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Mass Save audits
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OPOWER

Energy Efficiency

Part 2: Measurement

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- So far: the Allcott & Greenstone model of the energy efficiency gap, and nudges
- Today: how do we *measure* the energy savings from an efficiency program?
 - Running example: Mass Save home energy audits
 - Selection bias, experiments, and the LATE
- Next: the “weatherization wars” (Fowlie, Greenstone & Wolfram)
- Empirical theme: field experiments

Measuring energy savings

What if we're not sure how efficient a good is?

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- In our simple model of energy efficiency, an investment E is worth making if energy savings are worth more than the up front cost (and any difference in preference for the good)

$$\gamma pm(e_I - e_E)/(1 + r) > (c_E - c_I) + \xi$$

- A key assumption is that we *know* the energy rating e .
- In reality, this is more complicated for many goods
 - Cars may perform one way in ideal track conditions, and another in the real world
 - Energy lost via heat from an incandescent depends on how long it's on and ambient temperature
- What matters to consumers is *realized* energy savings
- This is also what matters for policymakers who might use taxpayer money to subsidize these investments

Where does home energy go?

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- Homes account for about **20%** of all U.S. energy use
- The average U.S. household spent **\$1,884** on energy in 2020
- **Space heating** is the single largest end use: 42% of household energy
 - The rest: water heating, air conditioning, appliances, electronics, lighting
- Heating bills depend a lot on climate and fuel (average spending on heat, 2020):
 - New Hampshire: \$981/year vs. Louisiana: \$244/year
 - Homes heated with fuel oil: \$1,164/year vs. natural gas: \$519/year

Sources: EIA, *Energy Explained* (2023 data); EIA, Residential Energy Consumption Survey (RECS) 2020.

- Over **30%** of Massachusetts homes were built before 1940 (vs. about 12% nationally)
 - Built long before modern insulation and energy codes: drafty and under-insulated
- Heating fuel: about 55% natural gas, 30% heating oil, 9% electricity
- Buildings are about **36%** of the state's greenhouse gas emissions
 - Space and water heating are 70% of residential emissions
- So the state's climate plan leans heavily on making homes more efficient (and switching them to electric heat pumps)

Sources: U.S. Census ACS; Mass. Clean Energy and Climate Plan / GHG inventory (2022 emissions).

How much could an audit save? The engineering view

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- EPA (Energy Star): air sealing + insulation save an average of **15%** on heating and cooling costs (11% of total energy costs), more in cold northern states
- DOE: upgrades identified in an audit can save **5–30%** on energy bills
- **Illustrative example** (made-up but plausible numbers):
 - Oil-heated home spends \$2,000/year on heat; 15% savings = \$300/year
 - Insulation + air sealing job costs \$5,000
 - Payback at full price: about 17 years. With Mass Save paying 75% (\$1,250 out of pocket): about 4 years

How much could an audit save? The engineering view

- EPA (Energy Star): air sealing + insulation save an average of **15%** on heating and cooling costs (11% of total energy costs), more in cold northern states
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 - Payback at full price: about 17 years. With Mass Save paying 75% (\$1,250 out of pocket): about 4 years
- Two questions:
 - ① If the returns are this good, why doesn't everyone do it? (the energy efficiency gap!)
 - ② These numbers come from engineering models of a "typical" home. Do *real* households save this much?

Example: Mass Save Home Energy Audits

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- **Mass Save:** Massachusetts' energy efficiency program, run jointly by the state's electric and gas utilities (Eversource, National Grid, etc.)
- Funded by an energy efficiency charge on every electric and gas bill in the state
- 2008 Green Communities Act requires utilities to pursue all energy efficiency that is *cost effective*
 - Utilities file three-year plans with state regulators; roughly \$4 billion for 2022–2024
 - Massachusetts is consistently ranked at or near the top of state energy efficiency scorecards

- **Mass Save:** Massachusetts' energy efficiency program, run jointly by the state's electric and gas utilities (Eversource, National Grid, etc.)
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 - Utilities file three-year plans with state regulators; roughly \$4 billion for 2022–2024
 - Massachusetts is consistently ranked at or near the top of state energy efficiency scorecards
- The front door to most of the residential program: a **free Home Energy Assessment** (audit)

What happens during an audit?

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- An energy specialist spends a few hours in your home
 - Inspects the attic, walls, basement, windows, heating and cooling systems
 - Installs some small measures on the spot at no cost (e.g., air sealing)
- You get a report of recommended upgrades, with **predicted** savings for each
- Audit unlocks further subsidies
 - 75–100% off recommended insulation
 - 0% financing (“HEAT Loan”) and rebates for heat pumps, etc.

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- You get a report of recommended upgrades, with **predicted** savings for each
- Audit unlocks further subsidies
 - 75–100% off recommended insulation
 - 0% financing (“HEAT Loan”) and rebates for heat pumps, etc.
- So “getting an audit” is really a *bundle*: information + small free measures + access to subsidized upgrades
- Whatever the household does *because of* the audit counts as part of its effect

How much energy does an audit save?

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- Ratepayers are paying for this, so it matters!
 - Regulators need savings estimates to decide whether the program is cost effective
 - Reported (“claimed”) savings come largely from engineering estimates of each installed measure
- We’d like to *measure* savings using actual energy bills

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- **Discussion:** You have monthly gas bills for every household in Massachusetts, and a list of who got an audit. How would you estimate the savings?

How much energy does an audit save?

- Ratepayers are paying for this, so it matters!
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 - Reported (“claimed”) savings come largely from engineering estimates of each installed measure
- We’d like to *measure* savings using actual energy bills
- **Discussion:** You have monthly gas bills for every household in Massachusetts, and a list of who got an audit. How would you estimate the savings?
 - Compare audited vs. non-audited homes?
 - Compare audited homes before vs. after?
 - What could go wrong with each?

