The Short-Run and Long-Run Effects of Behavioral Interventions: Experimental Evidence from Energy Conservation

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Abstract

We document three remarkable features of the Opower program, in which social comparison-based home energy reports are repeatedly mailed to more than six million households nationwide. First, initial reports cause high-frequency "action and backsliding," but these cycles attenuate over time. Second, if reports are discontinued after two years, effects are relatively persistent, decaying at 10-20 percent per year. Third, consumers are slow to habituate: they continue to respond to repeated treatment even after two years. We show that the previous conservative assumptions about post-intervention persistence had dramatically understated cost effectiveness and illustrate how empirical estimates can optimize program design.

JEL Codes: D03, D12, L94, Q41

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Appendix: For Online Publication

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Appendix I: Surveys of Self-Reported Actions

During the past three years, Opower has surveyed about six thousand people in treatment and control groups in six sites nationwide, including 800 people in Site 2. These are telephone surveys, and completion rates are typically between 15 and 25 percent. Respondents are asked if they have taken a series of specific actions to reduce energy use in the past 12 months. We group these actions into three major categories: *repeated actions* such as switching off power strips and turning computers off at night, *physical capital changes* such as purchasing Energy Star appliances, and *intermittent actions* such as replacing air filters on air conditioning or heating systems.

Table AI-1 presents the results, combining data across all sites where respondents were asked about an action. Column (1) presents the share of respondents that report taking the action in the past 12 months. For many of the physical capital changes and intermittent actions, the means are too high. While our focus is on the differences between treatment and control, not the means, this does generate concern about whether the surveys yield meaningful responses.

Column (2) shows that there is little difference between treatment and control for the vast majority of actions, and the standard errors are tight enough to detect differences of two to four percentage points. There are three differences: treated households are more likely to use fans to keep cool, have a home energy audit, and participate in utility energy efficiency programs. The latter two actions involve physical capital stock changes. Audits, which are typically offered as part of the utility's energy conservation programs, often include direct installation of new compact fluorescent lightbulbs and can be gateways to other utility programs. Other utility programs often feature subsidies for energy efficient physical capital such as appliances, heating and cooling systems, and insulation. Fortunately, these are the two areas where additional administrative data are available, and we analyze these administrative data in the body of the paper.

For each of the three major categories, the first row (in bold) presents a test of whether the average probability of taking all actions in that category differs between treatment and control. This aggregation across actions gives standard errors tight enough to detect differences of one to two percentage points, but treated households are still not different in any of these three tests. Throughout Table AI-1, the failure to reject equality between treatment and control would only be further reinforced by adjusting the p-values for multiple hypothesis testing.

There are multiple interpretations of these results. First, the intervention might increase the true probabilities of taking actions, but the surveys might not pick this up if demand effects, over-reporting, non-response, or some other factor differed systematically between treatment and control. However, while the survey results should be interpreted cautiously, it is not obvious what would cause the treatment group to systematically report that they do not take actions. Second, the treatment could cause small changes in the true probabilities of taking a wide variety of actions, none of which are statistically detectable. Such changes could potentially add up to the observed effects on electricity use even though no one action accounts for much on its own. Third, it is possible that the intervention does not affect the "extensive margin" reported in Table AI-1, which is whether or not people take a given action, but instead changes the intensity with which people take actions they were already taking. In other words, an important impact of the intervention could to increase attention and motivation to conserve in the same ways that people were already conserving, instead of giving information about new ways to conserve.

