Unlocking Flexible Demand: Evidence from Two Field Experiments

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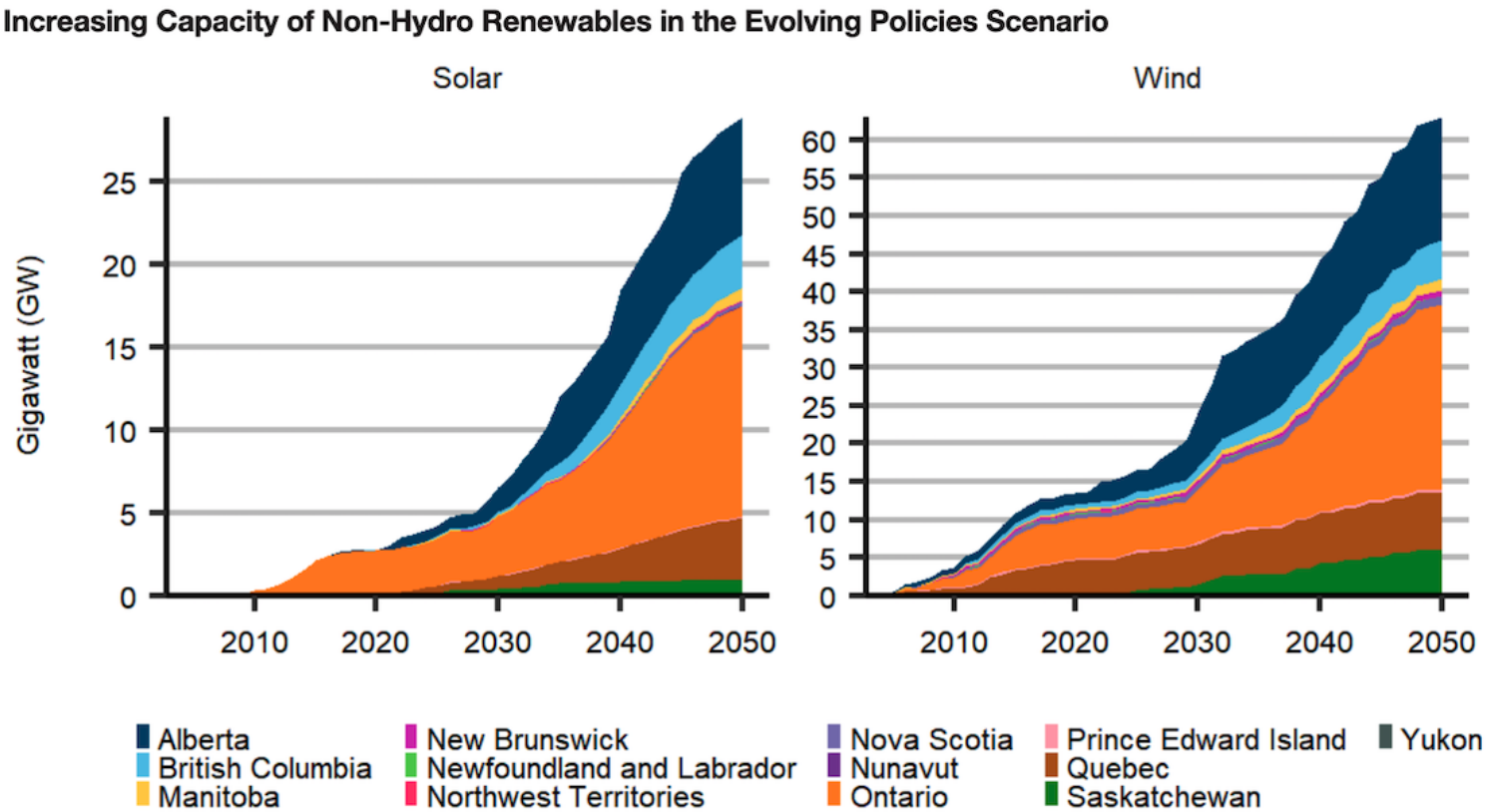
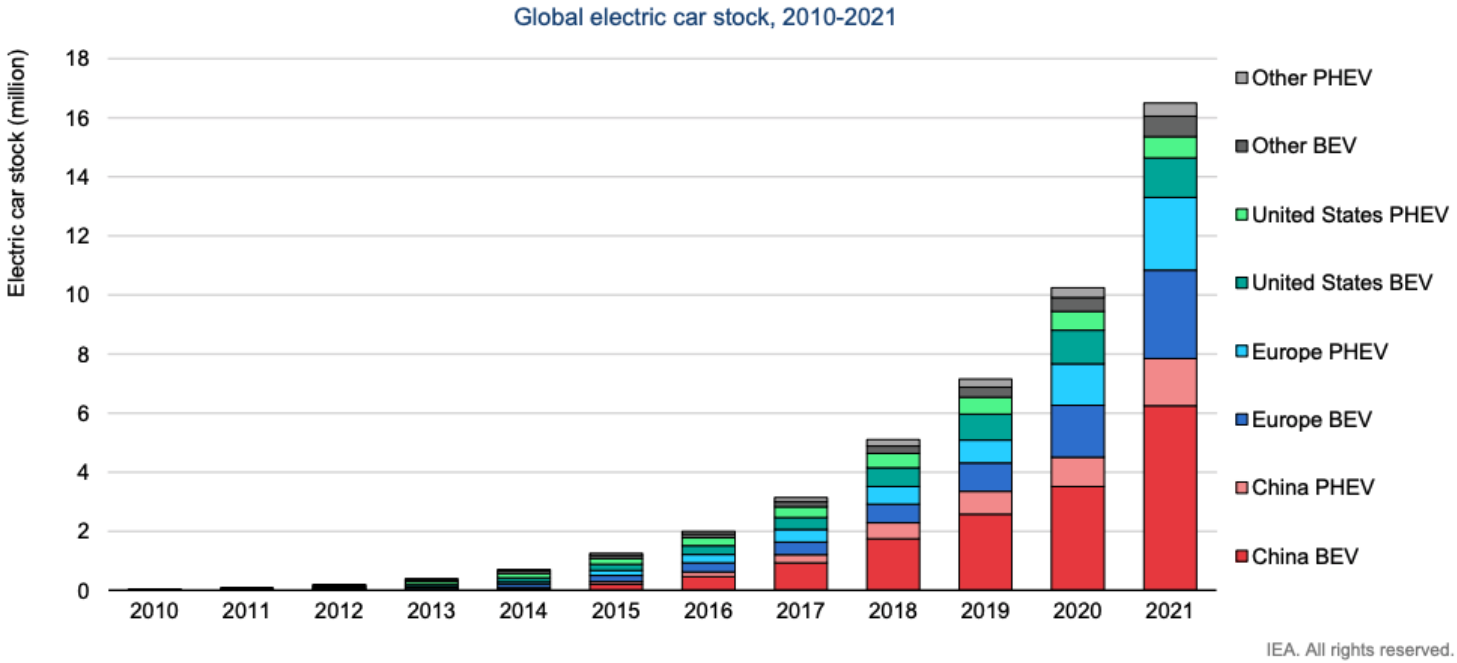
Growing Renewables in Canada



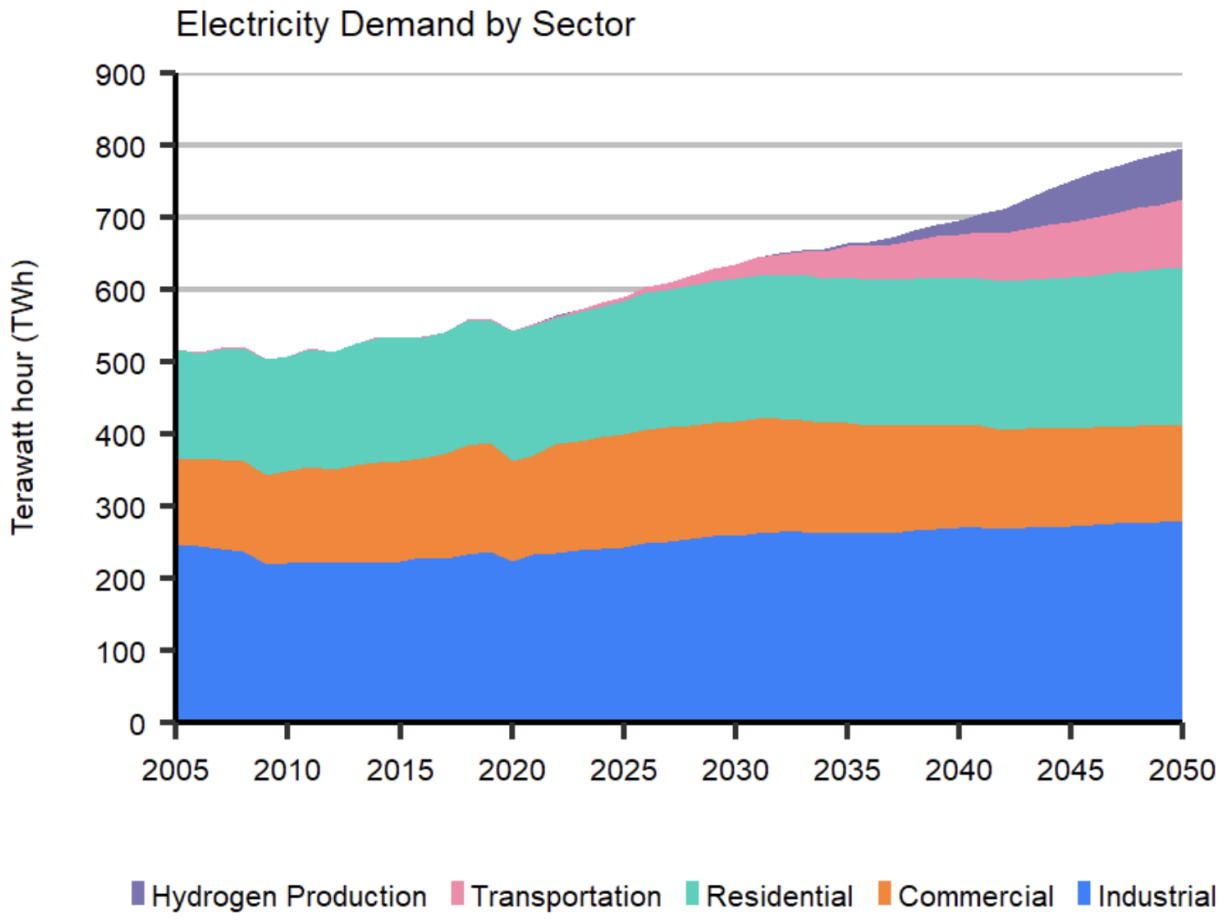
Canada Energy Regulator (2021)

