Moral Suasion and Durable Goods Investment: Persistent Effects of Social Comparison on Home Energy Use

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Motivation

Behavioral policies ("nudges") more and more popular - also for environmental applications.

- Allcott (2011, JPubE): 1.37%-3.32% reduction in electricity use (equivalent to a 11-20% price increase in the short-run and 5% in the long-run)
- Ferraro and Price (2013, ReStat): up to 4.8% reduction in water use (policy goal was 2%)

But: What underlying mechanisms are responsible? Are reductions persistent over time?

- Behavioral adjustments (shorter showers, higher room temp)
- Durable goods investment (more efficient appliances, new AC)

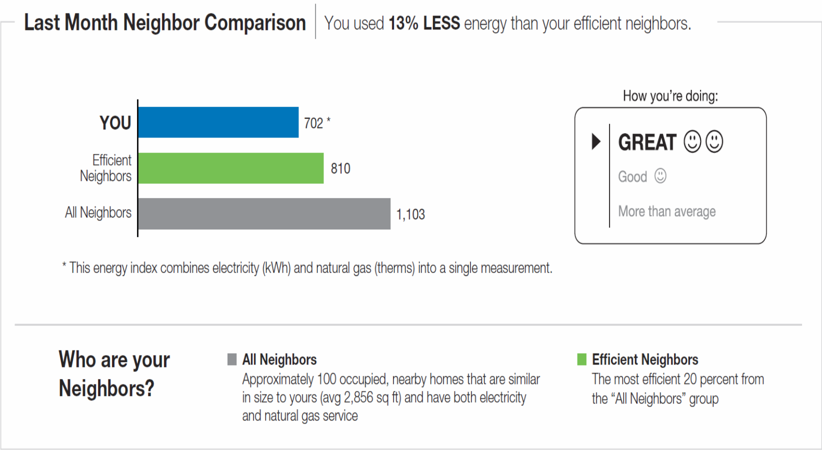
Motivation, Continued

Existing approaches cannot disentangle the two mechanisms

- Allcott and Rogers (2014, AER): After treatment is taken away, effects decay at 10-20% per year
- Ferraro et al. (2011, AER:P&P), Ferraro and Miranda (2013, REE), Bernedo et al. (2014, J Consumer Policy): Initial drop but effects remain detectable even after 7 yrs
- Literatures points more towards behavioral factors.

Contribution: Identify persistence through technology channel only.
Preview: We find strong evidence of substantial durable goods investment ($\approx$ 30% of initial response), consistent with theory predictions.

Treatment


Last Month Neighbor Comparison
You used 13% LESS energy than your efficient neighbors.
YOU
702 *
Efficient Neighbors
810
All Neighbors
1,103
How you're doing:
GREAT
Good
More than average
* This energy index combines electricity (kWh) and natural gas (therms) into a single measurement.
Who are your Neighbors?
All Neighbors
Approximately 100 occupied, nearby homes that are similar in size to yours (avg 2,856 sq ft) and have both electricity and natural gas service
Efficient Neighbors
The most efficient 20 percent from the "All Neighbors" group

Our approach

- Block out behavioral channel: focus on *home*, not household
- Utilize treatment of movers:
  - Treatment is discontinued at the time of move
  - Opower does not assign new occupants to treatment irrespective of initial treatment assignment of home
  - Use of the premise is still observed after move
- Data:
  - 41 RCTs within 22 utilities from 2008-2014
  - $\approx$ 5% of households move every year: N=366,754
  - We observe premise-month electricity use: N=12,834,331

Pre-move decision problem

Decision problem in time period t is to divide endowment m between: Numeraire consumption c_t, household production of final good z_t with energy, e_t, and investment in new technology (with existing stock k_{t-1}), I_t, as inputs (i.e. $z_t = f(e_t, k_{t-1} + I_t)$), and moral cost $s_t = g(e_t, a)$.

$$\max_{c_t, e_t, I_t} u(c_t) + v(z_t) - g(e_t, a)$$

$$\text{s.t. } m_t = c_t + p_I I_t + p_e e_t$$

$$z_t = f(e_t, k_{t-1} + I_t)$$

Optimal e_t, I_t characterized by:

$$v'(z_t) f_e(e_t, k_{t-1} + I_t) = p_e + g_e(e_t, a)$$

$$v'(z_t) f_k(e_t, k_{t-1} + I_t) = p_I$$

Takeaway: Repeated messaging acts like a permanent price change on energy consumption.