Table AI-1: Self-Reported Actions

"In the past twelve months, have you..."	(1) Mean	(2) Treatment-Control
Taken any steps to reduce energy use?	0.77	0.010 (0.012)
Repeated Actions	0.62	0.005 (0.008)
Adjusted your thermostat settings?	0.63	0.012 (0.015)
Unplugged devices and chargers?	0.65	-0.020 (0.039)
Switched off power strips or appliances when unused?	0.59	0.002 (0.014)
Turned off lights when unused?	0.96	0.005 (0.009)
Hung laundry to dry?	0.42	0.010 (0.024)
Used energy saving or sleep features on your computer?	0.56	0.008 (0.021)
Turned off computer at night?	0.65	-0.034 (0.023)
Used fans to keep cool?	0.80	0.072 (0.034)**
Physical Capital Changes	0.55	-0.002 (0.008)
Replaced incandescent light bulbs with LEDs?	0.70	0.013 (0.038)
Purchased Energy Star appliances?	0.74	0.002 (0.016)
Disposed of a second refrigerator or freezer?	0.26	-0.001 (0.015)
Installed light timers or sensors?	0.30	-0.018 (0.038)
Replaced incandescent light bulbs with CFLs?	0.81	0.000 (0.013)
Added insulation or replaced windows?	0.54	-0.039 (0.024)
Had a home energy audit?	0.19	0.057 (0.022)***
Installed a programmable thermostat?	0.79	-0.033 (0.032)
Intermittent Actions	0.62	0.006 (0.012)
Tuned up your AC system?	0.63	-0.016 (0.018)
Used a programmable thermostat?	0.59	0.009 (0.028)
Added weather-stripping or caulking around windows?	0.60	0.008 (0.018)
Cleaned or replaced heating or AC system air filters?	0.70	0.017 (0.038)
Participated in any utility energy effiency programs?	0.19	0.018 (0.010)*
Total number of surveys	5856	

Notes: This table presents survey data on self-reported energy conservation actions. Robust standard errors. *, **, ***: Statistically significant with 90, 95, and 99 percent confidence, respectively.

Appendix Tables

Notes for Tables A1-A4

Tables A1-A4 present alternative estimates of Tables 2 and 3. Tables A1 and A2 present alternative estimates of Equation (??) for the first four reports and all later reports, respectively. Tables A3 and A4 similarly present alternative estimates of Equation (??) for the first four reports and all later reports. All tables include the bimonthly group as well as the monthly and quarterly groups.

Within each table, there are two panels. In the first, the left column excludes weather controls, while the right column exactly replicates the estimates in the body of the paper, also reporting the estimated weather coefficients. In the second, the left column excludes outliers: all observations of Y_{it} greater than 300 kWh/day and all households i with average baseline usage greater than 150 kWh/day, which is five times the mean. Based on our inspection of the data, these high-usage observations appear to be correct, not measurement errors. However, they implicitly receive significant weight in the OLS estimation, so a small number of high-usage households could in theory drive the results. The right column replaces the original $\mathbf{M}_{it}$ with six variables: $1(CDD_{it}) > 0$, CDD_{it}, $1(0 < HDD_{it} \le 5)$, $1(5 < HDD_{it} \le 35)$, $HDD_{it} \cdot 1(5 < HDD_{it} \le 35)$, and $1(HDD_{it} > 35)$. This function was based on inspection of the relationship between ATEs and degree days for this site.

The outcome variable is electricity use, in kilowatt-hours per day. Standard errors are robust, clustered by household. *, **, ***: Statistically significant with 90, 95, and 99 percent confidence, respectively.

Table A1: Robustness Checks for Table 2, First Four Reports

	(1) Monthly Base	(2) Monthly Weather	(3) Quarterly Base	(4) Quarterly Weather	(5) Bimonthly Base	(6) Bimonthly Weather
1(Treated) · 1(Post-Arrival Period)	-0.172 (0.030)***	-0.185 (0.027)***	-0.201 (0.041)***	-0.197 (0.035)***	-0.129 (0.038)***	-0.152 (0.036)***
1(Treated) · 1(Arrival Period)	-0.062 (0.024)***	-0.062 (0.024)***	-0.067 (0.029)**	-0.070 (0.028)**	-0.047 (0.033)	-0.043 (0.033)
1(Treated)	-0.534 (0.065)***	-0.451 (0.086)***	-0.391 (0.067)***	-0.420 (0.084)***	-0.366 (0.059)***	-0.276 (0.106)***
1(Treated) · Heating Degrees		-0.004 (0.004)		0.002 (0.005)		-0.009 (0.008)
Heating Degrees		0.038 (0.016)**		0.020 (0.014)		0.083 (0.011)***
1(Treated) · Cooling Degrees				0.000 (0.010)		-0.031 (0.019)*
Cooling Degrees				0.281 (0.019)***		0.016 (0.027)
N	8,515,691	8,515,691	19,333,058	19,333,058	9,609,303	9,609,303

