'Oh Yea': Imputing Forgotten Responses in a Multi-Year Survey of Conservation Behavior *

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Abstract

Affirmative responses to questions about conservation behavior in a multi-year phone survey are conceived of as a compound event, performing the behavior and then recalling it during a survey. By decomposing these two events an unbiased estimate of true, rather than reported, conservation behavior is possible. This technique is applied to the telephone survey data to form estimates of the probabilities of performing conservation behaviors in each of two years, as well as the conditional probabilities of performing the conservation actions in the second year.

1 Introduction

In studies of household energy consumption and conservation, a wide array of behaviors have been found to be salient (e.g., [Lut01], [McM]). While consumer energy attitude surveys are fairly commonplace (e.g., [Com99], [Com01]), surveys focusing on actual behavior are rare, in part because of the difficulties in specifying and measuring behaviors using standard, closed-ended survey questions. The preferred alternative is to use open-ended questioning that allow consumers to report their energy-using and conservation-related actions in their own terms.

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Open responses are also maddening to manage and analyze. Interviewers must be carefully trained about prompting questions and the recording of responses. Databases must be designed to collect large amounts of free text. Analysts must be prepared for the long process of dividing and redividing responses into categories for every revision of the categories. Yes, they are maddening, but they provide the most honest and accurate information about how the survey respondents are thinking about an issue, without the mediation of expert language and categorization.

Open response surveys are also notorious for underreporting, almost as notorious as closed response surveys are for over reporting. However, these defects in both open and closed-ended questions are correctable. Closed response surveys can include questions that should be answered "true" by a very small portion of the population, to gage the extent that individuals are answering "yes" out of habit. Alternately, a series of similar questions can have their order randomized, producing several different versions of the same questionnaire. The randomization will help correct the inertia from answering "yes" to several questions in a row and continuing to answer "yes" to a question that should have a "no" response. Other techniques, such as adding nonsensical or self-contradictory questions, can be used to gage central tendency of an individual respondent and make the responses more comparable respondents. What is nice about closed response surveys is that these correcting mechanisms, though infrequently used, can be applied *in a single survey* to eliminate sources of bias and make the survey a much more precise instrument.

Open response surveys lack such simple single-pass tools that can be used to correct for the under/over-statement defects. The primary problem with open ended surveys is recall; the respondents do not remember all their actions while being interviewed. This is particularly difficult to detect within a survey since the logical mechanism to induce recall is prompting, which induces its own overstatement bias.

This paper will demonstrate that it is possible to correct for understatement in a longitudinal survey with retrospective questions in the second year. Simplistic use of a second year survey would collect the new responses reported in the second year, and then aggregate them with the previous year's open responses to produce a more complete set of open-ended responses. What this fails to do is capture those actions the respondents didn't mention either year. A more complete use of the data would be to estimate the rate that respondents recall their conservation actions.

In a recent survey of conservation behavior of California residential consumers [Lut01], the respondents were asked about conservation behaviors in one year and then asked about the continuation, initiation and termination of conservation behaviors the next year. Because the previous year's responses were not provided as prompts in the second year, there were many conservation behaviors reported the second year that were not mentioned in the first survey.

This paper will show that the true rates of conservation behavior are much higher than a simple agglomeration of the two years responses would suggest. Section 2 will describe the two surveys with respect to both the scope, and methodology used to categorize the responses. Section 3 will describe the statistical problem. Stating a conservation behavior during a survey is treated as a compound event, both performing the conservation action and reporting the action. Performing the action is then treated as a Markov process, the chance of performing the conservation action the next year is dependent on whether the action was performed, rather than reported the previous year. This allows for the probability of behavior, recall, and the conditional probability of performing the conservation reaction to be estimated. In Section 4 that follows, we will construct the reported conservation actions in each of the two years and show that the simple agglomeration of reported conservation behavior profoundly underestimates estimated conservation behavior. Section 5 will summarize the results as well as highlight the weaknesses and additional directions for this statistical technique.

2 Data

The data used in this analysis were acquired from California consumers and major utility companies ([Lut01]). Two telephone surveys were conducted, one immediately following the most recent electricity crisis and one a year later.

The first telephone survey of 1,666 randomly selected residential electricity consumers was conducted during the months of September and October of 2001. The survey sample was stratified by utility territory, with interviews of between 200 and 400 households conducted in each of the five major California utility service territories (Table 1).[1] The smaller utilities were over-sampled in order to allow statistical comparisons with the larger utilities in subsequent analysis. The sampling frame was constructed from utility customer accounts and random phone number samples, assuring that all households in the five utility territories were equally likely to be selected.

