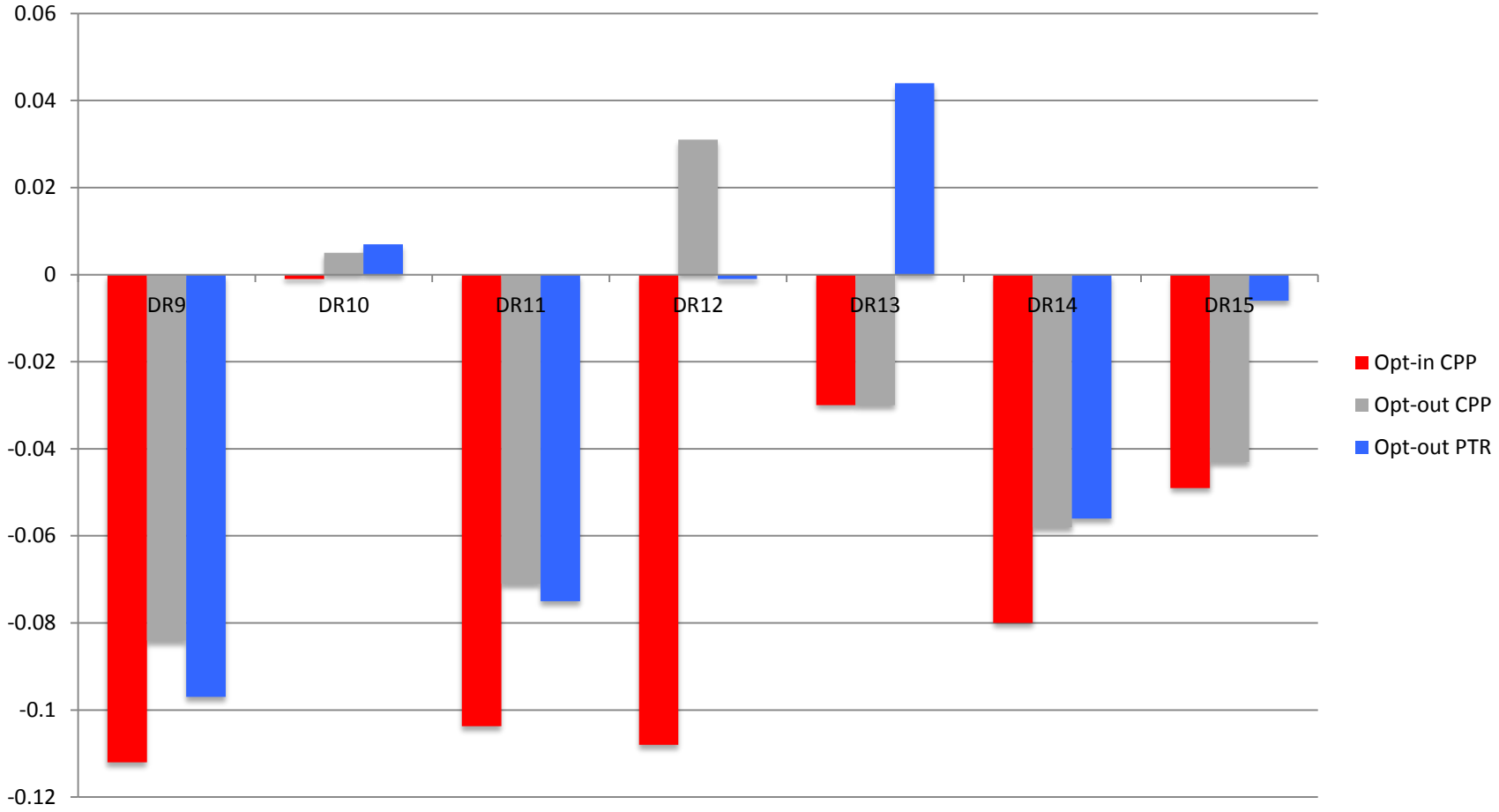
Remark 2: for winter season, the two CPP groups have similar peak-cut effects (ITT).

Estimation Results (ITT) for Each DR Day (winter 2013)



DR days: 12/6, 12/9, 12/18, 12/20, 1/15, 1/22, 1/23, 1/28.