	(1) Monthly Outliers	(2) Monthly Full M	(3) Quarterly Outliers	(4) Quarterly Full M	(5) Bimonthly Outliers	(6) Bimonthly Full M
1(Treated) · 1(Post-Arrival Period)	-0.183 (0.027)***	-0.185 (0.027)***	-0.190 (0.036)***	-0.193 (0.035)***	-0.154 (0.034)***	-0.160 (0.036)***
1(Treated) · 1(Arrival Period)	-0.061 (0.024)**	-0.061 (0.023)***	-0.070 (0.028)**	-0.069 (0.028)**	-0.032 (0.031)	-0.052 (0.029)*
1(Treated)	-0.430 (0.086)***	-0.580 (0.114)***	-0.413 (0.083)***	-0.408 (0.091)***	-0.228 (0.101)**	-0.379 (0.103)***
1(Treated) · Heating Degrees	-0.004 (0.004)		0.002 (0.005)		-0.011 (0.007)	
Heating Degrees	0.039 (0.016)**		0.021 (0.014)		0.089 (0.010)***	
1(Treated) · Cooling Degrees			0.000 (0.010)		-0.018 (0.016)	
Cooling Degrees			0.279 (0.019)***		-0.016 (0.022)	
N	8,514,078	8,515,691	19,330,176	19,333,058	9,589,391	9,609,303

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Table A2: Robustness Checks for Table 2, Later Reports

	(1) Monthly Base	(2) Monthly Weather	(3) Quarterly Base	(4) Quarterly Weather	(5) Bimonthly Base	(6) Bimonthly Weather
1(Treated) · 1(Post-Arrival Period)	-0.032 (0.009)***	-0.033 (0.009)***	-0.045 (0.022)**	-0.038 (0.022)*	-0.211 (0.060)***	-0.230 (0.061)***
1(Treated) · 1(Arrival Period)	-0.015 (0.007)**	-0.017 (0.007)**	-0.010 (0.019)	-0.005 (0.019)	-0.025 (0.047)	-0.129 (0.049)***
1(Treated)	-0.801 (0.058)***	-0.706 (0.059)***	-0.657 (0.092)***	-0.509 (0.095)***	-0.645 (0.089)***	-0.048 (0.143)
1(Treated) · Heating Degrees		-0.006 (0.003)**		-0.010 (0.005)**		-0.034 (0.008)***
1(Treated) · Cooling Degrees		-0.017 (0.007)**		-0.007 (0.013)		-0.050 (0.028)*
Heating Degrees		0.004 (0.010)		0.007 (0.011)		0.082 (0.013)***
Cooling Degrees		0.090 (0.012)***		0.023 (0.015)		0.463 (0.029)***
N	75,217,587	75,217,587	52,418,516	52,418,516	19,554,914	19,554,914

	(1) Monthly Outliers	(2) Monthly Full M	(3) Quarterly Outliers	(4) Quarterly Full M	(5) Bimonthly Outliers	(6) Bimonthly Full M
1(Treated) · 1(Post-Arrival Period)	-0.030 (0.009)***	-0.032 (0.009)***	-0.036 (0.022)	-0.035 (0.022)	-0.217 (0.060)***	-0.233 (0.061)***
1(Treated) · 1(Arrival Period)	-0.016 (0.007)**	-0.017 (0.007)**	-0.004 (0.019)	-0.006 (0.019)	-0.129 (0.049)***	-0.137 (0.050)***
1(Treated)	-0.696 (0.059)***	-0.762 (0.063)***	-0.509 (0.094)***	-0.555 (0.115)***	-0.041 (0.138)	-0.144 (0.141)
1(Treated) · Heating Degrees	-0.007 (0.003)**		-0.009 (0.005)*		-0.034 (0.008)***	
1(Treated) · Cooling Degrees	-0.017 (0.007)**		-0.007 (0.013)		-0.042 (0.026)	
Heating Degrees	0.004 (0.010)		0.007 (0.011)		0.082 (0.012)***	
Cooling Degrees	0.089 (0.012)***		0.022 (0.015)		0.444 (0.028)***	
N	75,201,504	75,217,587	52,409,856	52,418,516	19,513,453	19,554,914