Table 1: Completed Telephone Interviews in Each Utility Service Territory

	Year 1		Year 2		
	Sample	Respondents	Sample	Respondents	Yr 2 Response Rate
PG&E	3,500	399	355	198	55.8%
SDG&E	3,500	411	369	207	56.1%
LADWP	3,500	244	208	107	51.4%
SMUD	1,166	216	196	101	51.5%
SCE	1,200	396	354	202	57.1%

The second survey was conducted from late October 2002 to early January

[1]Year 2 sample based on Year 1 respondents who agreed to be resurveyed . Dual frame samples of 1,00 Random Digit Dial (RDD) + 2,500 Directory Listed (DL) for PG&E and LADWP. For SMUD a dual frame of 566 RDD + 600DL numbers. SCE supplied a random sample of 5,000 customers, 1,200 were called.

2003. Of the 1,482 households from the first survey that agreed to be reinterviewed, a total of 792 second-year surveys were completed, as well as an additional 23 partially completed surveys, for a total of 815, a 55% response rate.

A detailed literature review and construction of an extensive bank of previously tested survey questions provided a basis for developing the phone survey. Many questions were open-ended. For example, we asked respondents whether they had "made any changes in energy use" and, if so, "what those changes were," rather than eliciting responses from lists of possible conservation actions (and thereby reducing the risks of a "priming" effect that would result in over-reporting of behaviors). We gathered data on a variety of other topics in the same manner, including open-ended questions about conservation/efficiency actions planned for the future, knowledge of conservation programs, and views of California state policies needed to continue the conservation response. The resulting responses, from the interviewees' own points of view and in their own words, were then categorized and coded for analysis in combination with the pre-coded responses to close-ended questions.

In the research reported here, respondents who indicated that their energy-using practices had changed in any way as a result of the Summer 2001 energy situation were asked to describe those changes in their own words. As noted earlier, rather than providing closed-ended choices, which risk over-reporting of socially-desirable actions, we opted for an open-ended format.

2.1 Categorization of Behaviors

The resulting responses were then summarized by multiple analysts. Each produced their own conservation categorization scheme. Some of those schemes were maintained for other kinds of analysis.[2] The analysts then agreed on a single classification scheme. The open-ended responses were coded by multiple analysts (with disagreements among them negotiated) and ultimately categorized into nearly 100 different types of conservation behaviors. For the purposes of this paper, the results are presented using a collapsed coding scheme with 11 categories (Table 2).

It should be pointed out that this particular collapsed coding scheme is not the most reasonable from every point of view. There are an infinite number of categorizations and some are more useful than others in answering different kinds of questions. These broad categories represent a compromise between traditional categories of conservation behavior and those you would create if categories were determined by: behavioral/non-behavioral, fixture/non-fixture purchase, and a residual category. The categorization presented is more useful in responding to specific policy questions about the proliferation of Compact Fluorescent Lights (CFL's) and the like, while the latter is more appropriate for detecting and controlling for the differences in the behavior of renters and owners and households with and without credit constraints.

[2]It is not possible to create a universal categorization much in the same way it is not possible to create a universal translation language for the spoken and written word.

Table 2: Reported Conservation Behaviors

Shell Improvement	Hardware related one-time improvements to the house (windows, insulation, a new fixed appliance like water heater, AC, furnace, etc.)
Light Bulbs	Hardware related purchase/use of compact florescent bulbs or other energy saving/low-watt bulbs
Appliances	Hardware related purchased/use of new non-fixture-type appliances (refrigerator, washer/dryer, window AC, fans, etc.)
Lights Behaviors	Behaviors related to turning off lights or using fewer lights
Sm. Equip Behaviors	Behaviors related to household appliances (turn off, use less, unplug)
Lg. Equip Behaviors	Behaviors related to pools, spas, irrigation motors (turn off, use less often)
Not using A/C Behavior	Behavior related to not using the AC at all
Other Heat/Cool Behaviors	Behaviors related to heating or cooling other than not using the AC at all (e.g., use AC less, use ceiling fans, draw curtains, night venting, thermostat up/down)
H2O Behaviors	Behaviors related to using less water or using less hot water (e.g., shorter showers, wash in cold/warm water, turn water heater down)
Peak Behaviors	Behaviors related to using energy during off-peak hours (postpone major appliance use until evening e.g., washing, cooking, cleaning)
Vague Behaviors	Behaviors stated in general terms (e.g., "over-all conserver", "be less comfortable", "use little energy")

Once the coding and reallocation into broad categories was complete, the data for each respondent consisted of a list of:

- Conservation behaviors that they, in the first-year survey, said they performed.
- Conservation behaviors that they, in the second-year survey, said they are continuing to perform.
- Conservation behaviors that they, in the second-year survey, said they have discontinued.
- Conservation behaviors that they, in the second-year survey, said they have initiated as a new action.