The thought experiment we'd like to run

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- Take one household: say, a 1920s colonial in Newton, heated with gas
- Imagine two parallel versions of next winter:
 - **World 1:** they get an audit this fall (and do whatever follows from it)
 - **World 2:** they don't
- Everything else is *identical* in the two worlds: same weather, same gas prices, same family, same thermostat habits

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 - **World 2:** they don't
- Everything else is *identical* in the two worlds: same weather, same gas prices, same family, same thermostat habits
- The **causal effect** of the audit on this household =
gas use in World 1 — gas use in World 2
- This is a “what if” question: change *one* thing, hold everything else fixed
 - Same logic as a controlled experiment in a lab
- For the program, we care about the *average* of this effect across households

The problem: we only ever see one world

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- If the household got an audit, World 2 never happened. If they didn't, World 1 never happened.
- The world we don't see is called the **counterfactual**
- This is the **Fundamental Problem of Causal Inference**
 - It's a *missing data* problem: more data won't fix it

The problem: we only ever see one world

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- The world we don't see is called the **counterfactual**
- This is the **Fundamental Problem of Causal Inference**
 - It's a *missing data* problem: more data won't fix it
- Everything we do today is about finding a good **stand-in** for the missing counterfactual
 - Other households that didn't get an audit? Different houses, different people
 - The same household last winter? Different weather, different prices, maybe a new baby
- A stand-in is only good if it tells us what *would have happened* in the missing world

Potential outcomes: putting notation on the two worlds

Let $A_i = 1$ if household i gets an audit, and $A_i = 0$ otherwise.

Each household has two **potential outcomes** Y (energy use), one for each world:

- Y_{i1} : energy use if they get an audit (World 1)
- Y_{i0} : energy use if they don't (World 2)
- We observe Y_{i1} if $A_i = 1$, and Y_{i0} if $A_i = 0$. Never both.

Potential outcomes: putting notation on the two worlds

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- We observe Y_{i1} if $A_i = 1$, and Y_{i0} if $A_i = 0$. Never both.

For any household, the audit “**treatment effect**” is $Y_{i1} - Y_{i0}$ (negative = the audit saves energy)

Averages we might care about:

- **Average treatment effect (ATE)**: $E[Y_{i1} - Y_{i0}]$, averaged over *all* households
- **Average treatment effect on the treated (ATT)**:
 $E[Y_{i1} - Y_{i0} | A_i = 1]$, averaged over households that *actually got* audits

A hypothetical example: if we could see both worlds

Home	Y_{i0} (no audit)	Y_{i1} (audit)	Effect	A_i
Victorian (1890)	1,500	1,200	-300	1
Cape (1950)	1,000	850	-150	1
Colonial (1995)	700	650	-50	0
Condo (2015)	400	380	-20	0

Gas use in therms per year. Made-up numbers.

- True ATE (all four homes): $(-300 - 150 - 50 - 20)/4 = -130$
- True ATT (the two audited homes): $(-300 - 150)/2 = -225$

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Gas use in therms per year. Made-up numbers.

- True ATE (all four homes): $(-300 - 150 - 50 - 20)/4 = -130$
- True ATT (the two audited homes): $(-300 - 150)/2 = -225$
- Notice who chose to get audits: the old, leaky homes with the most to gain

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Victorian (1890)	?	1,200	?	1
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Colonial (1995)	700	?	?	0
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- Naive comparison: average use of audited homes minus average use of non-audited homes

$$\frac{1,200 + 850}{2} - \frac{700 + 400}{2} = 1,025 - 550 = +475$$

- "Audits *increase* gas use by 475 therms per year!"

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$$\frac{1,200 + 850}{2} - \frac{700 + 400}{2} = 1,025 - 550 = +475$$

- "Audits *increase* gas use by 475 therms per year!"
- What went wrong?

Want to learn about the causal effect of an audit. What if we compare audited and non-audited homes?

$$\begin{aligned}\hat{\beta} &= E[Y_{i1}|A_i = 1] - E[Y_{i0}|A_i = 0] \\ &= E[Y_{i1}|A_i = 1] - E[Y_{i0}|A_i = 1] \quad (\text{Causal effect: ATT}) \\ &\quad + E[Y_{i0}|A_i = 1] - E[Y_{i0}|A_i = 0] \quad (\text{Selection bias})\end{aligned}$$

(we just added and subtracted the red term)

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 \hat{\beta} &= E[Y_{i1}|A_i = 1] - E[Y_{i0}|A_i = 0] \\
 &= E[Y_{i1}|A_i = 1] - E[Y_{i0}|A_i = 1] \quad (\text{Causal effect: ATT}) \\
 &\quad + E[Y_{i0}|A_i = 1] - E[Y_{i0}|A_i = 0] \quad (\text{Selection bias})
 \end{aligned}$$

(we just added and subtracted the red term)

Our estimate is biased by “selection”: the difference in the *no-audit* world, across households who do and don’t get an audit.

In our example:

- Audited homes would have used $(1,500 + 1,000)/2 = 1,250$ therms without an audit, vs. 550 for the others
- $+475 = \underbrace{-225}_{\text{ATT}} + \underbrace{700}_{\text{selection bias}}$

- Suppose we run the regression

$$Y_i = \alpha + \beta A_i + \varepsilon_i$$

- With a single dummy variable on the right-hand side, the OLS estimate $\hat{\beta}$ is *exactly* the naive difference in means
- OLS is unbiased only if A_i is uncorrelated with the error ε_i
- ε_i contains everything else that drives energy use: house size and age, number of occupants, thermostat preferences, heating fuel, ...