Pre-move decision problem (cont'd)

To convey intuition we make the following assumptions:

- Linear utility in the numeraire: $u(c_t) = c_t$
- Cobb-Douglas production function: $z_t = e_t^{\alpha}(k_{t-1} + I_t)^{1-\alpha}$
- Linear moral cost: $g(e_t, a) = ae_t$
- Iso-elastic utility in z_t: $v(z_t) = z_t^{1-\sigma}/(1-\sigma)$

Yield following demand functions:

$$e_t(a, k_{t-1}) = \left(\frac{\alpha}{1-\alpha}\frac{p_I}{p_e + a}\right)^{\frac{\alpha+\sigma(1-\alpha)}{\sigma}} \left(\frac{1-\alpha}{p_I}\right)^{\frac{1}{\sigma}}$$

$$I_t(a, k_{t-1}) = \left(\frac{\alpha}{1-\alpha}\frac{p_I}{p_e + a}\right)^{\frac{\alpha(1-\sigma)}{\sigma}} \left(\frac{1-\alpha}{p_I}\right)^{\frac{1}{\sigma}} - k_{t-1}$$

Then easy to see that if $\sigma > 1$ (inelastic demand for z_t):

$$de_t/da < 0$$
$$dI_t/da > 0$$

New resident decision problem

To start assume homogeneous agents sort into homes that they treat as identical (Opower treatments causes $25-50 lower energy bill per year). Then in short-run:

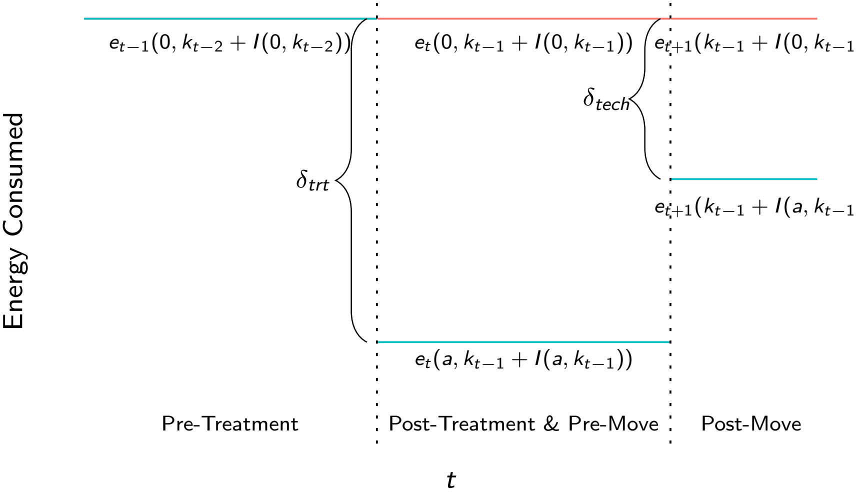
$$e_{t+1}(\tilde{a}, k_{t-1} + I_t) = \left(\frac{\alpha(k_{t-1} + I_t)^{(1-\alpha)(1-\sigma)}}{p_e + \tilde{a}} \right)^{\frac{1}{(1-\alpha)+\sigma\alpha}}$$

Where $\tilde{a} = 0$ because new tenant not in treatment. Then clear way to observe changes in I_t from changes in e_{t+1} from:

$$\frac{de_{t+1}}{dI_t} < 0$$

Notes:

1. Short-run assumption may seem strong for new tenants but only attenuates estimates.
2. Later consider predictions of a sorting model to see if drives results.