Table A3: Robustness Checks for Table 3, First Four Reports

	(1) Monthly Base	(2) Monthly Weather	(3) Quarterly Base	(4) Quarterly Weather	(5) Bimonthly Base	(6) Bimonthly Weather
1(Treated) · 1(Window) · Time	1.356 (1.265)	4.082 (1.302)***	0.706 (0.195)***	0.708 (0.187)***	1.012 (0.439)**	0.948 (0.426)**
1(Treated)	-0.413 (0.064)***	-0.098 (0.095)	-0.346 (0.071)***	-0.338 (0.084)***	-0.408 (0.067)***	-0.242 (0.104)**
1(Treated) · Heating Degrees		-0.013 (0.004)***		-0.000 (0.004)		-0.011 (0.008)
Heating Degrees		0.042 (0.016)***		0.021 (0.014)		0.085 (0.011)***
1(Treated) · Cooling Degrees				-0.004 (0.012)		-0.028 (0.019)
Cooling Degrees				0.282 (0.019)***		0.015 (0.027)
N	8,515,691	8,515,691	19,333,058	19,333,058	9,609,303	9,609,303

	(1) Monthly Outliers	(2) Monthly Full M	(3) Quarterly Outliers	(4) Quarterly Full M	(5) Bimonthly Outliers	(6) Bimonthly Full M
1(Treated) · 1(Window) · Time	4.061 (1.290)***	4.476 (1.309)***	0.674 (0.185)***	0.697 (0.187)***	0.744 (0.392)*	0.884 (0.417)**
1(Treated)	-0.083 (0.094)	-0.544 (0.120)***	-0.325 (0.083)***	-0.319 (0.089)***	-0.222 (0.101)**	-0.342 (0.101)***
1(Treated) · Heating Degrees	-0.014 (0.004)***		-0.001 (0.004)		-0.011 (0.007)	
Heating Degrees	0.043 (0.016)***		0.021 (0.014)		0.089 (0.010)***	
1(Treated) · Cooling Degrees			-0.004 (0.012)		-0.010 (0.016)	
Cooling Degrees			0.280 (0.019)***		-0.020 (0.022)	
N	8,514,078	8,515,691	19,330,176	19,333,058	9,589,391	9,609,303

Table A4: Robustness Checks for Table 3, After First Four Reports

	(1) Monthly Base	(2) Monthly Weather	(3) Quarterly Base	(4) Quarterly Weather	(5) Bimonthly Base	(6) Bimonthly Weather
1(Treated) · 1(Window) · Time	0.333	0.393	0.017	0.023	0.022	0.134
	(0.322)	(0.315)	(0.141)	(0.140)	(0.539)	(0.536)
1(Treated)	-0.777	-0.682	-0.606	-0.532	-0.551	-0.080
	(0.056)***	(0.058)***	(0.087)***	(0.091)***	(0.089)***	(0.141)
1(Treated) · Heating Degrees		-0.007		-0.006		-0.030
		(0.003)**		(0.004)		(0.008)***
1(Treated) · Cooling Degrees		-0.014		-0.005		-0.044
		(0.008)*		(0.013)		(0.029)
Heating Degrees		0.004		0.007		0.080
		(0.010)		(0.011)		(0.013)***
Cooling Degrees		0.089		0.023		0.460
		(0.012)***		(0.015)		(0.029)***
N	75,217,587	75,217,587	52,418,516	52,418,516	19,554,914	19,554,914