Connection to your econometrics class

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- OLS is unbiased only if A_i is uncorrelated with the error ε_i
- ε_i contains everything else that drives energy use: house size and age, number of occupants, thermostat preferences, heating fuel, ...
- If big, leaky houses are more likely to get audits, A_i is correlated with ε_i : **omitted variable bias**
- Selection bias is omitted variable bias in potential outcomes language
- Can we just add controls? Helps with what we can measure (square footage), but not with what we can't (preferences, plans to renovate)

Who gets an audit?

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- Households have **beliefs** about how much energy they would use with and without an audit (and the upgrades that follow)
 - Note these could be biased or just plain wrong
- There are also other things they do / don't like about getting an audit
 - Scheduling it, being home for a few hours, letting a stranger into your attic
- Get an audit if:

Expected savings + non-energy benefits > hassle cost

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- Who gets audits? What type of households?
 - Homeowners vs. renters? Recent home buyers? People with high bills? Environmentalists?

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- Who gets audits? What type of households?
 - Homeowners vs. renters? Recent home buyers? People with high bills? Environmentalists?
- Do you think these households would use more or less energy than average **without** an audit?

Who selects into audits?

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Simple model of energy efficiency investment

- Households have expectations $\tilde{E}[Y_{i1}]$ and $\tilde{E}[Y_{i0}]$ about energy use with and without an audit
 - These could be biased: $\tilde{E}[Y_i] \neq E[Y_i]$
- Compare expected savings $\tilde{E}[Y_{i0} - Y_{i1}]$ against the “cost” of the audit C_i .
 - The audit is free, but you still need to schedule it, be home, clear out the attic, etc.

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 - The audit is free, but you still need to schedule it, be home, clear out the attic, etc.

Who gets an audit?

- 1 Same C_i for everyone, correct expectations: audits go to the biggest savers – big, leaky, high-use homes.
 $E[Y_{i0}|A_i = 1] > E[Y_{i0}|A_i = 0]$, so the naive comparison *understates* savings.
- 2 Households vary in C_i or expectational errors: e.g., green households who already conserve may be most eager. Sign of the bias depends on these correlations.

What if we run an experiment?

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- Imagine we could randomly assign households to get audits.
- Since we assign A_i randomly, our selection bias term $E[Y_{i0}|A_i = 1] - E[Y_{i0}|A_i = 0]$ equals zero.

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- Imagine we could randomly assign households to get audits.
- Since we assign A_i randomly, our selection bias term $E[Y_{i0}|A_i = 1] - E[Y_{i0}|A_i = 0]$ equals zero.
- Unfortunately, in the real world we can't force people to let an auditor into their home.
- We can however, *encourage* them.
 - e.g., a mailer, a phone call offering to schedule, a gift card for completing an audit
- Allcott & Greenstone run exactly this kind of experiment for home energy audits in Wisconsin

Causal estimation under random *encouragement*

Let $Z_i = 1$ if household i is randomly encouraged. Taxonomy of household types (t):

- **Always takers** ($t = AT$): get an audit even without encouragement
($A_i = 1$ if $Z_i = 1$ or if $Z_i = 0$)
- **Never takers** ($t = NT$): don't get an audit even if encouraged
($A_i = 0$ if $Z_i = 1$ or if $Z_i = 0$)
- **Compliers** ($t = C$): only get an audit if encouraged
($A_i = 1$ if $Z_i = 1$; $A_i = 0$ if $Z_i = 0$)

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- **Compliers** ($t = C$): only get an audit if encouraged
($A_i = 1$ if $Z_i = 1$; $A_i = 0$ if $Z_i = 0$)

Who do we observe getting audits in each arm of the experiment?

	Encouraged ($Z_i = 1$)	Control ($Z_i = 0$)
$A_i = 1$	Always takers + Compliers	Always takers
$A_i = 0$	Never takers	Never takers + Compliers

If we compute the average energy use in each group,
what do we get?

	Encouraged ($Z_i = 1$)	Control ($Z_i = 0$)
$A_i = 1$	Always takers + Compliers	Always takers
$A_i = 0$	Never takers	Never takers + Compliers

- Let $Pr(t)$ be the probability of each compliance type in the population
- let Y_1^t and Y_0^t be the average energy use of each type with and without an audit.

$$E[Y|Z_i = 0] = E[Y_{i0}^{NT}]Pr(NT) + E[Y_{i0}^C]Pr(C) + E[Y_{i1}^{AT}]Pr(AT)$$

$$E[Y|Z_i = 1] = E[Y_{i0}^{NT}]Pr(NT) + E[Y_{i1}^C]Pr(C) + E[Y_{i1}^{AT}]Pr(AT)$$

If we difference these two equations, it's clear that the **only** group we learn about from this experiment is the compliers.

- If we simply difference the raw average of the treatment and control groups, we get:

$$E[Y|Z_i = 1] - E[Y|Z_i = 0] = (E[Y_{i1}^C] - E[Y_{i0}^C])Pr(C)$$

- This is referred to as the **Intent to treat effect** (ITT)
- The ITT is the average savings for compliers ($E[Y_{i1}^C] - E[Y_{i0}^C]$) times the share of compliers in the population.
- Define the average savings for compliers as the **Local Average Treatment Effect** (LATE).
- We can estimate the share of compliers by comparing the audit rate in the encouraged and control groups
- We can then recover the LATE by dividing the ITT by this share:

$$LATE = \frac{E[Y|Z_i = 1] - E[Y|Z_i = 0]}{Pr(A_i = 1|Z_i = 1) - Pr(A_i = 1|Z_i = 0)}$$

Example: an audit encouragement experiment

- Suppose we mail gift card offers to a random half of households
- 12% of encouraged households get an audit, vs. 4% of the control group
 - Share of compliers: $12\% - 4\% = 8\%$
- Average gas use is 0.4% lower in the encouraged group (ITT)

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 - Compliers who got an audit *because of* the gift card cut gas use by 5%
- Notice how small the ITT is. What does that imply for how big a sample we need?

