

# Knowledge is (less) power: experimental evidence from residential energy use

Katrina Jessoe   David Rapson

# Summary

- ▶ RCT: effect of high-frequency information of electricity usage on price elasticity
- ▶ Informed households more elastic
- ▶ Evidence of learning and habit formation

# Background

- ▶ Household electricity demand is inelastic
- ▶ Either inherently inelastic, or lack full information
- ▶ Infrequent billing: quantity used and usage by appliances unknown

## Experimental setup

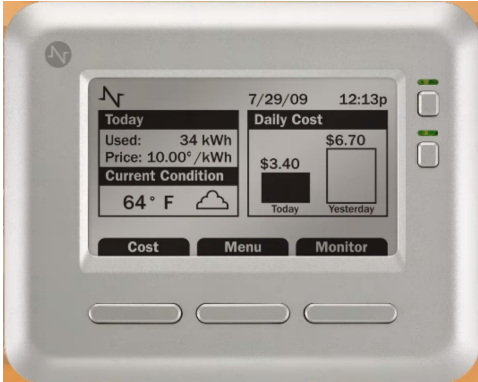
- ▶ Field experiment in Connecticut with United Illuminating Company, July and August 2011
- ▶ Sample of 437 households
- ▶ Random assignment into 3 groups
  - ▶ Control: 207
  - ▶ Price-only: 130
  - ▶ Price+IHD: 100

## Pricing events

- ▶ Day ahead (DA): Notified one day prior, 250% increase
- ▶ 30 minutes (TM): Notified 30 minutes prior, 625% increase

Event date	Desc	Type	Start hour	High temp	Mean temp	Humidity
07/21/11	4 hr \$0.50	DA	12	89	82	75
07/22/11	4 hr \$1.25	TM	12	103	90	61
08/04/11	2 hr \$0.50	DA	15	80	74	68
08/10/11	2 hr \$1.25	TM	16	88	80	63
08/17/11	2 hr \$1.25	TM	16	86	75	64
08/26/11	4 hr \$0.50	DA	12	84	78	69

## In-home display



Provides real-time usage, electricity price, estimated monthly usage and bill-to-date

# Data

- ▶ High frequency meter data, 15-minute intervals
- ▶ Data on receipt of event notification
- ▶ 2 surveys: demographics, characteristics, frequency of use of IHD
- ▶ Software issues caused random missing observations

# Balance

	Control		Price			Price + IHD		
	Mean	Obs.	Mean	Obs.	Difference	Mean	Obs.	Difference
<i>Panel A. Initial group</i>								
Off-peak usage (kWh/h)	1.230 (0.738)	207	1.282 (0.739)	130	0.052 (0.629)	1.225 (0.658)	100	-0.005 (0.058)
Peak usage (kWh/h)	1.519 (1.197)	207	1.533 (1.036)	130	0.014 (0.109)	1.413 (0.984)	100	-0.106 (0.772)
TOU Rate (1 = yes)	0.184 (0.388)	207	0.200 (0.402)	130	0.016 (0.373)	0.240 (0.429)	100	0.056 (1.153)
Home ownership (1 = yes)	0.768 (0.423)	203	0.798 (0.403)	129	0.030 (0.641)	0.773 (0.42)	97	0.005 (0.091)
Annual income (\$1,000)	72.00 (29.00)	203	74.00 (29.00)	129	2.000 (0.690)	71.00 (31.00)	97	-0.001 (0.181)
Home size (1,000 square feet)	1.529 (1.10)	189	1.880 (1.83)	119	0.351** (2.100)	1.451 (1.14)	91	-0.078 (0.550)
Age of home (years)	52.423 (30.29)	156	57.619 (31.34)	97	5.195 (1.309)	52.239 (26.94)	71	-0.184 (0.044)
<i>Panel B. Final group</i>								
Off-peak usage (kWh/h)	1.232 (0.74)	203	1.297 (0.73)	124	0.065 (0.77)	1.229 (0.63)	72	-0.003 (0.033)
Peak usage (kWh/h)	1.529 (1.20)	203	1.556 (1.04)	124	0.026 (0.20)	1.468 (0.99)	72	-0.061 (0.389)
TOU Rate (1 = yes)	0.182 (0.39)	203	0.202 (0.40)	124	0.019 (0.43)	0.181 (0.39)	72	-0.002 (0.032)
Home ownership (1 = yes)	0.774 (0.42)	199	0.821 (0.39)	123	0.047 (1.01)	0.855 (0.355)	69	0.081 (1.439)
Annual income (\$1,000)	72.00 (29.00)	199	75.00 (20.00)	123	0.003 (0.93)	76.00 (28.00)	69	0.004 (1.006)
Home size (1,000 square feet)	1.541 (1.10)	185	1.908 (1.84)	114	0.367** (2.16)	1.611 (1.16)	66	0.069 (0.433)
Age of home (years)	52.221 (30.43)	154	56.574 (31.02)	94	4.354 (1.09)	53.375 (28.59)	56	1.154 (0.247)