Exponential Electric Vehicle Growth



IEA (2022)

Anticipated Electrification



Canada Energy Regulator (2021)

Forecasted demand growth: 47% from 2021 to 2050

Quickly Evolving Landscape

- Clean Electricity Standard - Net-Zero by 2035
- Elevated carbon pricing
- Growth in variable renewable resources
- Growth in customer-sited tech: EVs, solar, batteries, heating

Quickly Evolving Landscape

- Clean Electricity Standard - Net-Zero by 2035
- Elevated carbon pricing
- Growth in variable renewable resources
- Growth in customer-sited tech: EVs, solar, batteries, heating
- Significant challenges:
  - Increased supply and demand-side variability
  - Increasing electrification
  - Substantial capital investments (Gen., T&D)
  - Ensuring cost-effective and reliability electricity

Role for Flexible Demand

1. **Need**. Higher shares of variable renewables, increased electrification & demand-side uncertainty, growth in coincidental peaks (e.g., EV "Rush Hour")
2. **Potential**. Growth of EVs (and other electrification) increases the potential magnitude of flexible load

   ... and also increases the need for DR!
3. **Ability**. Technology increases the ability to cost-effectively implement DR via automation

How best to implement DR?

- Time-vary rates (e.g, TOU) and critical peak pricing have been shown to reduce demand (Faruqui et al., 2014)
- Real-time pricing may not be the best policy for tariff design with behavioural biases, inattention, and transaction costs (Fabra et al. 2021)
- Growing evidence that households have a difficult time understanding marginal prices and complexity (Ito, 2014)
- Technology alone may not be sufficient to drive demand reductions (Brandon et al., 2022)
- Evidence automation can assist in DR when combined with pricing (Bollinger and Hartman, 2020; Blonz et al., 2021)

Evidence from Two Field Experiments

1. Incentives versus Nudges: Shifting EV Charging Behaviour

2. Centralized versus Decentralized Demand Response

1. Incentives versus Nudges: Shifting EV Charging Behaviour

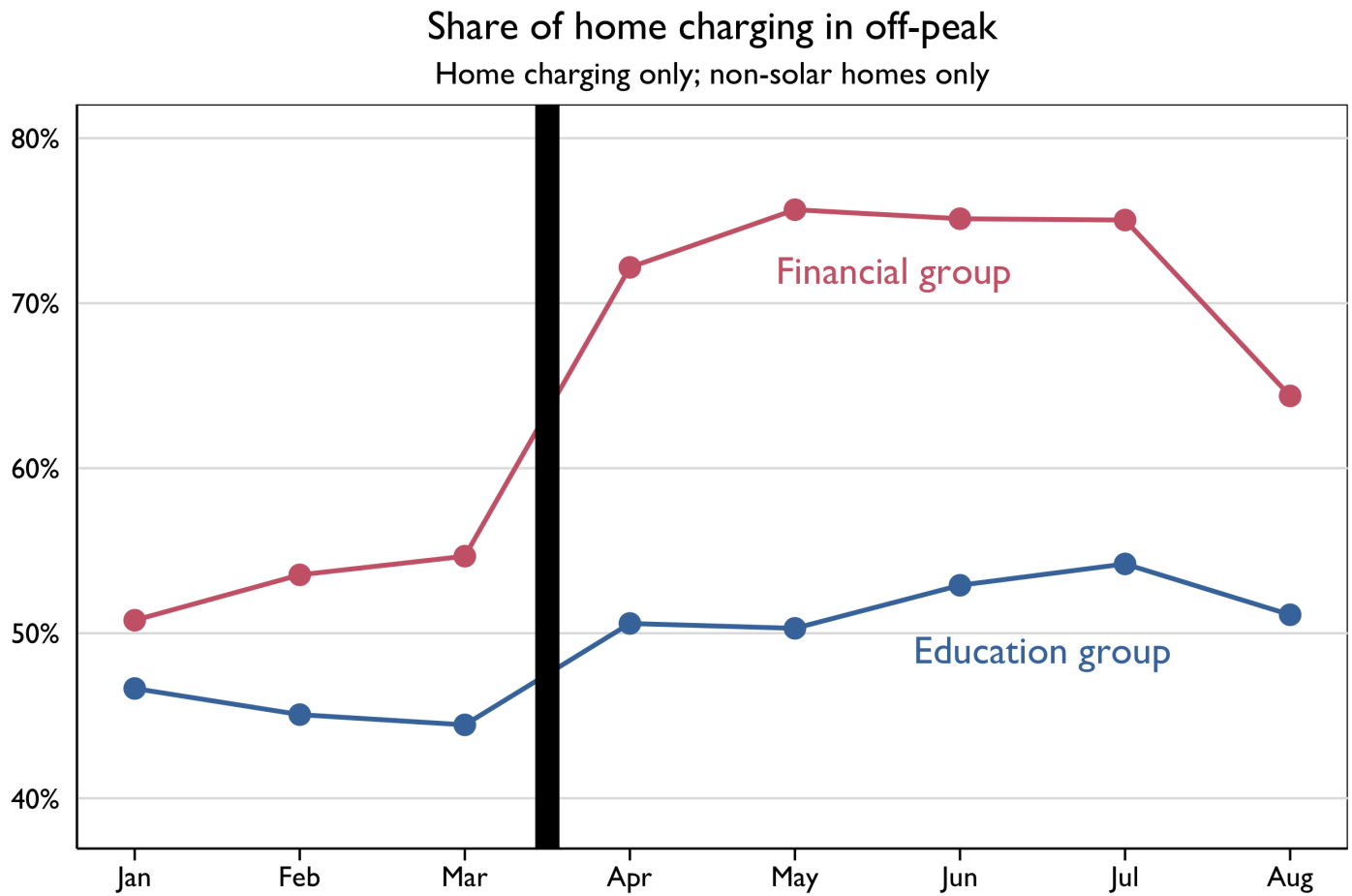
- **Focus: Electric Vehicle Charge Timing**
  - Coincidental EV charging can have significant impacts on local distribution networks

- **Financial Incentives versus Nudges**
  - Financial incentives to shift EV charging to off-peak hours
  - Nudge: educate HHs about the impact of EV charge timing & ask to shift charging