This tells us that even with an experiment (or a good instrumental variable), we can *never* learn about the true average savings for the entire population.

The best we can do is to learn the average (causal) effect for households that would get an audit if encouraged, but otherwise would not.

What do people think of this?

- Is the LATE the number Mass Save cares about?
- When might it be *exactly* the right number?

Weatherization

Case Study: Weatherization Assistance Program

- Largest residential energy efficiency program in the US
 - Benefited over 7 million homes since 1976
- Provides **free** home improvements to low income households
- The 2009 ARRA (stimulus) dramatically increased WP funding
 - \$450 million in 2009
 - \$5 billion 2011-2012

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- Provides **free** home improvements to low income households
- The 2009 ARRA (stimulus) dramatically increased WP funding
 - \$450 million in 2009
 - \$5 billion 2011-2012
- How large are the savings from this program? Was all this taxpayer spending worth it?
 - DOE says it was a huge success
 - Some economists question these results
 - Comparing the two approaches provides a good introduction to the challenges involved in measuring energy savings

- Participants first receive a free audit to identify needs
 - insulation, new windows, furnace upgrades, etc.
- Auditor **predicts** the savings from each measure and makes recommendations.
- This audit data and information on local weather, etc are fed into a model, the National Energy Audit Tool (NEAT).
- These estimates are just guesses, so we want to *measure* the savings using billing data.

DOE's evaluation found the WP to be a resounding success

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According to the , [DOE press release](#):

- For every dollar invested in weatherization, \$4.50 was generated in energy and non-energy benefits.
- Approximately 8,500 jobs were created or retained.
- Single-family homes saved an average of \$283 annually on energy costs.
- Carbon reduction of 2.2 million metric tons.

Conclusion: "The results demonstrate that weatherization provides cost-effective energy savings and health and safety benefits to American families."

Here is the [full report](#) and [summary of results](#).

How did the DOE arrive at these findings?

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- Fowlie, Greenstone and Wolfram looked under the hood of the 4,500 page (!) DOE study
 - Our judgment is that many of the DOE's conclusions are based on dubious assumptions, invalid extrapolations, the invention of a new formula to measure benefits that does not produce meaningful results, and no effort to evaluate statistical significance
- Found numerous mistakes/ inconsistencies
- DOE had no control group for health and well being measures

DOE energy calculations involve two comparisons

- Observed the treated population before and after, and a control group **after only**.
- Can't do difference-in-differences, so they **average the differences** between these groups...

To the best of our knowledge, this approach has never been used in any textbook or research paper previously.... The approach to estimating nonenergy benefits is unrecognizable, and we believe the resulting estimates have no meaningful interpretation

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- **More importantly:** FGW argue that weatherization is a "purposeful" decision.
 - What does this mean? What are some stories here?

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- **More importantly:** FGW argue that weatherization is a “purposeful” decision.
 - What does this mean? What are some stories here?
- DOE implicitly assumes no selection

Who opts into weatherization?

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- Let $WP_i = 1$ if household i is weatherized; Y_{i1} , Y_{i0} its energy use with and without WP
- Households weatherize if:

Expected savings + non-energy benefits > hassle cost

- WP is free, but you have to apply, document income, take off work, clean out the attic, etc.

Who opts into weatherization?

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Who opts into weatherization?

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- WP is free, but you have to apply, document income, take off work, clean out the attic, etc.
- Who adopts? Do you think they would use more or less energy than average **without** weatherization?
- Comparing weatherized to non-weatherized homes gives the causal effect plus a **selection bias** term:

$$E[Y_{i0}|WP_i = 1] - E[Y_{i0}|WP_i = 0]$$

- No reason to expect this to be zero. FGW's solution: an experiment.

Fowlie, Greenstone and Wolfram (2015)

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- 30,000 WP-eligible households in Michigan
- Randomized **encouragement** design:
 - 25% of households put in treatment group
 - received extensive outreach and assistance signing up for WP
 - but control households *still eligible* for WP under own volition

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Encouraged group (households)	8,648
Initial home visits	6,694
Robo-calls	23,500
Personal calls	9,171
Follow up appointments	2,720
Average cost/encouraged hh	\$55.00

Note: The table summarizes efforts to encourage a group of Michigan households to take up weatherization assistance. These households were selected randomly from a sub-population of households who were located in the service territory of our partner utility and presumptively eligible based on ex ante available income information.

Result 1: People do not seem to want to weatherize

- Average WP household received \$5,150 worth of home improvements **totally free**
- Yet in the control group, only 1% opt into the program
- In the treatment group, only 6% opt in despite extensive encouragement
- What do people make of this?

Result 1: People do not seem to want to weatherize

- Average WP household received \$5,150 worth of home improvements **totally free**
- Yet in the control group, only 1% opt into the program
- In the treatment group, only 6% opt in despite extensive encouragement
- What do people make of this?
- Takeway: there must be large hassle costs associated with this program.
 - What might those be?