# LPM

- ▶ Estimate LPM of treatment on mean off-peak usage and rate class; neither variable significant
- ▶ Estimate LPM of compliance on mean off-peak usage and rate class; rate class is significant
- ▶ Possible selective attrition

## LPM results

	Initial group		Compliers	
	Price	Price + IHD	Price	Price + IHD
Mean off peak kWh	0.021 (0.040)	−0.019 (0.040)	0.030 (0.029)	0.060 (0.071)
TOU rate (1=yes)	0.010 (0.074)	0.088 (0.071)	−0.018 (0.053)	−0.263** (0.109)
<i>F</i> -statistic	0.206	0.775	0.579	2.915
<i>p</i> -value	0.814	0.462	0.562	0.059
Observations	337	307	130	100

## Raw data 1

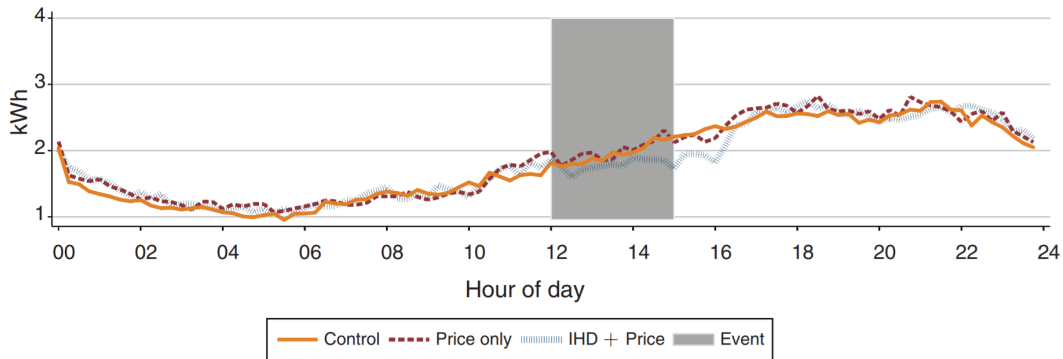


FIGURE 1. JULY 21, 2011: 4HR \$0.50 INCREASE, DAY-AHEAD NOTICE

## Raw data 2

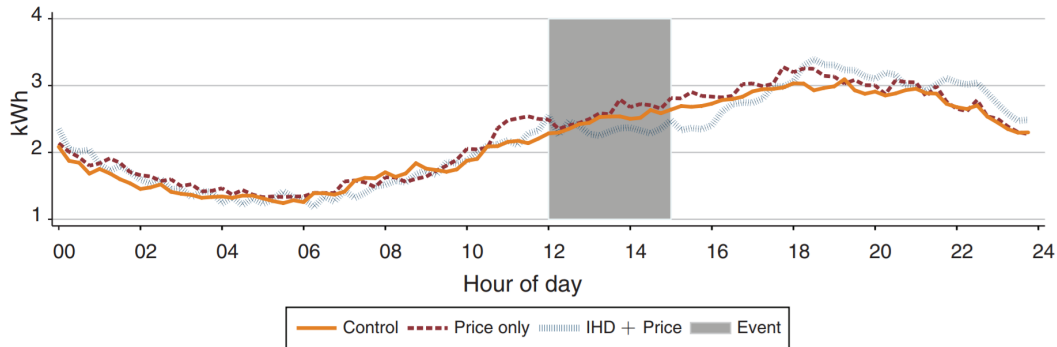


FIGURE 2. JULY 22, 2011: 4HR \$1.25 INCREASE, 30-MIN NOTICE

## Raw data 3

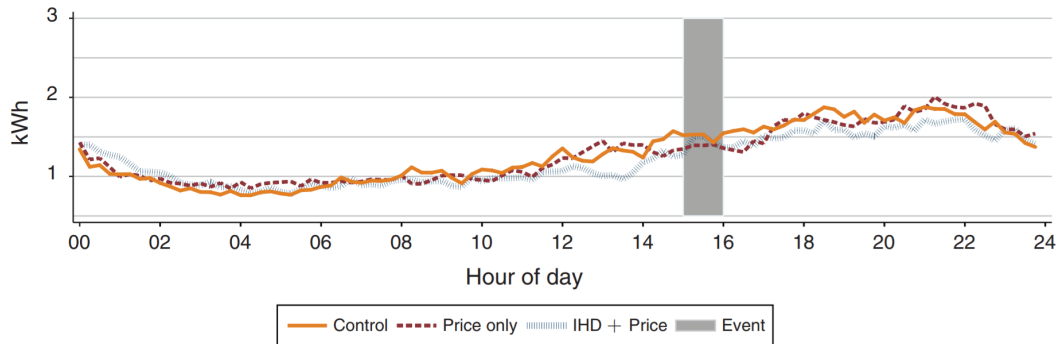


FIGURE 3. AUGUST 4, 2011: 2HR \$0.50 INCREASE, DAY-AHEAD NOTICE

## Raw data 4

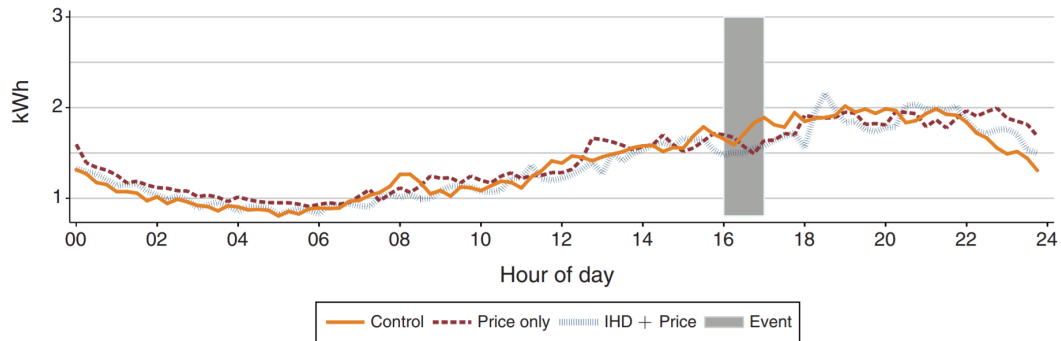


FIGURE 4. AUGUST 10, 2011: 2HR \$1.25 INCREASE, 30-MIN NOTICE

## Raw data 5

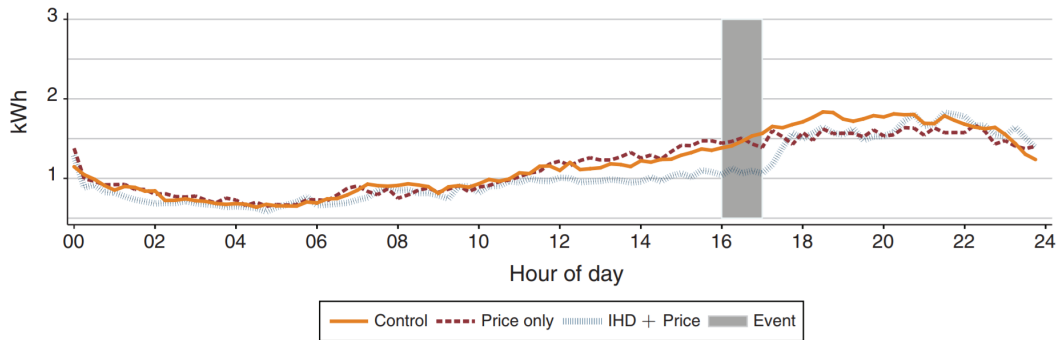


FIGURE 5. AUGUST 17, 2011: 2HR \$1.25 INCREASE, 30-MIN NOTICE