	(1) Monthly Outliers	(2) Monthly Full M	(3) Quarterly Outliers	(4) Quarterly Full M	(5) Bimonthly Outliers	(6) Bimonthly Full M
1(Treated) · 1(Window) · Time	0.312	0.449	0.037	0.023	-0.115	0.275
	(0.313)	(0.312)	(0.140)	(0.141)	(0.526)	(0.528)
1(Treated)	-0.672	-0.725	-0.532	-0.509	-0.070	-0.144
	(0.058)***	(0.061)***	(0.091)***	(0.104)***	(0.136)	(0.141)
1(Treated) · Heating Degrees	-0.007		-0.005		-0.031	
	(0.003)**		(0.004)		(0.008)***	
1(Treated) · Cooling Degrees	-0.014		-0.004		-0.037	
	(0.008)*		(0.013)		(0.026)	
Heating Degrees	0.004		0.007		0.080	
	(0.010)		(0.011)		(0.012)***	
Cooling Degrees	0.088		0.021		0.441	
	(0.012)***		(0.015)		(0.028)***	
N	75,201,504	75,217,587	52,409,856	52,418,516	19,513,453	19,554,914

Table A5: Placebo Report Arrivals

	(1)	(2)
	Base	Weather
1(Treated) · 1(Arrival Period)	-0.001	-0.007
	(0.016)	(0.015)
1(Treated) · 1(Post-Arrival Period)	0.011	-0.004
	(0.019)	(0.019)
1(Treated)	-0.671	-0.489
	(0.095)***	(0.093)***
1(Treated) · Heating Degrees		-0.012
		(0.005)**
1(Treated) · Cooling Degrees		-0.008
		(0.013)
Heating Degrees		0.007
		(0.011)
Cooling Degrees		0.023
		(0.015)
N	52,418,516	52,418,516

Notes: This table presents the estimates of Equation (**??**) for the quarterly group, for reports that the monthly group received but the quarterly group did not. The sample includes the period after the quarterly group's first four reports. The left column does not control for degree days, while the right column does. The outcome variable is electricity use, in kilowatt-hours per day. Standard errors are robust, clustered by household. *, **, ***: Statistically significant with 90, 95, and 99 percent confidence, respectively.

Table A6: Persistence by Subgroup

	(1) Site 1 Levels	(2) Site 1 Decays	(3) Site 2 Levels	(4) Site 2 Decays	(5) Both Sites Levels	(6) Both Sites Decays
1(Dropped)	-0.601	-0.832	-0.650	-0.805	-0.626	-0.812
	(0.090)***	(0.097)***	(0.101)***	(0.108)***	(0.068)***	(0.072)***
1(Dropped) · 1(Quarterly)	0.077	0.324	0.233	0.293	0.169	0.290
	(0.188)	(0.202)	(0.177)	(0.190)	(0.131)	(0.139)**
1(Dropped) · Baseline Usage	-0.283	-0.477	-0.632	-0.561	-0.476	-0.495
	(0.163)*	(0.184)***	(0.142)***	(0.154)***	(0.107)***	(0.119)***
1(Dropped) · 1(Post-Drop) x Time		0.211		0.131		0.164
		(0.057)***		(0.054)**		(0.040)***
Quarterly Decay Difference		-0.232		-0.050		-0.109
		(0.122)*		(0.093)		(0.075)
Baseline Usage Decay Difference		0.183		-0.061		0.017
		(0.111)*		(0.081)		(0.067)
N	956,848	956,848	1,387,473	1,387,473	2,344,321	2,344,321

Notes: This table presents the estimates of Equation (??), allowing γ and δ^{LR} to differ for monthly vs. quarterly groups and as a function of $\widetilde{Y}^b$, which is baseline usage normalized to mean 0, standard deviation 1. The sample is limited to the post-drop period and includes only dropped and control group households. The outcome variable is monthly average electricity use, in kilowatt-hours per day. Standard errors are robust, clustered by household. *, **, ***: Statistically significant with 90, 95, and 99 percent confidence, respectively.