FGW as an encouragement design

- FGW can't assign weatherization, only *encouragement* ($Z_i = 1$ if in outreach group)
 - **Always takers:** weatherize with or without outreach
 - **Never takers:** don't weatherize even with outreach
 - **Compliers:** weatherize *only* because of the outreach
- Comparing average energy use across the randomized groups gives the **intent to treat** effect (ITT)
- Share of compliers:
$$Pr(WP_i = 1 | Z_i = 1) - Pr(WP_i = 1 | Z_i = 0) = 6\% - 1\% = 5\%$$

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- Share of compliers:
 $Pr(WP_i = 1|Z_i = 1) - Pr(WP_i = 1|Z_i = 0) = 6\% - 1\% = 5\%$
- **LATE** = ITT / 0.05: average savings for compliers

$$LATE = \frac{E[Y|Z_i = 1] - E[Y|Z_i = 0]}{Pr(WP_i = 1|Z_i = 1) - Pr(WP_i = 1|Z_i = 0)}$$

- Only 5% of the sample are compliers: the ITT is tiny, which is why FGW need 30,000 households

The authors estimate two models of energy savings

$$\ln(y_{imt}) = \beta \mathbf{1}\{WP\}_{imt} + \alpha_{im} + \alpha_{mt} + \epsilon_{imt}$$

- Quasi-experimental approach: Difference in differences
 - Estimates average treatment effect on treated (ATET)
- Experimental approach: Instrumental variables
 - Typically we think of an RCT as randomly assigning $\mathbf{1}\{WP\}$
 - But in this case it just increased the probability of assignment
 - Can use IV to predict probability of $\mathbf{1}\{WP\}$, ie use treatment group assignment as an instrument
 - If treatment effects differ across households, this will recover the local average treatment effect (LATE)
 - Or the treatment effect of “compliers”

Result 2: Energy savings were 10-20%

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Panel A: Dependent variable is monthly energy consumption (in logs)

	Total Energy		Gas	Electricity
	(1)	(2)	(3)	(4)
	OLS-FE	IV-FE	IV-FE	IV-FE
WAP	-0.10** (0.01)	-0.20* (0.08)	-0.21** (0.08)	-0.10 (0.10)
Imputed baseline consumption MMbtu/month		7.52	6.38	2.19
F-statistic	.	267.41**	260.10**	266.78**
Households	27,990	27,229	26,054	27,115
Observations	1662781	1653583	1528526	1638337

- $IV < OLS$. Suggests selection bias term
 $E[Y_{i0}|WP_i = 1] - E[Y_{i0}|WP_i = 0]$ is greater than zero.
- ie households selecting into WP would have had **higher than average** non-WP usage

While these savings are substantial, they are significantly less than the up front costs

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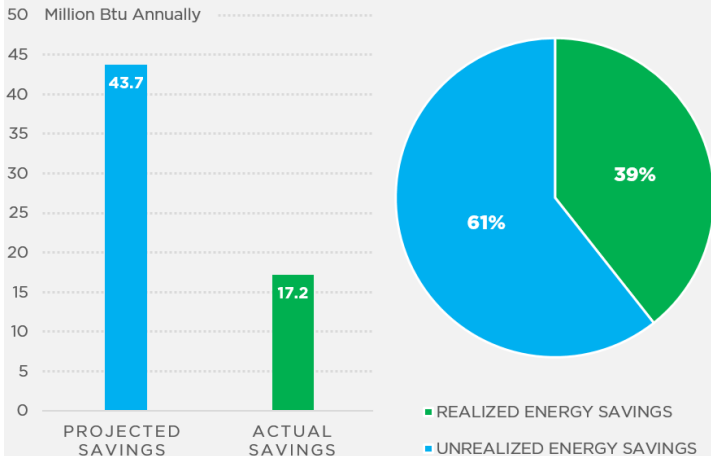
Panel B: Present value of (discounted) savings

Time Horizon	Discount rate		
	3 percent	6 percent	10 percent
10 years	\$2,003	\$1,728	\$1,443
16 years	\$2,949	\$2,373	\$1,837
20 years	\$3,493	\$2,693	\$1,999

- Average WP household received \$5,150

Engineering model projected savings were 2.5 times larger

Figure 1: NEAT-Projected Energy Savings Versus Actual Savings in the Average Recipient Household



Source: Fowlie (2015)

Even accounting for environmental externalities, the program still has negative costs

Ex Ante (NEAT) vs Ex post (FGW) benefit estimates

Panel C: Social internal rate of return

10 years	-1.0%	-20.0%
16 years	5.4%	-9.5%
20 years	7.0%	-6.1%

Panel D: CO_2 abatement cost - 3 percent discount (\$/ton CO_2)

10 years	\$29	\$552
16 years	-\$19	\$329
20 years	-\$35	\$255

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Could low savings be due to a rebound effect?

- What is the rebound effect?
- Do you think it would be large here?

Could low savings be due to a rebound effect?

- What is the rebound effect?
- Do you think it would be large here?
- Why does it matter if there's a rebound effect?

We don't have much evidence on rebound effects

- Typically hard to measure
- FGW randomly contacted a subset of treated and non-treated households
- Went to 1,658 households on cold days
 - Asked what the thermostat was set to
- 899 people let them in the house (688 let them close the door)
 - Moved to the center of the room and waved two thermometers around

Result 3: No evidence of a rebound effect

	Thermometer		Thermostat	
	(1)	(2)	(3)	(4)
Base temperature	72.36** (0.95)	72.17** (1.24)	69.26** (0.96)	68.91** (1.29)
Weatherized home	0.57 (0.41)	0.65 (0.44)	-0.57 (0.29)	-0.56 (0.33)
Heating Degree Days	-0.16** (0.03)	-0.15** (0.04)	0.04 (0.03)	0.05 (0.04)
Propensity Score Weights?	N	Y	N	Y
R-squared	0.02	0.02	0.01	0.01
Observations	1359	1359	899	899

Note: The table reports measured indoor temperature differentials across weatherized (WAP) and unweatherized households. Columns (1) and (2) have the indoor thermometer temperature reading as a dependent variable while columns (3) and (4) use the survey thermostat readings. Columns (2) and (4) are weighted so that surveyed population better represents total quasi-experimental sample. Standard errors clustered at the household level.