Energy Consumed
$e_{t-1}(0, k_{t-2} + I(0, k_{t-2}))$
$e_t(0, k_{t-1} + I(0, k_{t-1}))$
$e_{t+1}(k_{t-1} + I(0, k_{t-1}$
δ_{tech}
δ_{trt}
$e_{t+1}(k_{t-1} + I(a, k_{t-1}$
$e_t(a, k_{t-1} + I(a, k_{t-1}))$
Pre-Treatment
Post-Treatment & Pre-Move
Post-Move
t

Empirical Specifications: Details

Difference-in-Differences (DiD) framework:

$$\begin{aligned} Y_{it} = \alpha_0 + \beta_1 \cdot T_i + \beta_2 \cdot post\_Treatment_{it} + \beta_3 \cdot T_i \cdot post\_Treatment_{it} \\ + \beta_4 \cdot post\_Move_{it} + \beta_5 \cdot T_i \cdot Post\_Move_{it} \\ + \omega_i + \lambda_t + \epsilon_{it}, \end{aligned} \tag{1}$$

where β_3 is δ_{trt} and β_5 is δ_{tech}.

Two model specifications in the following tables:

1. Experiment FEs only (ω_i)
2. Experiment + Month-of-Sample FEs (seasonality) (λ_t)

Main Results

	(1)	(2)
Treatment	11.04***	8.01***
	(1.88)	(1.88)
Post-Treatment	-42.95***	-28.98***
	(1.38)	(1.49)
T · Post-Treatment (δ_{trt})	-32.30***	-23.81***
	(1.76)	(1.77)
Post-Move	-205.05***	-190.07***
	(1.92)	(2.48)
T · Post-Move (δ_{tech})	-9.98***	-9.88***
	(2.39)	(2.41)

Caveats

- Very large Post-Move coefficient: Homes remain on the market
  - Various exclusion rules for low-usage months after move
  - Can reduce it to 0 and still maintain persistence
- Other factors (e.g. political affiliation) that influence electricity demand
  - Persistence is robust to a wide range of additional controls
  - Pre-Treatment use, climate (HDD/CDD), environmental concern/political affiliation (ZIP code), vacancy

Sorting

Do homes with technology adoption attract "greener" after-move tenants? If green people sort into such homes, we might overstate impact of tech.

Two empirical approaches to consider:

1. Home Vacancies
    - High vacancy ⇒ buyer's market
    - High vacancy ⇒ more available homes
    - High vacancy ⇒ relatively cheap to buy capital already in home versus later investments
2. Environmental Concern Index
    - Green ZIP ⇒ more awareness of efficient technology
    - Green ZIP ⇒ people care more about efficient tech when making purchase decision
    - Green ZIP ⇒ more likely to have green mover

Sorting: Home Vacancies

	(1)	(2)
T · Post-Treatment	-34.52***	-24.73***
	(2.89)	(2.91)
Vacancy · T · Post-Treatment	0.29	0.14
	(0.26)	(0.26)
Post-Move	-188.75***	-172.25***
	(3.56)	(3.98)
Vacancy · Post-Move	-1.87***	-1.97***
	(0.36)	(0.36)
T · Post-Move	-22.21***	-19.42***
	(4.31)	(4.33)
Vacancy · T · Post-Move	1.42***	1.13***
	(0.42)	(0.42)

Sorting: Environmental Concern

	(1)	(2)	(3)
T · Post-T	-33.8806***	-29.0296***	-33.1675***
	(3.3802)	(2.7775)	(3.3579)
Env · T · Post-T	0.2064***	10.8266***	0.1949***
	(0.0560)	(4.0381)	(0.0566)
Post-Move	-214.1177***	-204.1012***	-217.9247***
	(3.8199)	(3.2478)	(3.9030)
Env · Post-Move	0.5165***	31.7878***	0.5906***
	(0.0573)	(4.2070)	(0.0585)
T · Post-Move	-11.1139***	-8.9277**	-11.8116***
	(4.2832)	(3.5321)	(4.4152)
Env · T · Post-Move	0.0587	0.5435	0.0745
	(0.0696)	(5.1452)	(0.0714)

Conclusion

- Strong evidence for persistence of treatment effects in home
- Results robust to additional controls, low-usage exclusion
- Results robust to alternative models (sorting)
- Persistence is driven by behavioral changes *and* technology (model prediction)
- Findings have impacts on cost-effectiveness and optimal design of social comparison interventions

Sorting Model Sketch

Does a sorting model describe the data? Derive testable predictions to see.

Sketch of a model: If new residents have heterogeneity in a that's independent of messaging then will solve a two-period model. First period tech is fixed and second period can make investments. Extent of sorting then depends on price of investments (which are same everywhere) vs. price of existing capital in home (which depends on each market's supply and demand).