Table A7: Table 4 with Balanced Panel

	(1) Site 1	(2) Site 2	(3) Site 3
1(Treated) · 1(Pre-Treatment)	0.033	-0.039	-0.010
	(0.088)	(0.055)	(0.073)
1(Treated) · 1(1st Year)	-0.565	-0.515	-0.652
	(0.065)***	(0.065)***	(0.093)***
1(Treated) · 1(2nd Year Until Drop)	-0.882	-0.701	-0.859
	(0.076)***	(0.078)***	(0.102)***
1(Treated) · 1(Post-Drop)	-0.605	-0.554	-0.618
	(0.088)***	(0.093)***	(0.126)***
1(Continued) · 1(Pre-Treatment)	-0.045	0.023	-0.038
	(0.093)	(0.060)	(0.055)
1(Continued) · 1(1st Year)	-0.018	0.070	-0.110
	(0.067)	(0.071)	(0.066)*
1(Continued) · 1(2nd Year Until Drop)	0.005	0.045	-0.070
	(0.078)	(0.085)	(0.075)
1(Continued) · 1(Post-Drop)	-0.329	-0.299	-0.418
	(0.089)***	(0.100)***	(0.095)***
N	2,924,939	3,800,809	4,226,607

Notes: This table presents the estimates of Equation (**??**), omitting the third and fourth lines, with the sample limited to households that never move. It replicates Table 4, except with a balanced panel. The outcome variable is monthly average electricity use, in kilowatt-hours per day. Standard errors are robust and clustered by household in Sites 1 and 2 and by block batch in Site 3. *, **, ***: Statistically significant with 90, 95, and 99 percent confidence, respectively.

Table A8: Robustness Checks for Table 5

	(1)	(2)	(3)	(4)	(5)	(6)
	Site 1	Site 1	Site 2	Site 2	Site 3	Site 3
	No Weather	Balanced	No Weather	Balanced	No Weather	Balanced
1(Treated) · 1(1st Year)	-0.565	-0.578	-0.450	-0.469	-0.641	-0.722
	(0.042)***	(0.045)***	(0.043)***	(0.045)***	(0.084)***	(0.083)***
1(Treated) · 1(2nd Year Until Drop)	-0.867	-0.923	-0.659	-0.597	-0.865	-0.783
	(0.053)***	(0.065)***	(0.052)***	(0.065)***	(0.092)***	(0.106)***
1(Treated) · 1(Post-Drop)	-0.786	-0.826	-0.718	-0.595	-0.725	-0.551
	(0.090)***	(0.093)***	(0.095)***	(0.091)***	(0.129)***	(0.130)***
1(Continued) · 1(Post-Drop)	-0.243	-0.188	-0.087	-0.183	-0.163	-0.422
	(0.091)***	(0.098)*	(0.105)	(0.103)*	(0.106)	(0.108)***
1(Dropped) · 1(Post-Drop) x Time	0.176	0.161	0.114	0.106	0.086	0.080
	(0.053)***	(0.050)***	(0.047)**	(0.044)**	(0.045)*	(0.044)*
1(Continued) · 1(Post-Drop) x Time	0.091	0.067	-0.062	-0.067	-0.079	-0.044
	(0.041)**	(0.039)*	(0.039)	(0.036)*	(0.034)**	(0.034)
N	3,294,294	2,924,939	4,435,689	3,800,809	5,063,949	4,226,607
Weather Controls	No	Yes	No	Yes	No	Yes

Notes: This table presents the estimates of Equation (**??**), omitting the second line. These are robustness checks for Table 5. Within each site, the left column excludes weather controls, while the right column limits the sample to households that never move. The outcome variable is monthly average electricity use, in kilowatt-hours per day. Standard errors are robust and clustered by household in Sites 1 and 2 and by block batch in Site 3. *, **, ***: Statistically significant with 90, 95, and 99 percent confidence, respectively.