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- What did people learn from this debate?

- What did people learn from this debate?
- I personally think it's unfair lump ORNL together with polluters in India
- But selective attention affects all of us, and ORNLs response shows clear signs of this.
- Highlights the benefits of independent evaluators

- Energy efficiency
 - engineering models over-estimate
 - people really can't be bothered
 - rebound effect small
- Broader
 - importance of transparent and independent evaluation
 - RCTs in energy able to deal with selection

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- Long-standing interest in energy efficiency due to externalities.
- More popular than Pigouvian taxes because it seems like a “win-win”
- We describe this claim in a simple economic model that simply says that the net gains to consumers are the energy savings less the up-front cost difference.

$$\text{Net Savings} = pm(e_I - e_E)/(1 + r) - \xi - (c_E - c_I)$$

- failure to adopt when net gains are positive is a mistake (and correcting that mistake makes people better off)
- model clarifies what we need to know to conclude people are making mistakes

Quantifying the energy efficiency gap is challenging

- people are heterogeneous
 - particularly wrt to usage m
 - what is the right r ? credit card rate?
 - even if you know those values on average, you would get it wrong for half the population
- goods involve many attributes, not just energy:
 - ξ probably not zero (as in light bulbs)
- we actually don't know $(e_I - e_C)$ with certainty
 - engineering estimates can differ in the real world for lots of reasons (weatherization an extreme example)

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For all these reasons, many simple calculations of the energy efficiency gap (ie McKinsey) are probably misleading.

- Many careful studies have tried to measure the gap using field experiments.
- While people surely make mistakes, the tldr from nearly two decades of evidence suggests people aren't making massive mistakes.

Unused this year

The Role of Sales Agents in Information Disclosure: Evidence from a Field Experiment

Hunt Allcott

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Richard L. Sweeney

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With a large nationwide retailer, we run a natural field experiment to measure the effects of energy use information disclosure, customer rebates, and sales agent incentives on demand for energy-efficient durable goods. Although a combination of large rebates plus sales incentives substantially increases market share, information and sales incentives alone each have zero statistical effect and explain at most a small fraction of the low baseline market share. Sales agents strategically comply only partially with the experiment, targeting information to more interested consumers but not discussing energy efficiency with the disinterested majority. These results suggest that seller-provided information is not a major barrier to energy-efficiency investments at current prices in this context.

Data, as supplemental material, are available at <http://dx.doi.org/10.1287/mnsc.2015.2327>.

Keywords: energy efficiency; energy-using durables; information disclosure; randomized field experiments

History: Received March 16, 2015; accepted July 17, 2015, by John List, behavioral economics. Published online in *Articles in Advance*.

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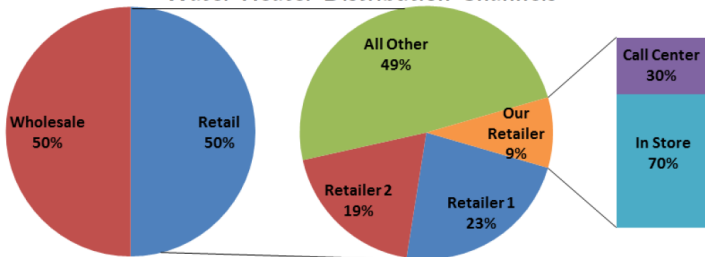
Water Heaters

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- Focus on water heaters: Second largest home energy use:
Energy cost = 29 billion/year
- Lifetime energy cost > upfront price
- Mundane product → conceptually interesting
- Randomized control trial (RCT) with large nationwide retailer
- At call center: vary Energy Star info, rebates, and sales incentives
- Measure effects on demand
- Extensive surveys and audits of sales agents and consumers

- ▶ Approx one water heater per US household
- ▶ Half fueled by natural gas

Water Heater Distribution Channels



- ▶ 96% of production from three manufacturers

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Kenmore 50 gal. 12-Year
Natural Gas Water Heater



~~\$664.99~~



Kenmore Elite 50 gal. 12-Year
Natural Gas Water Heater



~~\$1010.99~~ \$917.99



Kenmore 50 gal. 6-Year
Natural Gas Water Heater



\$699.99



Kenmore 50 gal. 6-Year Tall
Natural Gas Water Heater



~~\$484.99~~ \$460.99



Kenmore 50 gal. 6-Year
Natural Gas Water Heater
(Select California Markets)



~~\$640.99~~ \$570.99

- 6-year warranty: \$ $\approx$ 220 incremental price, \$ $\approx$ 40/year savings
 - 13-18% IRR
- But Energy Star market share $\approx$ 1/30.
- 12-year warranty: Energy Star bundled with premium features

		<u>Information</u>		<u>Spiff</u>
		<i>Treatment</i>	<i>Control</i>	\$25
<u>Rebate</u>	\$0	Phases 1-3		Phases 2, 3
	\$25			Phase 3
	\$100			

1/3 of agents randomly assigned to only Info Control

<u>Phase</u>	<u>Dates</u>	<u>Sales</u>
1	Nov 21-April 6	8875
2	April 7 -June 13	3658
3	June 14-July 7	1038