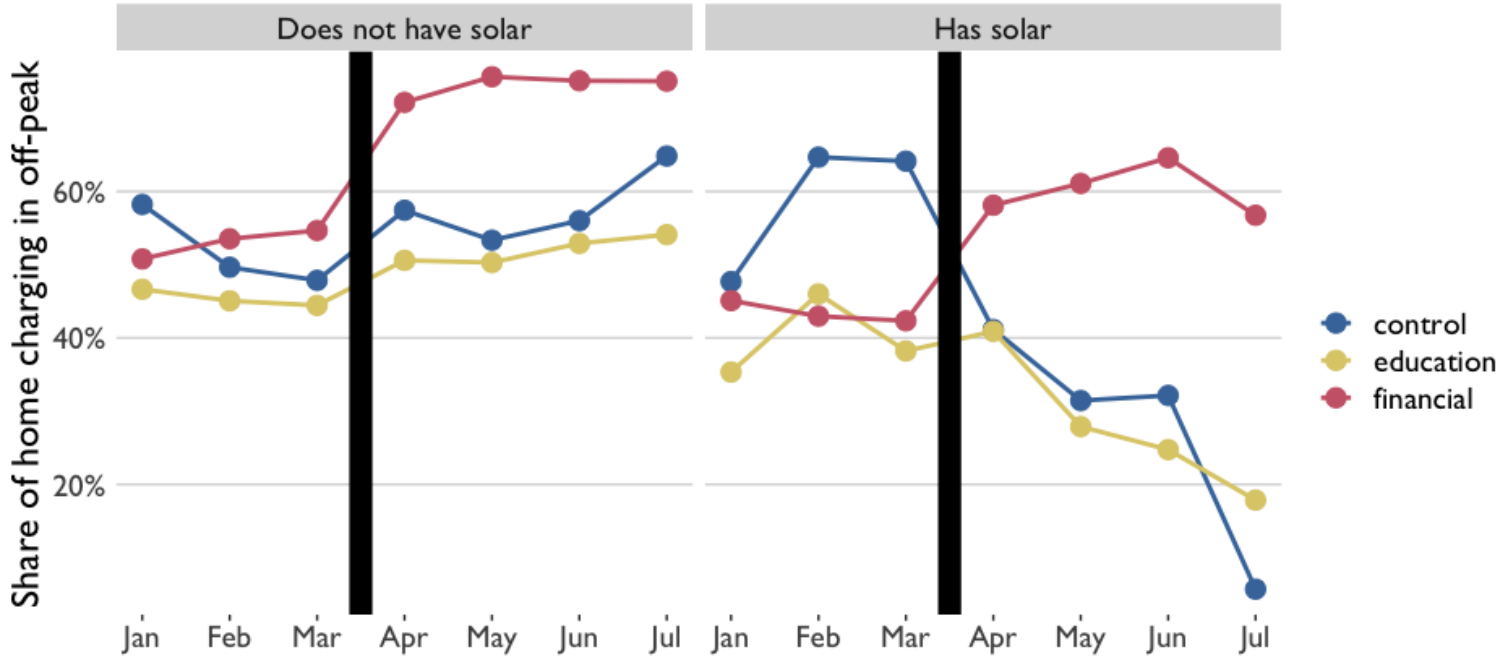
What we do

- Partner with a Canadian utility in an urban population center
- Time-invariant rates that change at most monthly
- Recruit EV owners to sign up to a program
  - 250 HHs signed up
- Send HHs a physical device to track charging (+ driving data)
- Monitor their consumption for 3 months pre-treatment
- Randomized them into control, nudges, financial
  - Financial receive 3.5 cents per KWh discount for off-peak charging

Shift in Electric Vehicle Charge Timing



Shift in Electric Vehicle Charge Timing



What we learned

- Nudge group is (statistically) indistinguishable from the control group (Ito, Ida, and Tanaka, 2018)
- Modest financial incentive can induce considerable demand shifting
- HHs have considerable flexibility in EV charging loads
  - Indicates that financial incentives can have a large impact on EV charging
- **Challenge:** TOU-based price incentives may not be sufficient to overcome (or might enhance) pressure on local dist. network

2. Centralized Versus Decentralized Demand Response

- **Centralized Versus Decentralized**
  - Can we rely entirely on price signals to facilitate DR?
  - Potential value in leveraging technology + automation
  - Centralized/Automation $\rightarrow$ potential for enhanced coordination

1. **Centralized/Automation**
   - Install technology that can adjust demand remotely
   - Utility initiates load reduction in response to DR event
   - Households given ability to *opt-out*

2. **Decentralized**
   - Households can reduce load in response to DR event
   - Some given ability to respond with load control technology
   - Others require more manual response

Research Goal

Compare centralized vs decentralized DR in terms of:

- Take-up rates (**acceptability**)
- Consumption changes during DR events (**responsiveness**)
- Consistency of response (**reliability**)
- Opt-out and attrition (**satisfaction**)

What we do

- We partnered with (another) Canadian utility
- We randomize eligible HHs into various treatment groups
  - *Offers made to 1,763 households*
- We install load control devices in the homes of certain HHs (water heaters, EV chargers, thermostats)
  - *Gives us extremely rich data at the device level!*
- We run random "peak events" with unique schedules
  - *Allows us to compare not just across groups, but across event vs non-event days for all households*
- Consumption reductions are rewarded financially
  - *From $1 for a 10% reduction to up to $6 in the "high incentive" event for a 50% reduction*
- Started Feb 2022, ongoing for 18 months

Treatment assignment

We group eligible HHs on important observables (kmeans clustering) and then randomize offers to one of 5 groups:

	DR control	Load control tech	Price incentive	Usage info
Central	Utility*	✓	✓	✓
Tech	HH	✓	✓	✓
Manual	HH		✓	✓
Info	HH			✓
Control	HH			

*HH has ability to opt-out

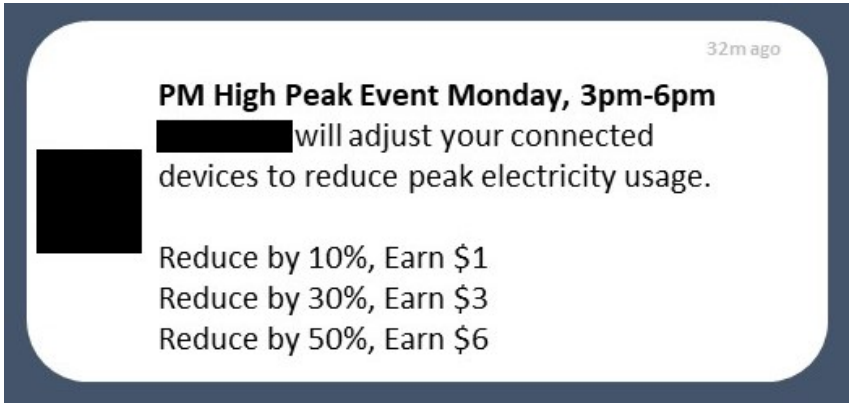
- Central vs Tech: effect of automation/control (passive vs active response)
- Tech vs Manual: effect of technology

Random "Peak" events

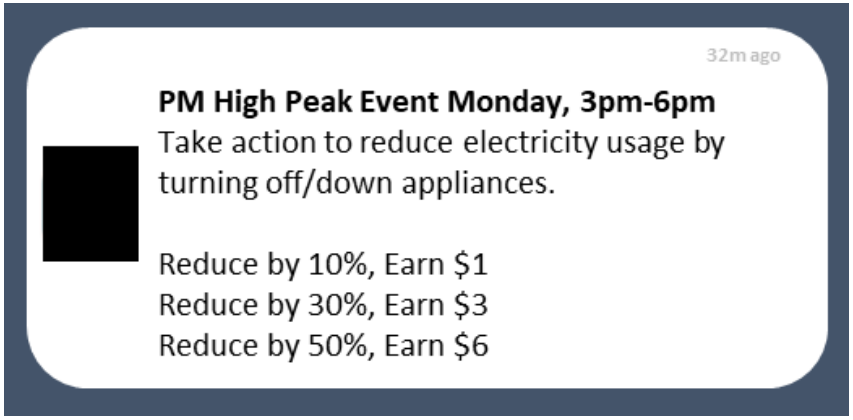
- Central, Tech, and Manual groups all receive "peak" events
- Randomize event schedule across households
  - Event time: Weekdays, morning (7-10am) or evening (5-8pm)
  - Event type: "Peak" or "High Peak" (high incentive payment)
  - HHs generally receive 1 event per week, 3-4 per month, and only one "High Peak" event per month
- Incentives: based on reduction from household's baseline
  - Regular Peak: (10%, 30%, 50%) = ($1, $2, $3)
  - High Peak: (10%, 30%, 50%) = ($1, $3, $6)

Example of Peak Event messaging

Central group 21hr notification with incentives



Tech/Manual group 21hr notification with incentives



Program Acceptance

Acceptance Rates by Group

	Central	Tech	Manual	Info	Control
Invited	423	382	409	259	188
Accepted	177	184	242	177	188
	(42%)	(48%)	(59%)	(68%)	(100%)

Acceptance Detailed

Choice Group

- We also randomized 102 HHs into a *Choice* group
- 38 Accepted (37%)
- HHs provided their preference rankings