Table A9: Lifetime Extrapolated Cost Effectiveness for the Dropped Group Design

Site	1	2	3
Program cost ($/household)	17	18	20
Electricity Savings (kWh/household)			
Savings during treatment	523	405	628
(Standard Error)	(25)	(25)	(52)
Post-treatment savings	889	798	1491
(Standard Error)	(54)	(63)	(159)
Total savings	1412	1203	2119
(Standard Error)	(60)	(68)	(167)
Cost Effectiveness (cents/kWh)			
Zero Persistence Assumption	3.31	4.44	3.20
(Standard Error)	(0.16)	(0.27)	(0.26)
Observed Persistence	1.23	1.49	0.95
(Standard Error)	(0.05)	(0.08)	(0.07)
Dropped Group Electricity Cost Savings ($millions)			
Zero Persistence Assumption	0.65	0.47	0.76
(Standard Error)	(0.03)	(0.03)	(0.06)
Observed Persistence	1.75	1.39	2.57
(Standard Error)	(0.07)	(0.08)	(0.2)

Notes: This re-creates Table 7 over the projected lifetime of effects. Savings are extrapolated using the estimated linear decay parameter $\widehat{\delta}^{LR}$. Standard errors are calculated using the Delta method.

Appendix Figures

Figure A1: Breakdown of Household Electricity Use

US Household Electricity Use
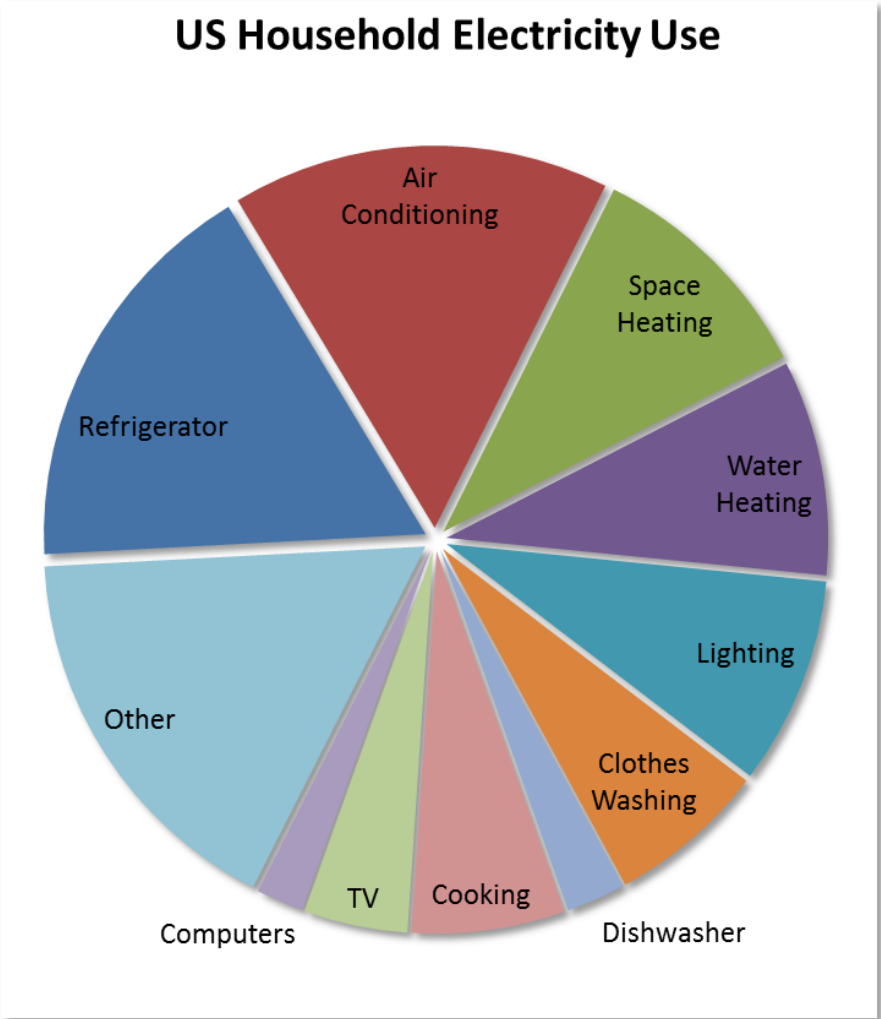
Notes: This figure shows the breakdown of electricity use for the average American household in 2001, the most recent year for which detailed figures are available. Source: U.S. Energy Information Administration (2009).