Each of these behaviors is explicitly allocated to one of the 11 categories shown in Table 2. Looking at the number of behaviors in each category does not make that much sense. Obviously there may be many, for example, peak switching behaviors, that the respondents initiated in the second year. The respondent could have several shell improvements in one year, e.g., they talked about insulation added to the floor, and walls as two separate items, and then the next year, they described it as just "added insulation" which would be translated into a single behavior. Rather than have the analysis dependent on the degree to which the respondents subdivided their behaviors, the analysis will focus on the existence of conservation behavior in each category rather than the count.

Section 3 that follows, will focus on how to determine the actual conservation behavior from the respondents' stated behavior. While it is not possible to make that determination for each individual respondent, estimates of the population behavior can be constructed.

3 Estimating Conservation Behavior

Open ended responses are not always the whole truth. There are many reasons why a respondent would not tell the interviewer about every conservation action. The respondent may simply forget to mention a conservation behavior. They may not mention a conservation behavior because it is so obvious, like turning off the lights. They may also not mention a conservation behavior because they have already mentioned several much more important conservation behaviors and the missed one did not raise to that level of importance. Surveys are an indication of the behavior, not the behavior itself.

In order for survey respondents to *report* that they performed a behavior they have to both perform the behavior and remember to tell the interviewer, a compound event as in equation 1. The probability of the respondents telling the interviewer that they performed some conservation action is the product of these events. The notation below shows that the probability of reporting an action in period one,$P_{s,t=1}$,is simply the product of the probability of *recalling* the action,P_r,and the probability of performing the action in the first year,$P_{a,t=1}$. This relationship holds for each of the conservation actions and is expected to differ across conservation actions. In other words, it is expected that some behaviors, like less frequent dishwasher use, will be less frequently recalled than shell improvements, but each has a chance of being forgotten.

$$P_{s,t=1} = P_r P_{a,t=1} \tag{1}$$

Because there is always a chance that the respondent will forget to tell the interviewer about a behavior, $1 - P_r$, there is always weak understatement of the behaviors in both the first and second survey.

This particular formulation does not allow for the possibility that respondents are giving a false but socially acceptable response. This possibility is quite small because of the minimal prompting provided by the interviewer. For each conservation category, if we assume that the recall probability, P_r, is the same in both survey years, we can estimate the true count of behaviors in both periods, even the behaviors that the respondents forgot to tell us about in *both* surveys.

3.1 Conditional Probabilities

Behaviors in the second year are dependent on what the respondents *did*, the action the previous year, not what they reported. For example, the probability that a household will actually turn off unused lights this year is dependent on if they turned them off last year, not on if they told this fact to an interviewer. Reported behavior in the second year is subject to the same kind of forgetfulness process as in the first year. So, it is possible that the respondent could not tell an interviewer about a conservation action in both years.

Equation 2 below expresses the sentiment that telling an interviewer that a conservation action is being taken this year depends on the chances of actually performing the conservation action, $P_{a,t=2|a,t=1} + P_{a,t=2|\ a,t=1}$, when the respondent did, $P_{a,t=2|a,t=1}$, or did not, $P_{a,t=2|\ a,t=1}$, perform a conservation action in the previous year. Once again, the conservation actions are only reported to the interviewer if they recalled during the interview, which happens with probability, P_r, given that the respondent actually performed the action. Again, the probability of recall, P_r, is assumed to be the same in both years, but different across conservation actions.

$$P_{s,t=2} = P_r(P_{a,t=2|a,t=1} + P_{a,t=2|\ a,t=1}) \tag{2}$$

The implication here is that in each year for each behavior the respondents can be in one of three states: (P)erformed and (R)eported an action (PR), performed but did not report an action ($P \sim R$), or, did not perform an action ($\sim P$).[3]

[3] This analysis will ignore the possibility that the respondents will report conservation behavior that did not perform, so there is no chance of observing the state were the agent reports a behavior they did not perform $R \sim P$.