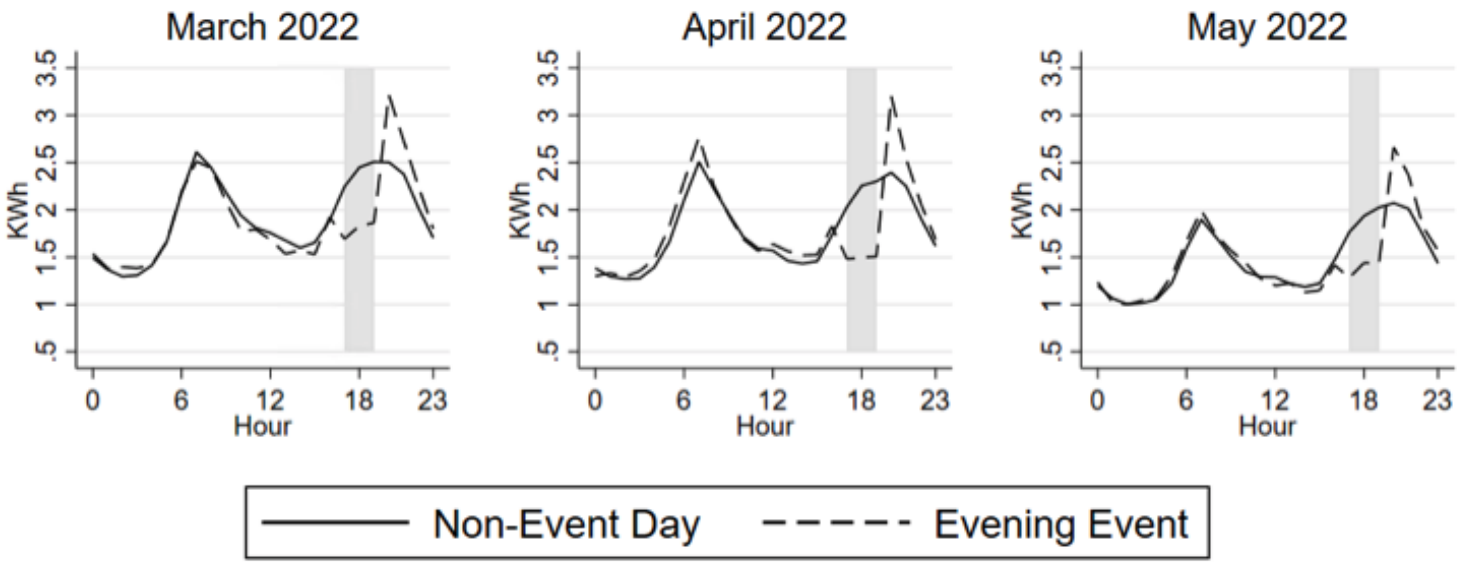
Choice Group Preferences

	Central	Tech	Manual	None
First Choice	25 (43%)	26 (45%)	7 (12%)	0 (0%)
Second Choice	10 (17%)	29 (50%)	14 (24%)	5 (9%)
Third Choice	8 (14%)	1 (2%)	18 (31%)	31 (53%)

Note. 26% of HHs had a strong preference to avoid Central group

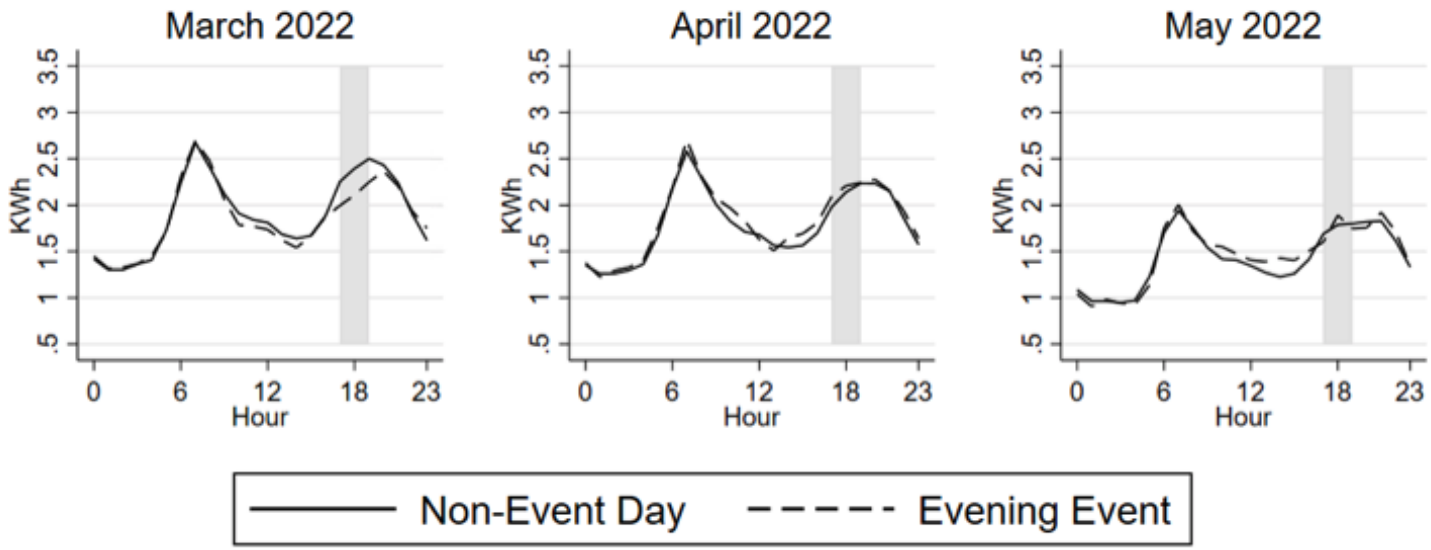
Descriptive analysis of consumption patterns

Central Group: Non-event vs Evening Event days



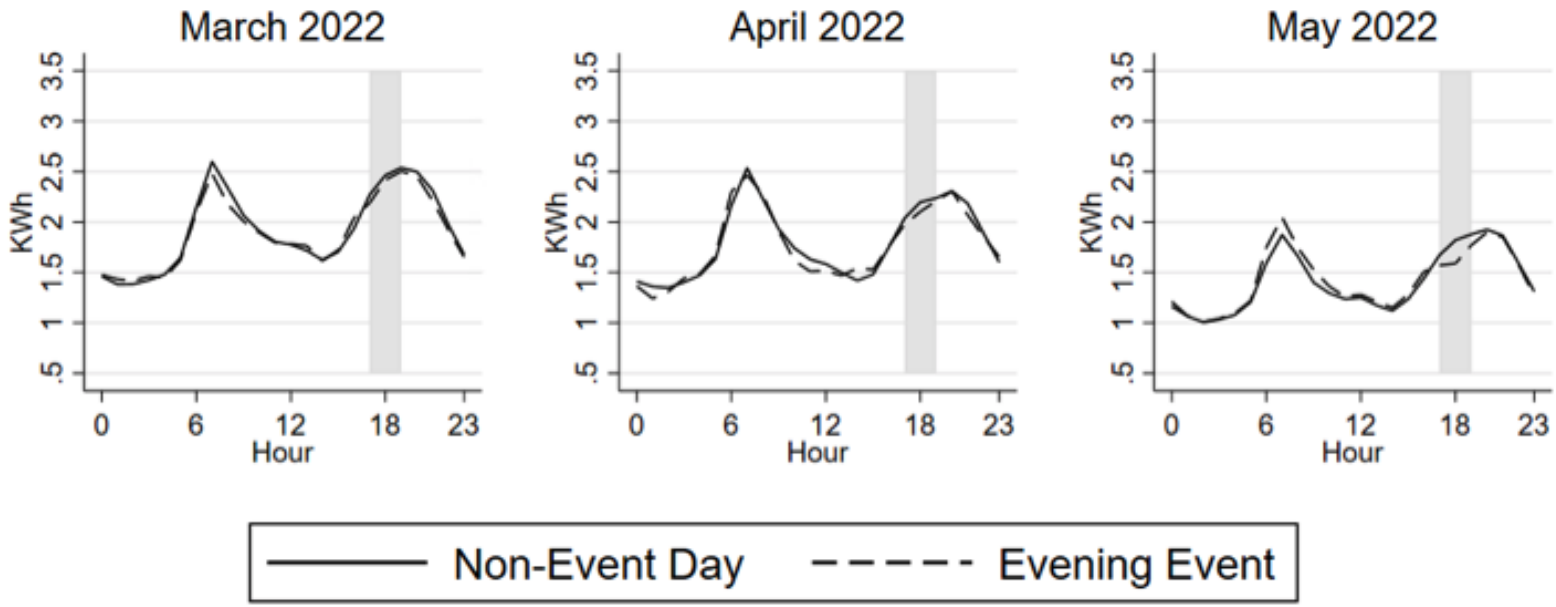
Descriptive analysis of consumption patterns

Tech Group: Non-event vs Evening Event days



Descriptive analysis of consumption patterns

Manual Group: Non-event vs Evening Event days



Estimation Strategy

Difference-in-Difference Regression:

$$ln(kwh)_{ihdmy} = \beta \cdot \mathrm{I} + \mu_i + \gamma_{ym} + \phi_d + \lambda_h + \mathrm{W}_h + \epsilon_{ihdmy} \quad (1)$$

I: Interaction of interest (and relevant standalone terms)

- $EventFlag_{ih} * Group_i$
- $EventFlag_{ih} * EventTypeTime_{ih} * Group_i$
- $EventFlag_{ih} * HHTech$ (using group-specific estimation)

