Do Smart Technologies Deliver?

Smart Thermostats and Energy Conservation

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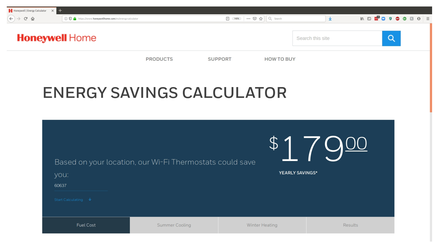
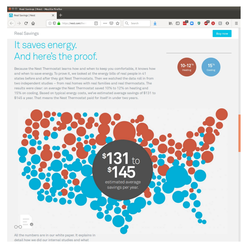
1. Motivation: Big Costs & Bold Claims

- Residential energy use has significant private and social costs
  - Private: ~$2,000 in energy bills per household per year (EPA, 2019)
  - Social: ~20% of all US carbon pollution (EIA, 2019b)
- Largest share (~40%) of residential energy goes to heating & cooling (EIA, 2019a)

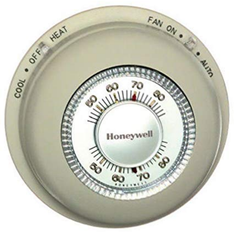




- Smart thermostat claim: ↑ efficiency ⇒ ↓ energy use w/out ↓ consumer utility
  - Based on engineering or correlation studies, not from "the field"
- Policy implications: ENERGY STAR & Smart Grid Investment Grant (SGIG) programs

2. Abstract: Smart Thermostat Field Experiment

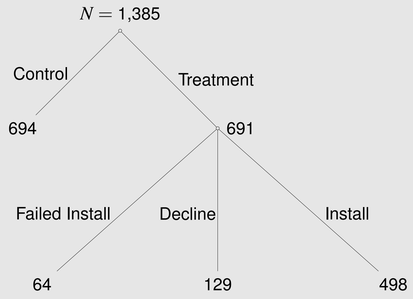
- Goal: Test the hypothesis that smart thermostats reduce energy consumption

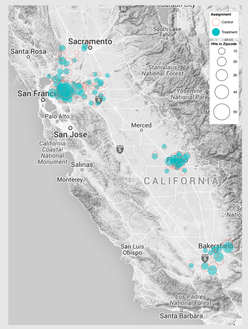


- Data: field experiment conducted by Opower & Honeywell w/ PG&E
  - Treatment: free installation of Honeywell smart thermostat linked to Opower platform
  - Smart: Programmable schedule, smartphone app, & set point comparison (Allcott, 2011)
- Observed outcome: 18 months of high-frequency data on household energy use
  - Hourly electricity (~16 million obs.)
  - Daily natural gas (~700 thousand obs.)
- Empirical model: difference-in-differences instrumental variables (DDIV)
- Results: No evidence smart thermostats affect energy use
- Potential mechanisms: descriptive evidence from user interactions w/ smart thermostat (~4 million obs.)
  - Consistent with user behavior dampening savings

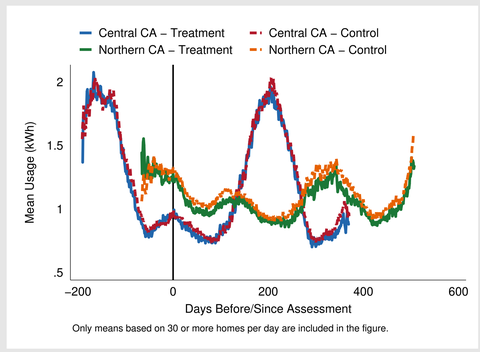
3. Experimental Design

3.1 Sample Randomization & Spatial Balance





3.2 Descriptive Evidence



Only means based on 30 or more homes per day are included in the figure.

3.3 Empirical Model: DDIV

- Second-stage equation

$$e_{it}^{j} = \alpha_i^j + \beta_P^j P_t + \gamma^j S_i P_t + X_{it}\beta_X^j + u_{it}^j,$$

where

- $e_{it}^{j} \equiv$ energy use of type $j \in$ {electricity, natural gas}
- $S_i \equiv$ an indicator for installation of a smart thermostat in home i
- $P_t \equiv$ an indicator for post-assignment status in time period t
- Two-stage least squares (2SLS) estimation w/ $Z_{it}^{j} = \left(\delta_i^j, P_t, T_i P_t, X_{it}\right)'$
  - $T_i \equiv$ an indicator for household i's treatment status in our experiment

References

Allcott, Hunt, "Social norms and energy conservation," *Journal of Public Economics*, 2011, *95* (9), 1082 – 1095. Special Issue: The Role of Firms in Tax Systems.

Energy Information Administration, "Annual Energy Outlook 2019 with Projections to 2050," Technical Report, U.S. Department of Energy, Office of Energy Analysis January 2019.

___ , "Monthly Energy Review," Technical Report, U.S. Department of Energy, Office of Energy Statistics August 2019.

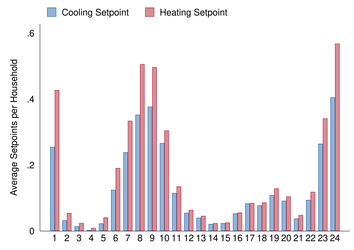
Environmental Protection Agency, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2017," Technical Report, U.S. Environmental Protection Agency 2019.

4. Results: Null & Robust

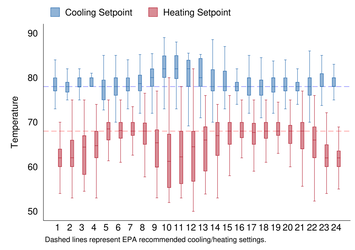
	(1)	(2)	(3)	(4)	(5)	(6)
	Power Use (kWh or thm)					
Panel A: Electricity (kWh)						
$\hat{\gamma}^{kWh}$	-0.032	-0.030	-0.002	0.001	0.001	-0.015
	(0.036)	(0.035)	(0.022)	(0.023)	(0.023)	(0.025)
$N \times T$	16,421,734	16,421,734	16,421,734	16,421,734	16,421,734	16,421,734
rk Wald F statistic	756.934	786.942	1,919.304	1,922.893	1,922.896	1,826.542
Panel B: Natural Gas (thm)						
$\hat{\gamma}^{thm}$	0.007	0.003	-0.002	-0.004	-0.004	-0.012
	(0.081)	(0.074)	(0.038)	(0.035)	(0.035)	(0.018)
$N \times T$	677,304	677,304	677,304	677,304	677,304	677,301
rk Wald F statistic	756.364	784.043	1,946.015	1,950.550	1,950.541	1,842.502
Wave & Weather Controls		x	x	x	x	x
HH Fixed Effects			x	x	x	
Month-of-Year Effects				x	x	
Day-of-Week Effects					x	x
HH-by-MOY Effects						x

Note: Standard errors clustered at the household level. *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

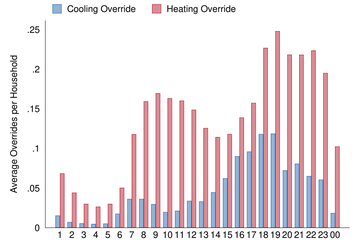
5. Potential Mechanisms: Descriptive Evidence



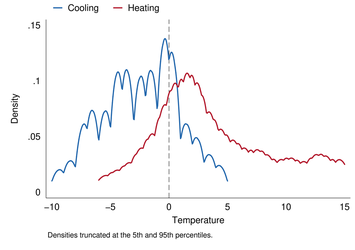
Do users program thermostats? ✓



Program for energy savings? ✓



Deviations from program? ✓



Deviations ↑ energy use? ✓