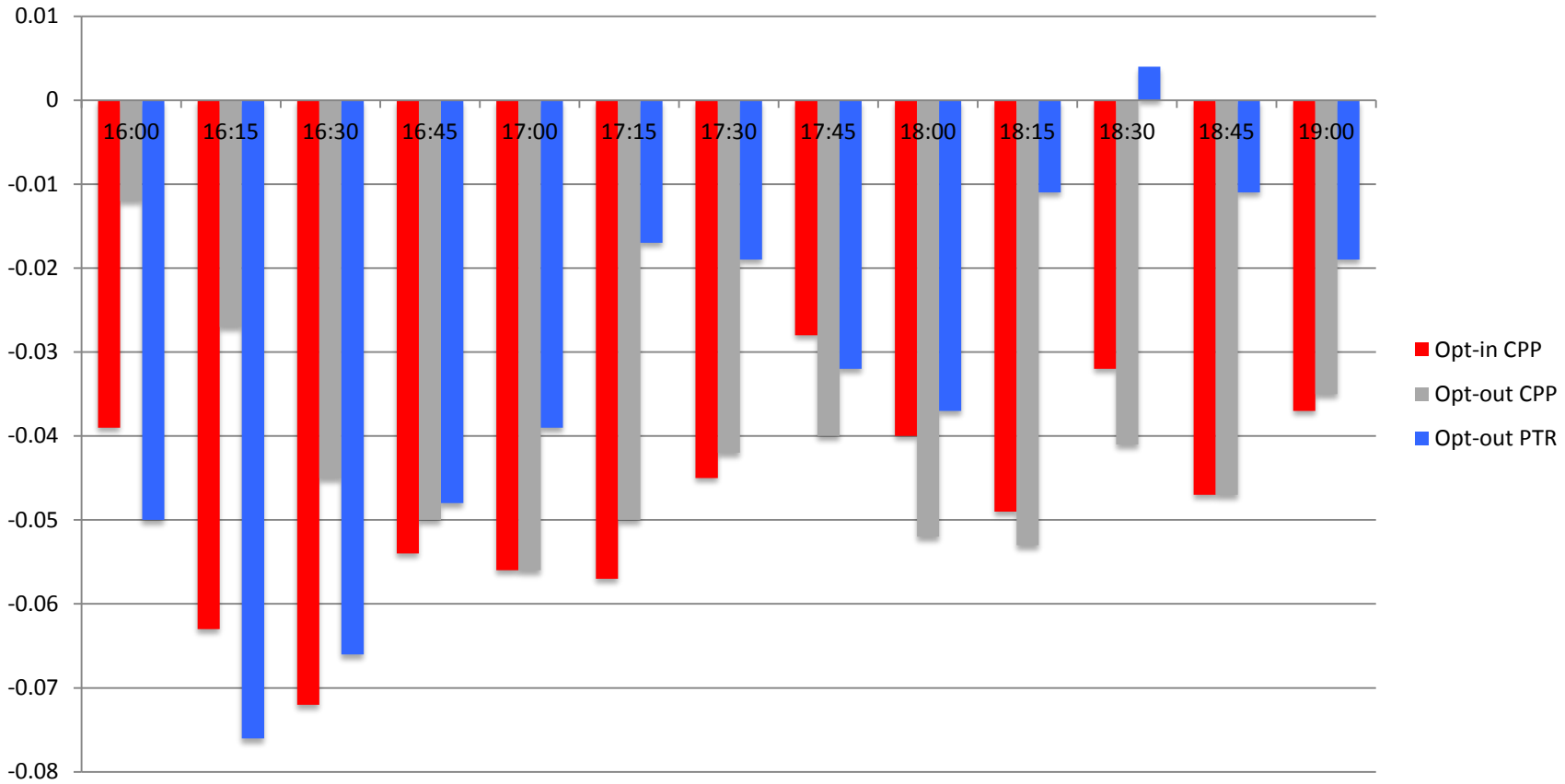
Estimation Results (ITT) for Each DR Day (winter 2013)



DR days: 1/30, 2/3, 2/6, 2/7, 2/10, 2/11, 2/12.

Remark: Opt-in CPP has best peak-cut effects during the 2nd half of winter season.

Estimation Results (ITT) for Every 15 Minutes (winter 2013)



Note: peak-cut effects are computed for every 15 minutes from 16:00 to 19:00.