Mapping experiment to the model

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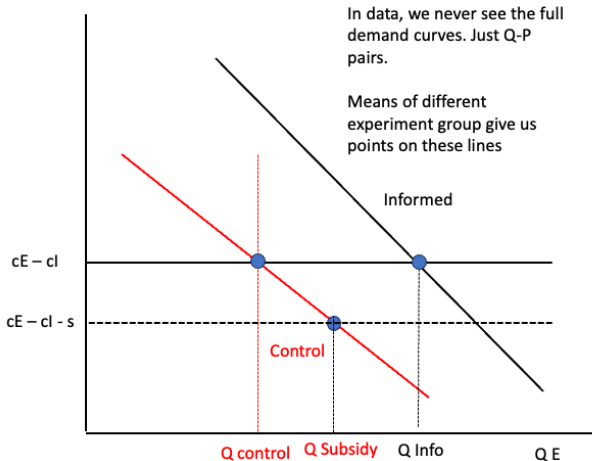
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Let me take a moment to tell you about our Energy Star models. Energy Star water heaters cost about \$220 more than a standard model, but they save a typical household \$40 each year, so you would make up that price difference in about six years. Over 12 years, which is the normal life of a water heater, you would save \$480 in energy bills. Energy Star models may not be available for every home. If possible, would an Energy Star water heater be of interest to you?

Effect of treatments on Energy Star takeup

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1(100 Rebate)	0.006 (0.003)**	0.012 (0.005)**	0.037 (0.013)***
1(25 Rebate)	0.001 (0.001)	0.002 (0.003)	0.003 (0.005)
1(Information)	0.000 (0.002)	0.000 (0.004)	0.004 (0.007)
1(Spiff)	-0.002 (0.002)		0.001 (0.007)
1(Spiff and 25 Rebate)	-0.004 (0.002)**		-0.007 (0.005)
1(Spiff and 100 Rebate)	0.040 (0.022)*		0.219 (0.118)*
R^2	0.01	0.01	0.01
N	23,347	20,240	23,347
Regression Type:	ITT	Self- Report IV	Scaled ITT

Consumers are confused about Energy Star

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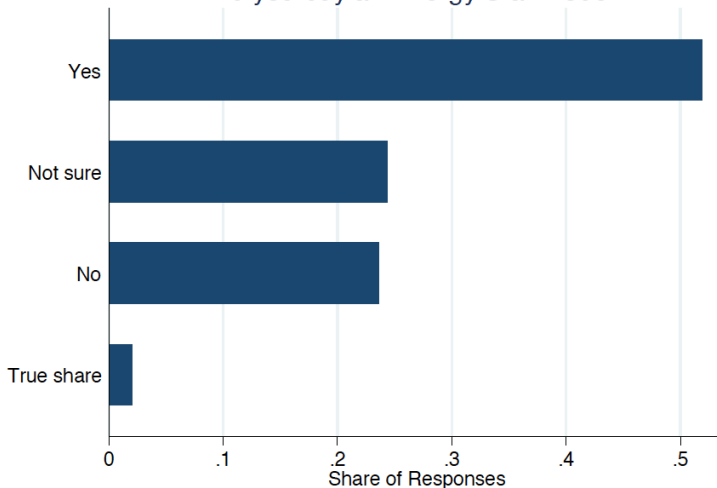
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Did you buy an Energy Star model?



But they do not underestimate energy savings

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How much money do you think the natural gas for the water heater will cost each year?

10th	50th	90th	Mean	Yellow Tag
50	200	600	305	Approx 300

*How much less money do you think the natural gas would cost each year for an
Energy Star water heater compared to a similarly-sized non-Energy Star water heater?*

10th	50th	90th	Mean	Yellow Tag
0	50	300	129	Approx 30

Implied percent savings from Energy Star

10th	50th	90th	Mean	Yellow Tag
5	25	67	32	Approx 10

Punchline: They are just not interested in the value proposition.

But they do not underestimate energy savings

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Punchline: They are just not interested in the value proposition.

What are some reasons for this?

How much of the energy efficiency gap is behavioral?

- Lots of common behavioral econ “failures” seem to apply to energy.
- Can think of salient anecdotes / examples where we can easily fool people once.
- Big leap between that and a scalable policy intervention.
- Allcott (2011) was the first paper to really to this.
- How did he do it?

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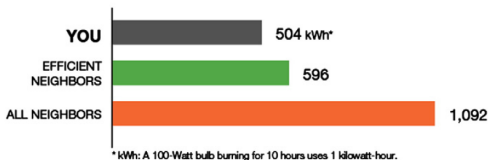
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Last Month Neighborhood Comparison

Last month you used **15% LESS**
electricity than your efficient neighbors.

YOUR EFFICIENCY STANDING:



- OPOWER provides information energy efficiency to electricity consumers
 - social comparison (above)
 - action items (next slide)
- Allcott (2011) randomly varied which households got the information
 - used billing data to estimate the impact on electricity use.

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tailored for you based on your energy use and housing profile

Smart Purchases

Save a lot by spending a little

Install occupancy sensors
Have trouble remembering to turn the lights off? Occupancy sensors automatically switch them off once you leave a room—saving you worry and money.

Sensors are ideal for rooms people enter and leave frequently (such as a family room) and also areas where a light would not be seen (such as a storage area).

Wall-mounted models replace standard light switches and they're available at most hardware stores.

SAVE UP TO
\$30 PER YEAR

Great Investments

Big ideas for big savings

☐ **Save money with a new clothes washer**
Washing your clothes in a machine uses significant energy, especially if you use warm or hot water cycles.

In fact, when using warm or hot cycles, up to 90% of the total energy used for washing clothes goes towards water heating.

Some premium-efficiency clothes washers use about half the water of older models, which means you save money. SMUD offers a rebate on certain washers—visit our website for more details.

SAVE UP TO
\$30 PER YEAR

Action Steps | Personalized tips chosen for you

Quick Fixes

Things you can do right now

☐ **Adjust the display on your TV**
New televisions are originally configured to look best on the showroom floor—at a setting that's generally unnecessary for your home.