## Raw data 6

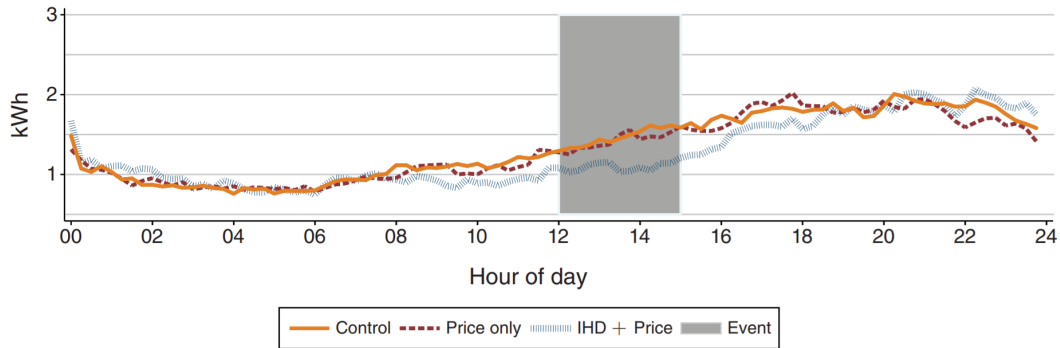


FIGURE 6. AUGUST 26, 2011: 4HR \$0.50 INCREASE, DAY-AHEAD NOTICE



## Difference in means

Event type	Variable	Mean kWh during events			Difference in mean kWh wrt control	
		Control	Price	Price + IHD	Price	Price + IHD
<i>Sample: Unbalanced panel</i>						
DA	Mean	1.65	1.59	1.35	−0.06	−0.30*
	SD	(1.51)	(1.25)	(1.22)		
	Obs	207	130	100		
TM	Mean	2.07	1.99	1.79	−0.07	−0.28
	SD	(1.77)	(1.54)	(1.42)		
	Obs	186	128	87		
<i>Sample: Balanced panel</i>						
DA	Mean	1.79	1.67	1.54	−0.13	−0.25
	SD	(1.56)	(1.13)	(1.24)		
	Obs	172	90	77		
TM	Mean	2.17	2.17	1.92	0.00	−0.25
	SD	(1.79)	(1.39)	(1.44)		
	Obs	172	90	77		

## DiD estimation

- ▶ Estimation equation:

$$q_{it} = \sum_{g \in \{P, P+I\}} \beta_g D_{it}^g + \gamma_g + \delta_e + \mu_{it}$$

- ▶ Intent-to-treat (ITT) and Treatment-on-the-Treated (ToT) estimator

# DiD results

Event type:	All (1)	All (2)	All (3)	All (4)	Day ahead (DA) (5)	30min (TM) (6)
<i>Panel A. ITT unbalanced panel</i>						
Price-only	-0.031 (0.036)	-0.054 (0.036)	-0.027 (0.036)	-0.038 (0.036)	-0.071* (0.042)	0.006 (0.044)
Price + IHD	-0.116** (0.048)	-0.137*** (0.048)	-0.123*** (0.047)	-0.137*** (0.046)	-0.171*** (0.051)	-0.084 (0.057)