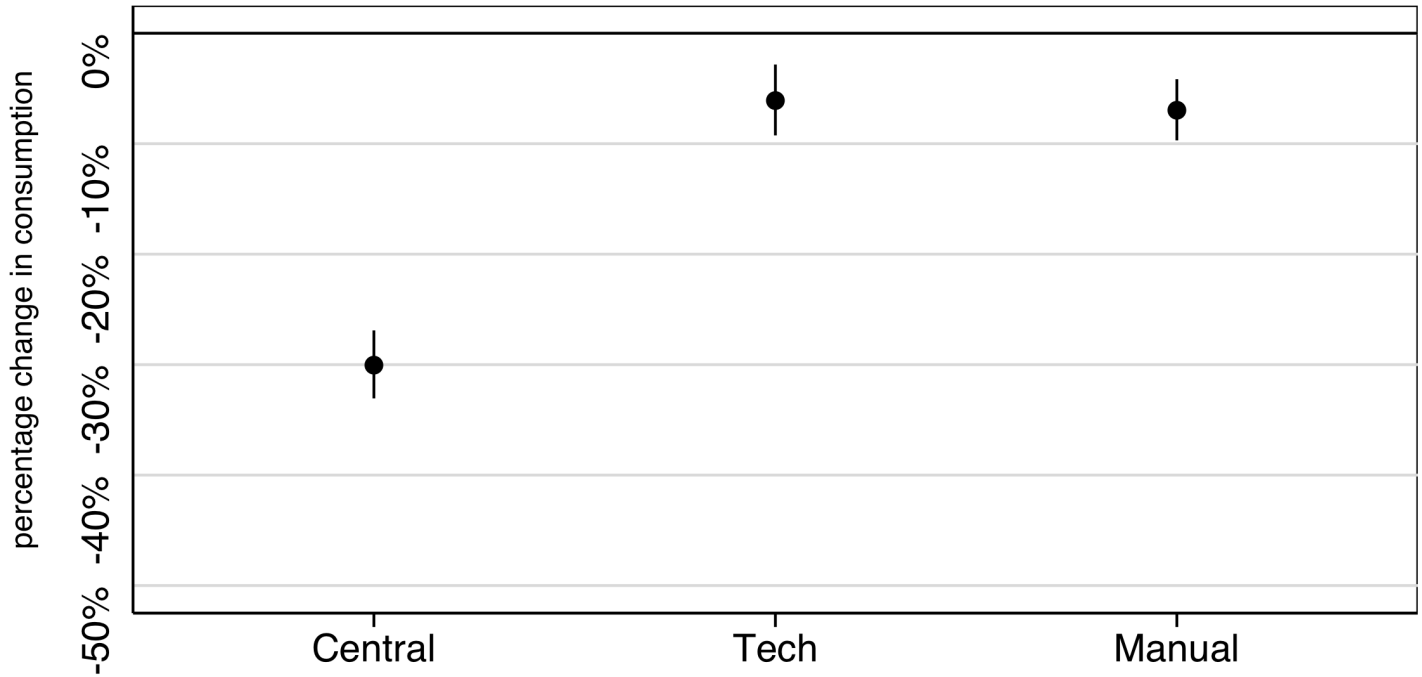
W_h: Hourly weather variables, incl. nonlinear terms

- Cooling degrees above 18.33 C (65 F)
- Heating degrees below 18.33 C (65 F)
- Relative humidity

Data: Sept 2021 - July 2022, all groups (incl. control)

Regression results: Hourly consumption changes by group

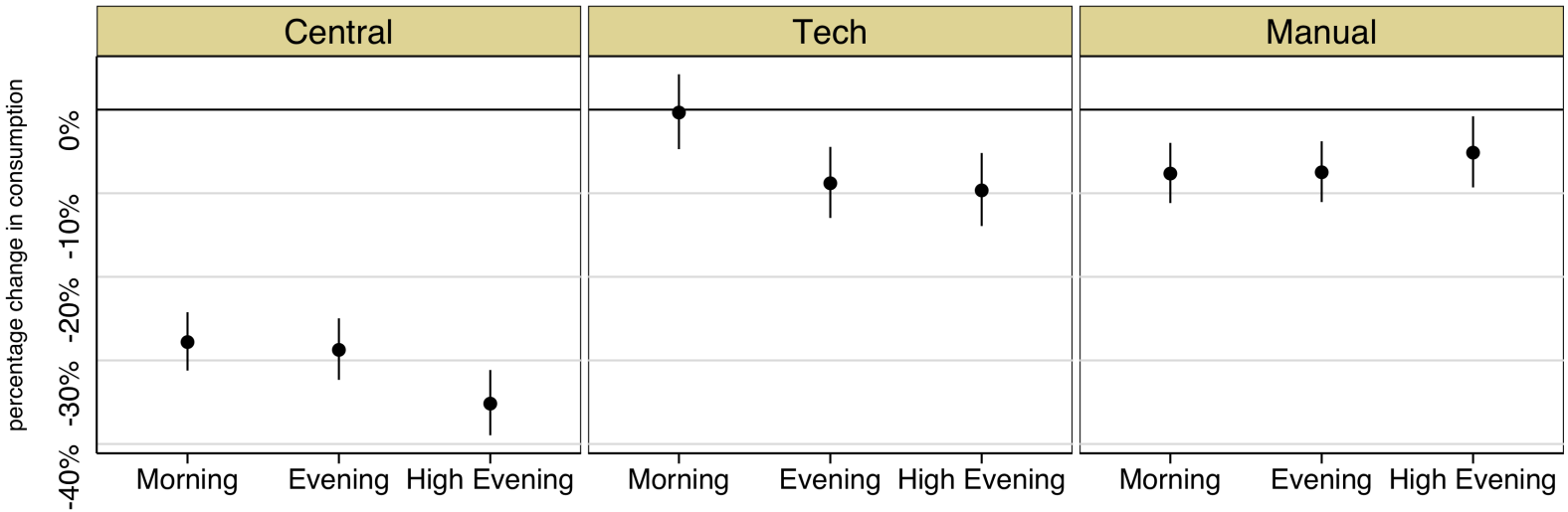
Central control is crushing Tech group...



...and Tech group not doing better than Manual group

Percent changes: -30% (Central), -6% (Tech), -7% (Manual)

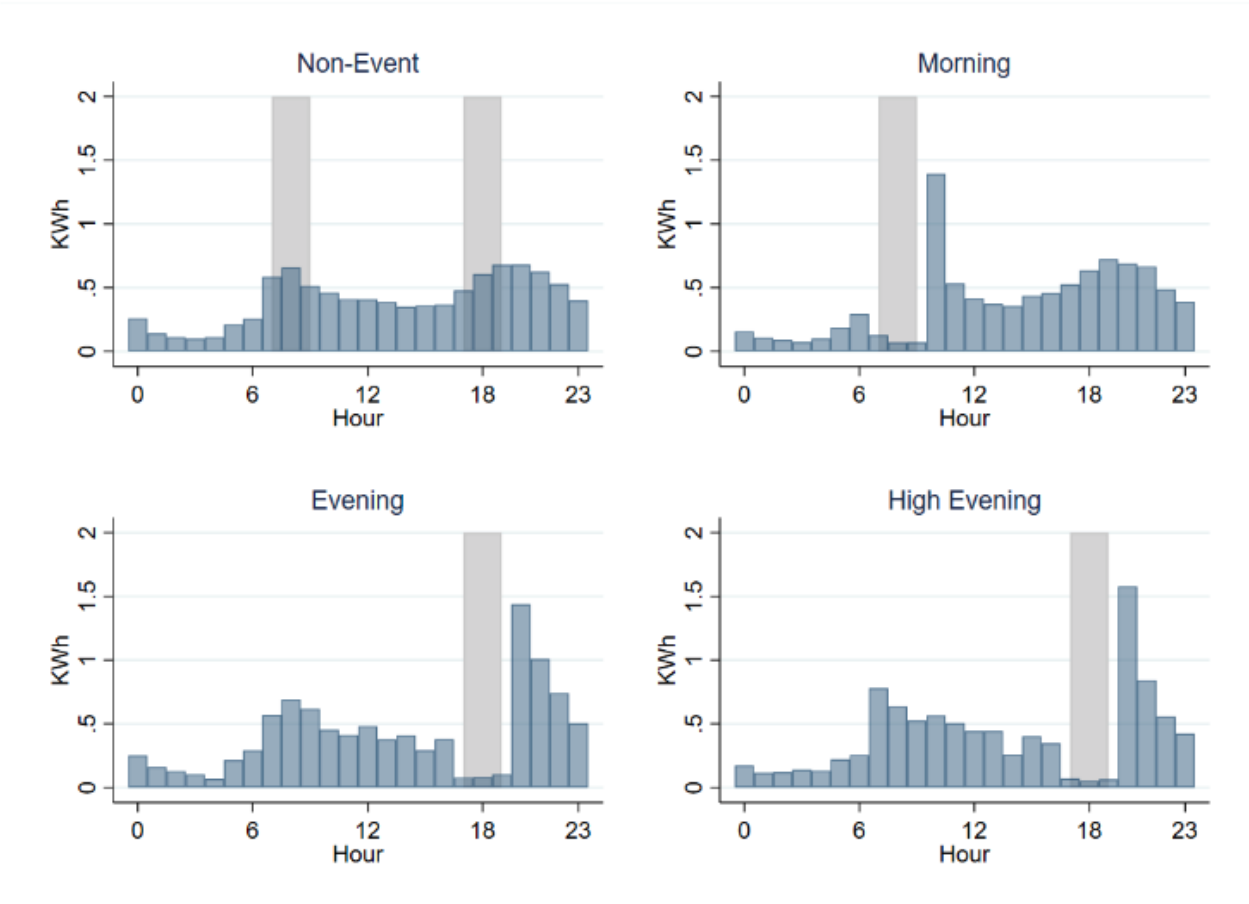
Hourly consumption results by event type



- Central control responding to greater incentives
- Tech group is not taking action in mornings