Changing your TV's display settings can reduce its power use by up to 50% without compromising picture quality. Use the "display" or "picture" menus on your TV: adjusting the "contrast" and "brightness" settings have the most impact on energy use.

Dimming the display can also extend the life of your television.

SAVE UP TO
\$40 PER TV PER YEAR

Smart

Savings

☐ **Install**

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Source: Allcott (2011)

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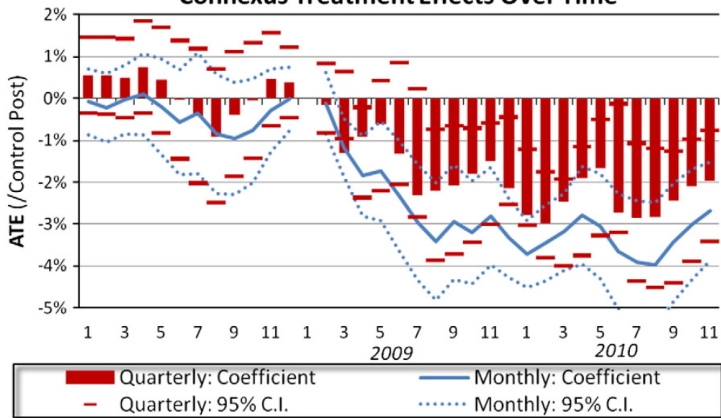
OPOWER

Overview of OPOWER projects.

Experiment			N		
Number	Region	Start date	Households	Treatment	Observations
1	Rural Midwest	February, 2009	8175	8175	343,729
2	Urban Midwest	July, 2009	37,484	18,790	1,264,375
3	Urban Midwest	July, 2009	56,187	28,027	1,873,482
4	Rural Midwest	January, 2009	78,273	39,024	3,421,306
5	Suburban Mountain	October, 2009	11,612	7,254	394,525
6	Suburban Mountain	October, 2009	27,237	16,947	914,344
7	West Coast	October, 2009	24,940	23,906	570,386
8	Rural Midwest	April, 2009	17,889	9,861	794,457
9	Urban Northeast	September, 2009	49,671	24,808	1,712,530
10	Rural Midwest	February, 2009	8,429	8,390	360,577
11	West Coast	October, 2008	79,229	34,893	3,121,879
12	West Coast	January, 2009	25,211	5,570	985,148
13	West Coast	January, 2009	17,849	3,852	672,629
14	West Coast	January, 2009	22,965	22,846	893,322
15	West Coast	September, 2009	39,336	19,663	671,990
16	West Coast	March, 2008	59,666	24,761	2,543,372
17	West Coast	April, 2008	24,293	9903	1,036,768
Combined		March, 2008	588,446	306,670	21,574,819

Source: Allcott (2011)

Connexus Treatment Effects Over Time



Source: Allcott (2011)

OPOWER: No “boomerang” effect

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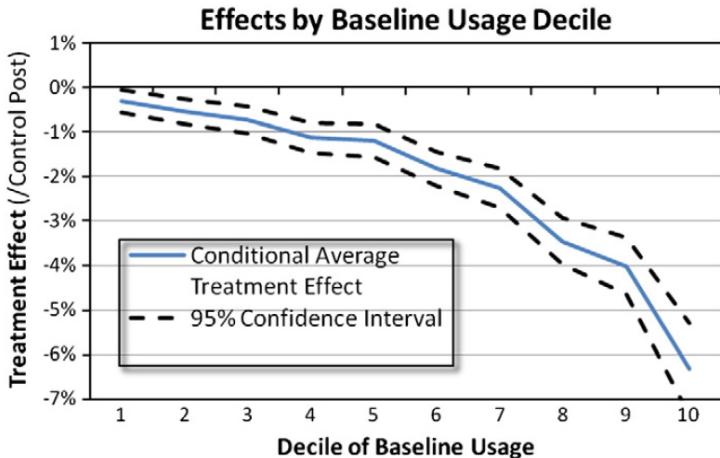
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Source: Allcott (2011)

Allcott & Mullainathan (2010)

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- OPOWER cost: 2.5 cents per kWh saved
- Long run marginal cost of electricity: 8 cents per kWh
- Net savings: 5.5 cents per kWh
- Marginal carbon intensity: .34 tons CO₂ pe kWh
- OPOWER carbon abatement cost: -\$165 per ton CO₂
- Approximate cost of wind \$20 per ton of CO₂

Conclusion: Nudges should be an important part of any cost-effective climate policy

OPOWER: Long-run backsliding?

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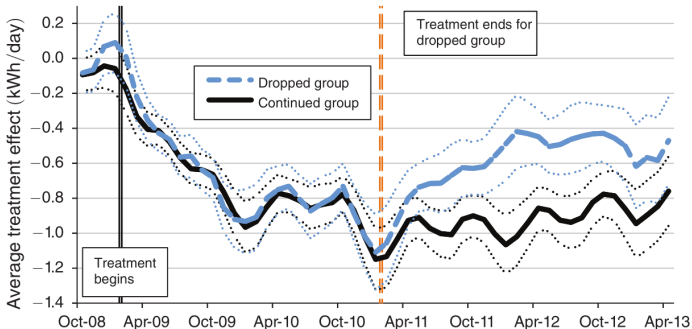
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Panel A. Site 1



Source: Allcott & Rogers (2014)

Effects decay, but slowly $\sim 10\text{-}20\%$ per year

What do we take away from OPOWER Results

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What do we take away from OPOWER Results

- Something atypical going on
- Possible explanations
 - New information (good)
 - Attention (good)
 - Guilt (bad)