Prob( $P = P + I$ )	0.096*	0.098*	0.051*	0.044**	0.066*	0.130
$R^2$	0.001	0.054	0.536	0.583	0.583	0.583
<i>Panel B. ToT unbalanced panel</i>						
Price-only	-0.032 (0.037)	-0.056 (0.037)	-0.028 (0.037)	-0.040 (0.037)	-0.074* (0.044)	0.007 (0.046)
Price + IHD	-0.143** (0.058)	-0.170*** (0.058)	-0.153*** (0.057)	-0.170*** (0.057)	-0.217*** (0.064)	-0.100 (0.067)
Prob( $P = P + I$ )	0.061*	0.052*	0.030**	0.023**	0.025**	0.115
$R^2$	0.001	0.054	0.536	0.583	0.583	0.583
HH FEs	No	No	Yes	Yes	Yes	Yes
Hour-by-day FEs	No	Yes	No	Yes	Yes	Yes
Number of events	6	6	6	6	3	3
Number of HHs	437	437	437	437	437	401

## IHD effect?

- ▶ 2 possible channels:
  - ▶ increased awareness of price events
  - ▶ learning
- ▶ Rule out first channel
- ▶ Confirmation of receipt of notification indicates awareness of price events

## Ruling out price salience

- ▶ Interact treatment dummy with confirmation dummy:

$$q_{it} = \sum_{g \in \{P, P+I\}} \sum_{A \in \{0,1\}} \beta_g D_{it}^g \times 1A_{it=A} + \gamma_i + \sigma_h + \mu_{it}$$

- ▶ Idea: Conditional on confirmation, there is a difference in response
- ▶ Conditional on non-confirmation, no difference in response