Device level results: Hot water heaters

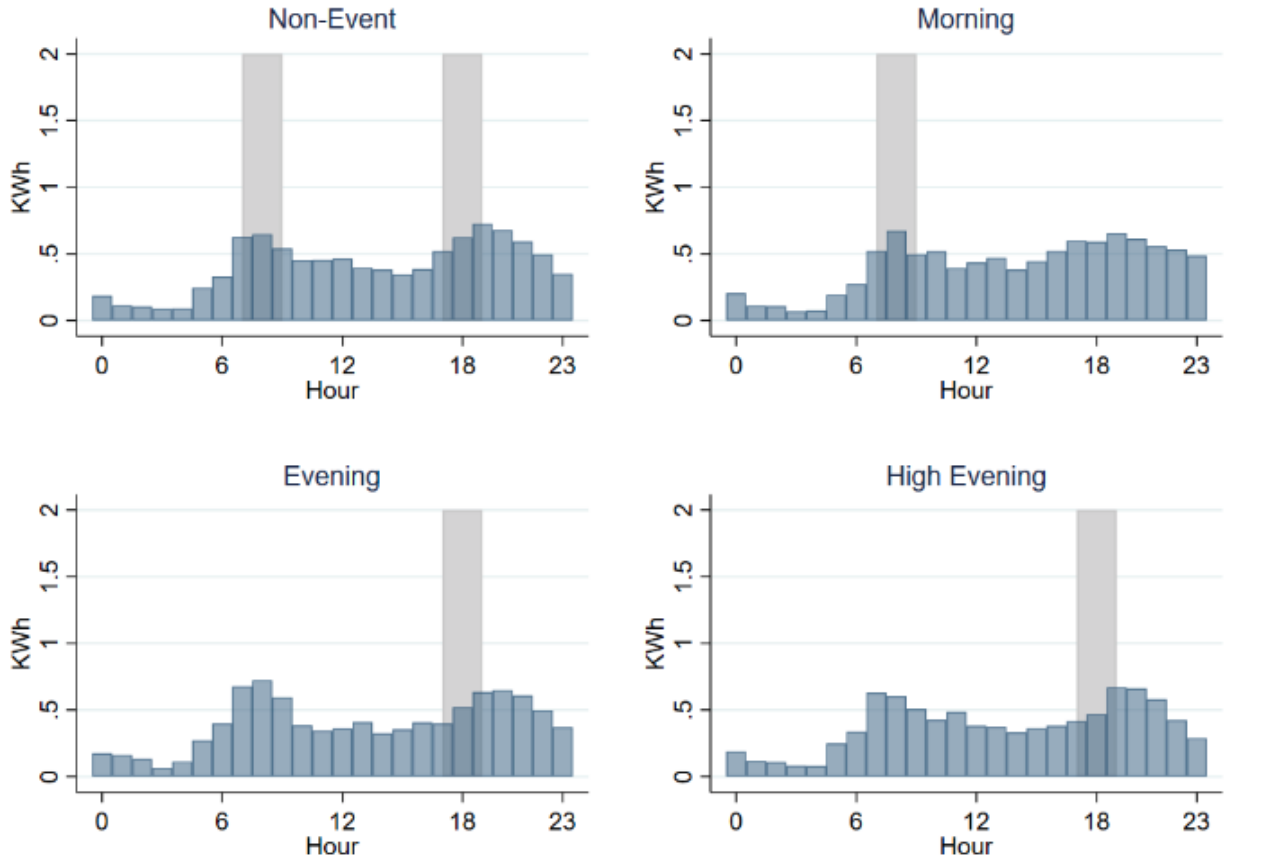
Mean Hot Water Consumption (March 2022) - Control versus Tech



Central observes large reductions on hot water heaters; almost no response from Tech

Device level results: Hot water heaters

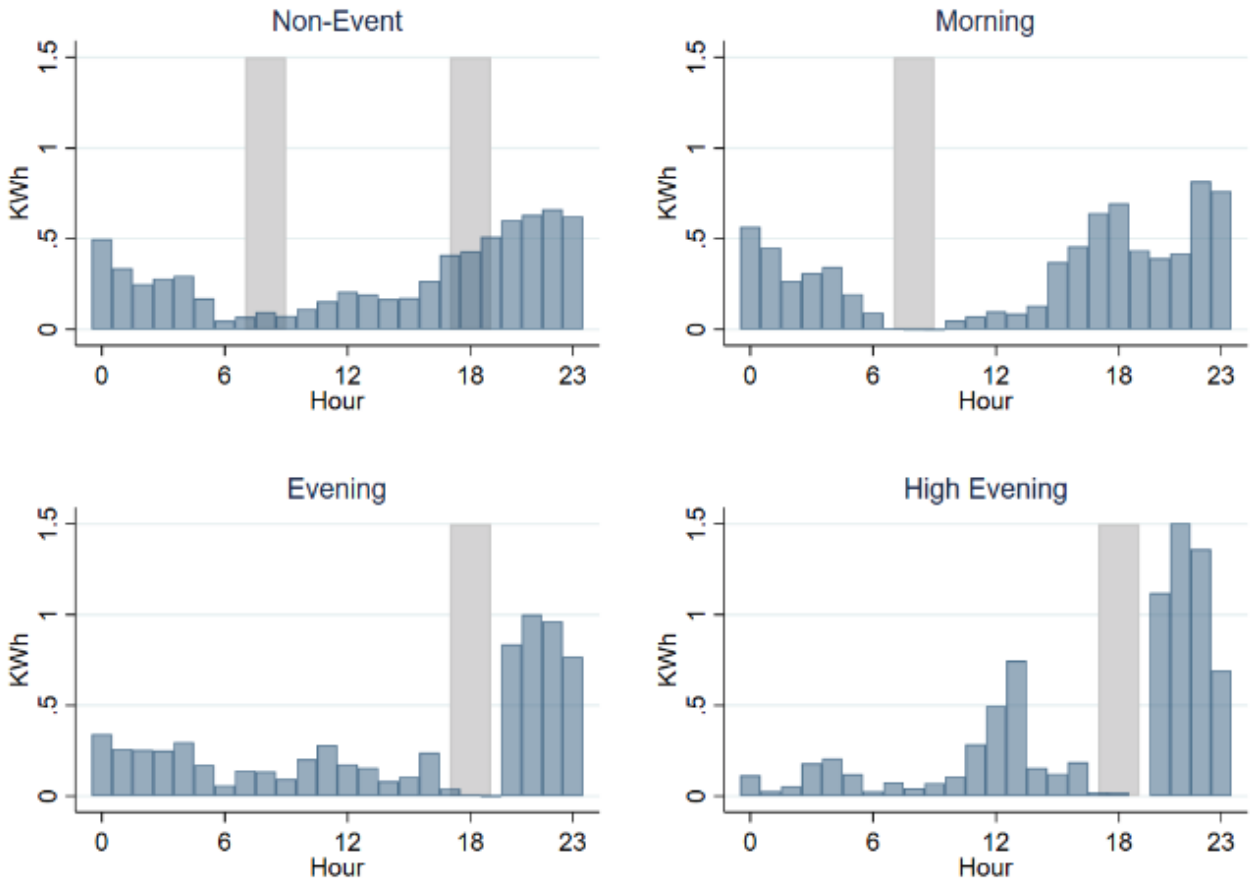
Mean Hot Water Consumption (March 2022) - Control versus Tech



Central observes large reductions on hot water heaters; almost no response from Tech

Device level results: Level 2 EV chargers

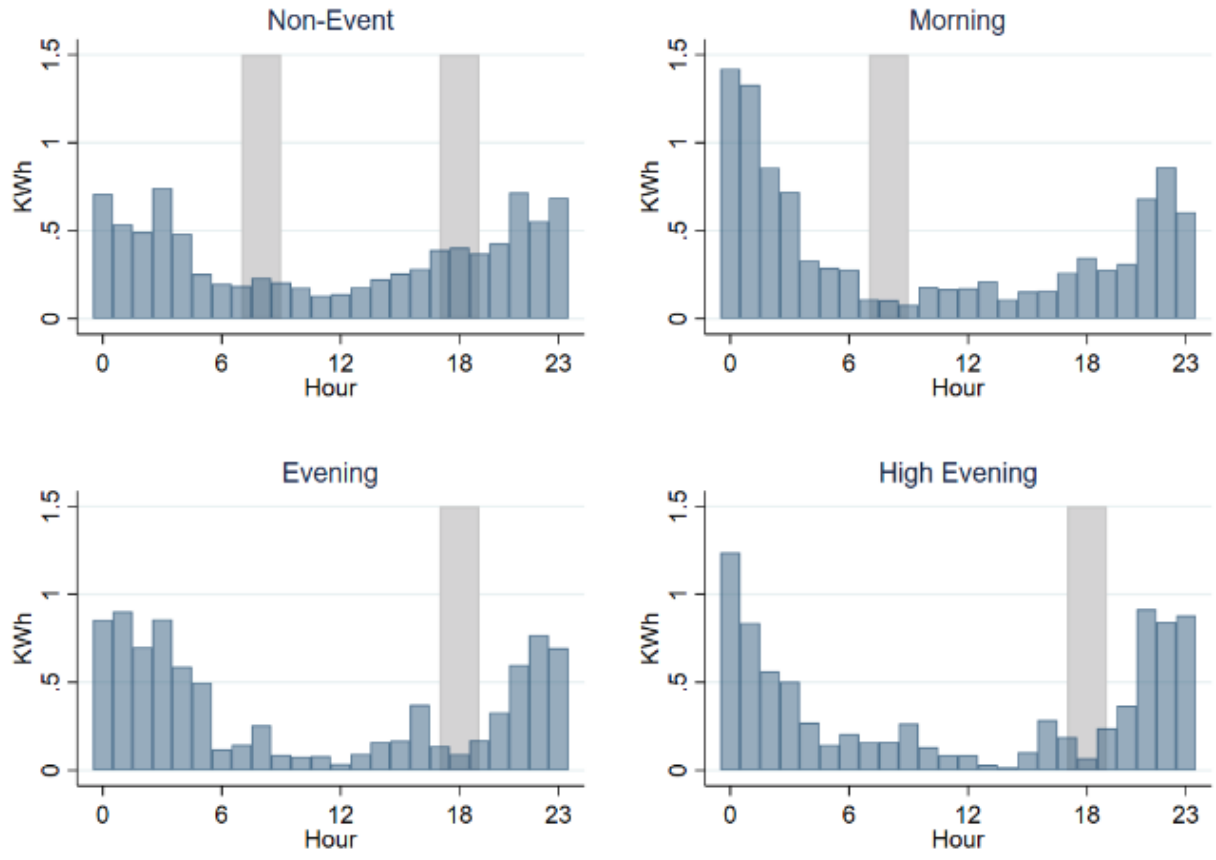
Mean Level 2 EV Consumption (March-July 2022) - Control versus Tech