Figure A2: High-Frequency Effects with Standard Errors
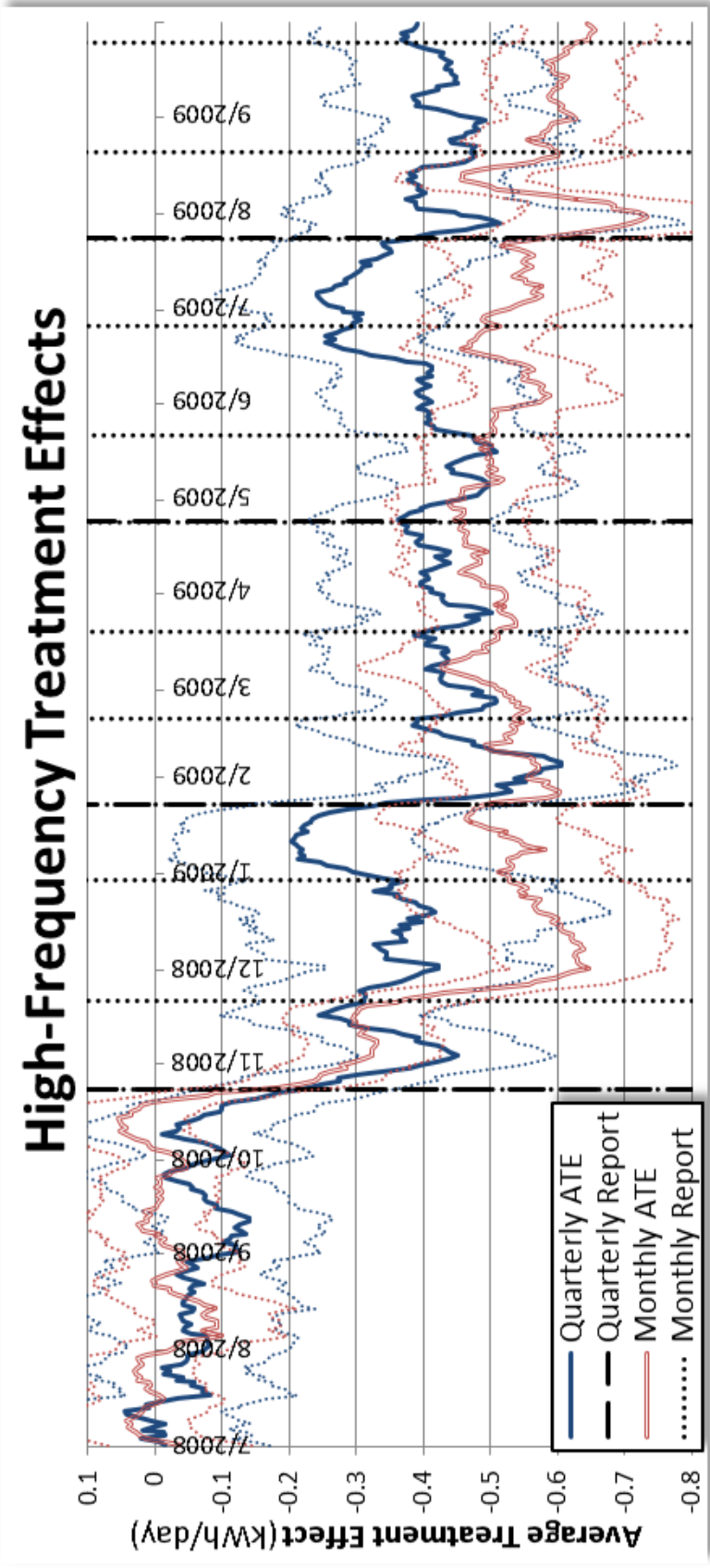
Notes: This figure plots the seven day running mean treatment effects for each day of the first year of treatment for the monthly and quarterly treatment groups, as estimated by Equation (**??**). This replicates Figure 2 but also includes standard errors.