## Price salience results

Event type:	All events (1)	DA events (2)	TM events (3)
Price $\times$ 1[Not confirmed]	-0.007 (0.048)	-0.043 (0.066)	0.038 (0.057)
Price + IHD $\times$ 1[Not confirmed]	-0.050 (0.080)	-0.104 (0.087)	0.037 (0.110)
Price $\times$ 1[Confirmed]	-0.049 (0.040)	-0.080* (0.046)	-0.005 (0.051)
Price + IHD $\times$ 1[Confirmed]	-0.162*** (0.052)	-0.192*** (0.057)	-0.113* (0.062)
<i>p</i> -value (PIHD $\times$ NC = P $\times$ NC)	0.628	0.557	0.991
<i>p</i> -value (PIHD $\times$ C = P $\times$ C)	0.047**	0.073*	0.120

## Learning via IHD interaction

- ▶ Frequency of interaction with IHD indicates learning
- ▶ Interact treatment dummy with interaction intensity

$$q_{it} = \sum_{g \in \{P, P+I\}} \sum_A \beta_g D_{it}^g \times 1A_{it=A} + \gamma_i + \sigma_h + \mu_{it}$$

## IHD interaction results

	Percent of HHs	All events	DA events	TM events
Price + IHD $\times$ 1[0/None]	4	-0.453** (0.196)	-0.690*** (0.181)	-0.161 (0.338)
Price + IHD $\times$ 1[1-2 times]	10	-0.013 (0.139)	-0.028 (0.137)	0.007 (0.160)
Price + IHD $\times$ 1[3-5 times]	8	0.02 (0.083)	-0.02 (0.083)	0.06 (0.091)
Price + IHD $\times$ 1[More than 5 times]	40	-0.248*** (0.077)	-0.279*** (0.085)	-0.204** (0.086)
Price + IHD $\times$ 1[Missing]	38	-0.023 (0.096)	-0.065 (0.095)	0.037 (0.119)
<i>p</i> -value (PIHD $\times$ >5 = PIHD $\times$ 1-2)		0.123	0.102	0.225
<i>p</i> -value (PIHD $\times$ >5 = PIHD $\times$ 3-5)		0.011**	0.017**	0.020**



## Load-shifting and spillovers

- ▶ Conservation during event may be offset by load-shifting
- ▶ Reduction in usage before and after event
- ▶ Add 2-hour before and after event indicators to ITT specification

## Load-shifting and spillovers results

	DA events	TM events
Price-only: 2hrs pre-event	0.002 (0.038)	0.053 (0.038)
Price-only: 2hrs post-event	-0.043 (0.046)	-0.051 (0.045)
Price + IHD: 2hrs pre-event	-0.097** (0.042)	-0.024 (0.045)
Price + IHD: 2hrs post-event	-0.103* (0.054)	-0.027 (0.056)

## Habit formation

- ▶ Multiple exposures cause reduction in usage outside of price events
- ▶ Estimate average daily decrease in usage at different hours of the day

$$q_{it} = \sum_g \beta_g D_{it}^g + \sum_g \sum_{hod} \lambda_{g,hod} \times D_i^g \times d + \gamma_i + \sigma_h + \mu_{it}$$

- ▶  $hod$  is hour-of-day binary indicator
- ▶  $d$  is running variable for day, 1 to 62

## Habit formation results

	Price	Price + IHD
12–1 PM Calendar day trend	–0.0023 (0.0016)	–0.0030** (0.0015)
1–2 PM Calendar day trend	–0.0024 (0.0015)	–0.0027* (0.0014)
2–3 PM Calendar day trend	–0.0025* (0.0014)	–0.0032** (0.0013)
3–4 PM Calendar day trend	–0.0027* (0.0014)	–0.0031** (0.0013)
4–5 PM Calendar day trend	–0.0033** (0.0014)	–0.0034*** (0.0013)
5–6 PM Calendar day trend	–0.0032** (0.0014)	–0.0033** (0.0013)
6–7 PM Calendar day trend	–0.0038** (0.0015)	–0.0032** (0.0014)
7–8 PM Calendar day trend	–0.0037** (0.0017)	–0.0029** (0.0015)

## Interpretation

- ▶ Attenuation of main effect estimate due to reduction in baseline usage
- ▶ Larger spillovers for price+IHD indicates even larger effect of information feedback on elasticity
- ▶ Similar cumulative response irrespective of information feedback, but information may allow better response to short-run incentives
- ▶ Habit formation in both groups, possible large GHG abatement benefits