Baseboard Heater Results

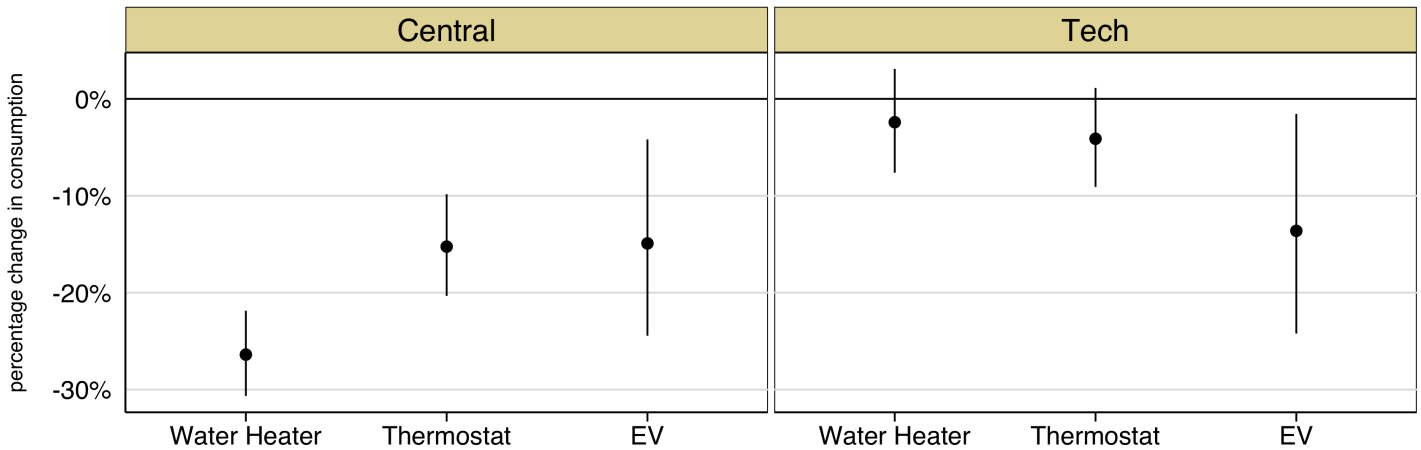
Device level results: Level 2 EV chargers

Mean Level 2 EV Consumption (March-July 2022) - Control versus Tech



Baseboard Heater Results

Regression Results: Technology-Specific Effects



- Water heaters are key driver for Central
- Limited response for Tech outside of EV which are similar to Central

Summing up

- Rewards for responding to random "peak pricing" events
- Central group dominates in terms of responsiveness
  - Even when attempting to lower cost of effort for manual response by providing load control tech
  - Importance of minimizing effort costs when presenting consumers small stakes rewards ("picking up pennies")
- We find Tech group not better than Manual!
  - Still must respond to each event; cognitively costly?
  - Do they understand their tech?
  - **Evidence that EV decisions are different**
- Who is OK being controlled?
  - Central group has lower take-up rate

Conclusions & Policy Implications

- Suggest considerable role for automation + default opt-in
  - Avoids customer inattention
  - Minimizes (eliminates?) transaction costs
- Results raise questions over the strength of price-based incentives (leaving flexibility on the table) and potentially the limited value of Tech-only
  - Supports work questioning the value of smart thermostats (Brandon et al., 2022)
- Additional scope to add value with automated appliances:
  - Higher frequency DR
  - Pre-cooling/heating
  - Coordinated load-control based on local distribution constraints
- Main barriers: (i) physical load-controllers are costly and (ii) ensuring wide-scale acceptance to hand over control

Conclusions & Policy Implications

Potential Market Design:

- DER aggregators/retailers collect customers with default opt-in load-controlled appliances
- Participation in wholesale and AS markets and formal DR mechanisms (FERC Order 2222)
- Enhanced value by coordinating with a Utility to minimize distribution-level peaks
  - Automation + local coordination particularly valuable (relative to price-based incentives) in this setting
  - Increasingly important with growing EVs + Heat Pump loads
- Real-world implementation challenges, but our results show there could be considerable value in this setting

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Financial Versus Nudges - Messaging

Nudge Group Messaging

"To help **reduce costs** for all CITY NAME and **reduce strain on electric infrastructure**, EV drivers can use their EV scheduled charging feature to charge **between 10:00PM and 6:00AM** when grid demand is low, or **wait until 10:00PM** to plug in. This simple change can make a big impact and will benefit the entire system as EV adoption continues."

Financial Group Messaging

"In addition, to encourage you to charge during off-peak hours, effective immediately **UTILITY will issue you a 3.5 cent/kWh reward for charging that takes place between 10:00PM and 6:00AM**. This reward will be paid monthly through the BLANK platform. You are still free to charge your car whenever you like, and there will be no changes to your electric service."

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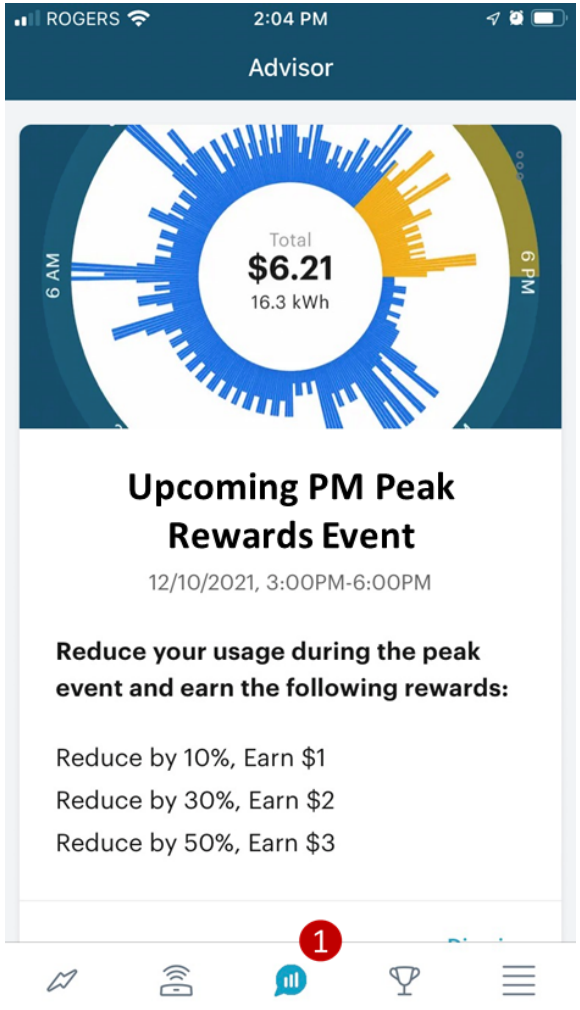
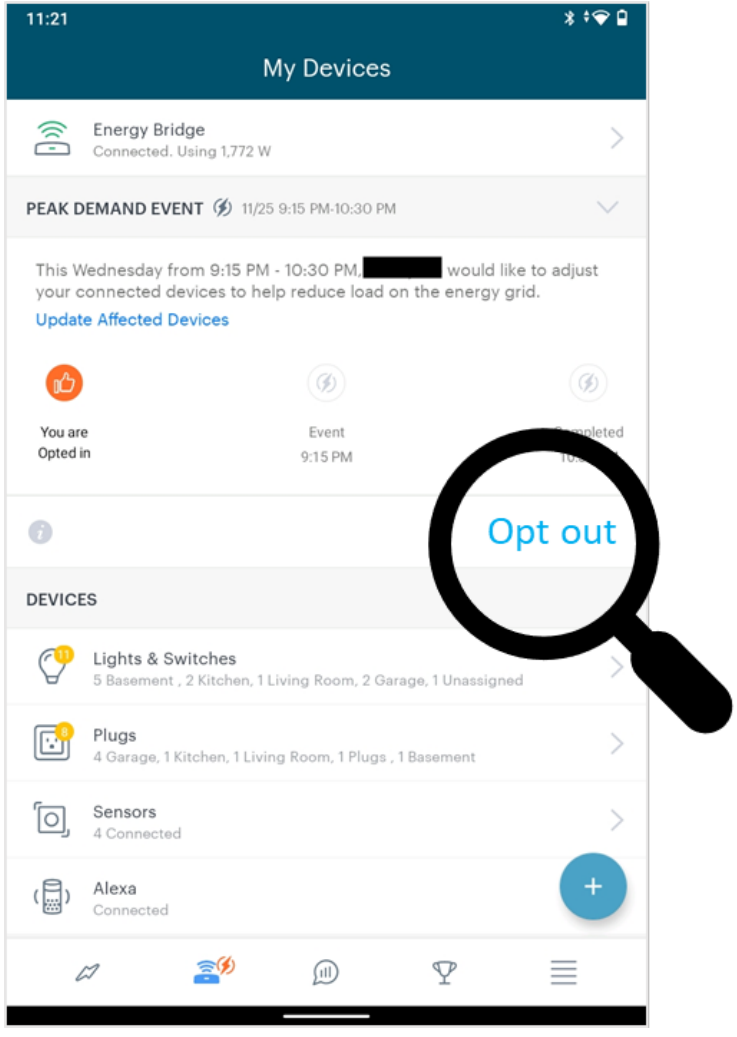
Example of Peak Event messaging

In-app notification



Central - Opt out of DLC



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Program Acceptance

Acceptance Rates by Group

	Central	Tech	Manual	Info	Control
Invited	423	382	409	259	188
Accept (Initial)	245 (58%)	261 (68%)	273 (67%)	198 (77%)	188 (100%)
Accept (Final)	177 (42%)	184 (48%)	242 (59%)	177 (68%)	188 (100%)
Withdrawn	68 [28%]	77 [30%]	31 [11%]	21 [11%]	0 [0%]

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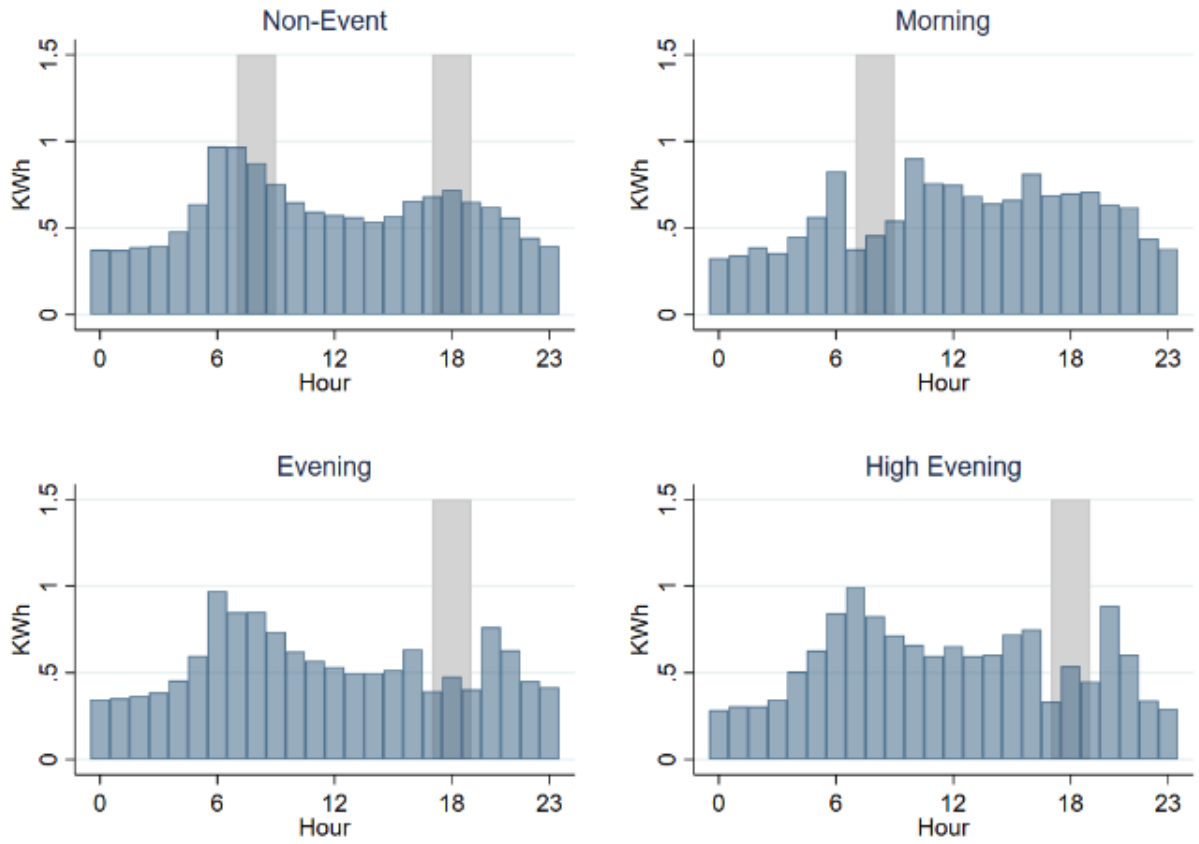
Device level results: Baseboard Heaters

Mean Heater Consumption (March 2022) - Control versus Tech



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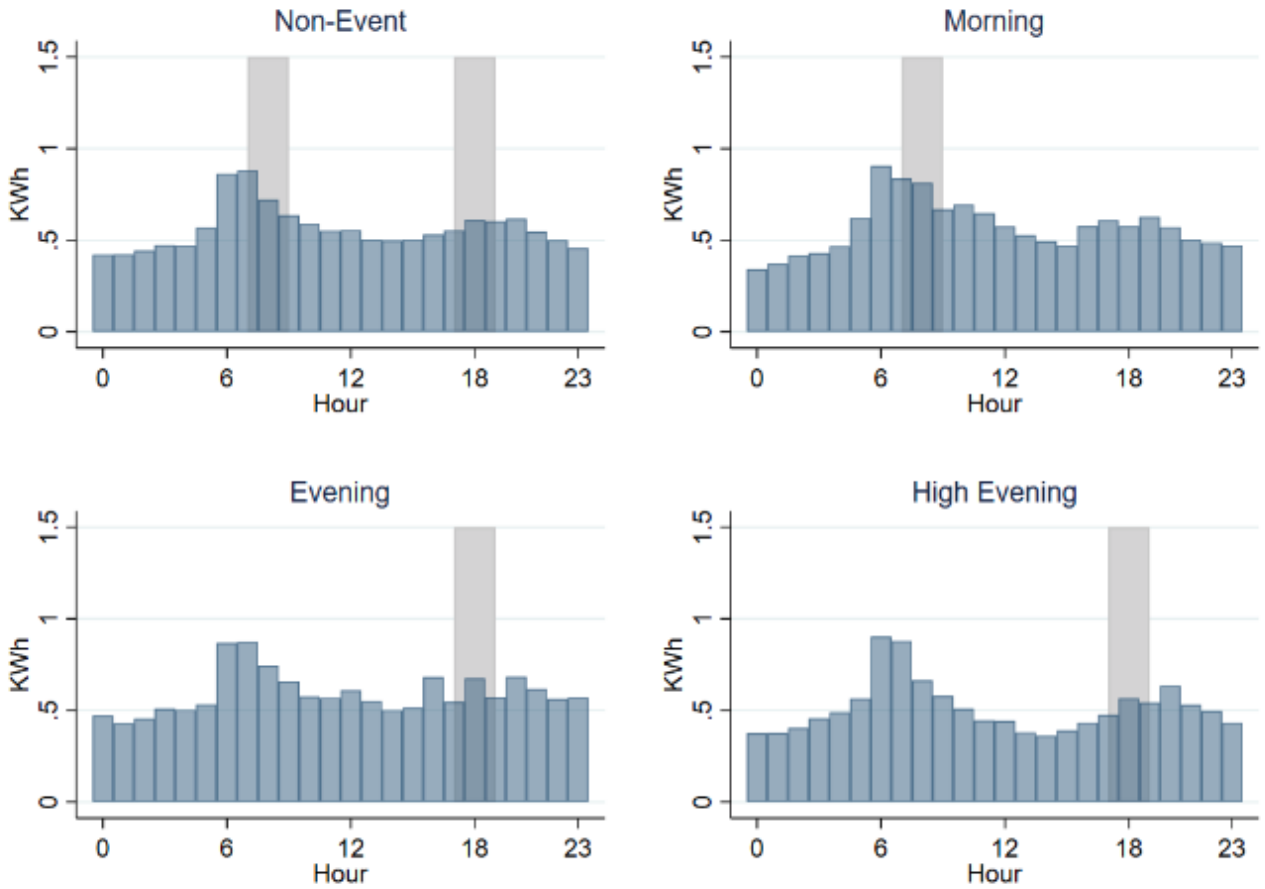

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