We can think of the respondents as possibly transitioning from one state to another. For example, conditional on the respondent performing and reporting an action the previous period there is a certain probability that they will either perform and report the action (PR), perform and not report ($P \sim R$), and not perform,($\sim P$) an action in year two. This is usually represented as a state transition matrix that describes the chances of moving from the first-year state and the second-year state.[4]

$$\begin{pmatrix} P_{t=2}R_{t=2} \\ P_{t=2} \sim R_{t=2} \\ \sim P_{t=2} \end{pmatrix}^T = \begin{pmatrix} A_1 & A_2 & A_3 \\ A_4 & A_5 & A_6 \\ A_7 & A_8 & A_9 \end{pmatrix} \begin{pmatrix} P_{t=1}R_{t=1} \\ P_{t=1} \sim R_{t=1} \\ \sim P_{t=1} \end{pmatrix}$$

The element, A_2,in the state transition matrix is interpreted as the probability of performing an action and reporting it in year 2 given that you performed an action and did not report it in year one. We can find the probability of being in PR, $P \sim R$ and P states in the second period if we know the probability of each in the first period. The main problem is that these states are not directly observable, we only have the reported actions. Those that did not report an action could have not performed a conservation action, $\sim P$, or performed one and then not told the interviewer, $\sim RP$.

3.2 Connecting Observed States to Behavioral States

The two year survey structured what could and could not be observed. The first-year survey is simplest, in that it asked people what they did. The second-year survey provides many more nuances since respondents were asked what conservation actions they were continuing to do, what they discontinued, and what they initiated as new. The two surveys combined allowed for the construction of the observational state, O, of each conservation behavior for each survey respondent. Each of these observational state, O, can be allocated to one or more of the behavioral state, A:

- A_1- Performed and reported a behavior in first-year survey, and performed and reported a behavior in second-year survey.
- A_2- Performed but did not report a behavior in first-year survey, and performed and reported a behavior in second-year survey.
- A_3- Did not perform a behavior in first-year survey, and performed and reported a behavior in second-year survey.
- A_4- Performed and reported a behavior in first-year survey, and performed but did not report a behavior in second-year survey.
- A_5- Performed and did not report a behavior in first-year survey, and performed but did not report a behavior in second-year survey.

[4] The first-year state is described by the far right vector of probabilities (P$_{t=1}R_{t=1}P_{t=1} \sim R_{t=1} \sim P_{t=1}$).

- A_6- Did not perform a behavior in first-year survey,and performed but did not report a behavior in second-year survey.
- A_7- Performed and reported a behavior in first-year survey, and did not perform a behavior in second-year survey.
- A_8- Performed but did not report a behavior in first-year survey, and did not perform a behavior in second-year survey.
- A_9- Did not perform a behavior in first-year survey, and did not perform a behavior in second-year survey.

What we (O)bserve in the survey are the following events:

1. Reports a behavior in year one and then in year two:
   (a) O_1 reports continuing the behavior. (A_1)
   (b) O_2 reports discontinuing the behavior. (A_7)
   (c) O_3 reports initiating the action as a behavior action.(A_1)
   (d) O_4 reports nothing (A_4 or A_7)
2. Does not report a behavior in year one and then in year two:
   (a) O_5 reports continuing the behavior.(A_2)
   (b) O_6 reports discontinuing the behavior.(A_8)
   (c) O_7 reports initiating the action as a new behavior. (A_3)
   (d) O_8 reports nothing (A_5, A_6 , A_8, or A_9)

This mapping can then be translated into statements about the probability of each observational state, e.g., $P(O_1)$, in terms of both the probability of each behavioral state, e.g., $P(A_1)$, and the primal probabilities:$P_{a,t=2|\ a,t=1}$, $P_{a,t=2|a,t=1}$, $P_{a,t=1}$.

$$
\begin{aligned}
P(O_1) + P(O_3) &= P(A_1) = (P_r P_{a,t=1})(P_r P_{a,t=2|a,t=1}) && (3)\\
P(O_2) = P(A_7) &= (P_r P_{a,t=1})(1 - P_{a,t=2|a,t=1}) && (4)\\
P(O_4) = P(A_4 \vee A_7) &= (P_r P_{a,t=1})((1 - P_r)P_{a,t=2|a,t=1}) + && (5)\\
&\quad (P_r P_{a,t=1})(1 - P_{a,t=2|a,t=1}) \\
P(O_5) = P(A_2) &= ((1 - P_r)P_{a,t=1})(P_r P_{a,t=2|a,t=1}) && (6)\\
P(O_6) = P(A_8) &= ((1 - P_r)P_{a,t=1})(1 - P_{a,t=2|a,t=1}) && (7)\\
P(O_7) = P(A_3) &= (1 - P_{a,t=1})(P_r P_{a,t=2|\ a,t=1}) && (8)\\
P(O_8) &= && (9)\\
P(A_5 \vee A_6 \vee A_8 \vee A_9) &= ((1 - P_r)P_{a,t=1})((1 - P_{a,t=2|a,t=1}) + \\
&\quad ((1 - P_r)P_{a,t=2|a,t=1})) \\
&\quad (1 - P_{a,t=1})(((1 - P_r)P_{a,t=2|\ a,t=1}) + \\
&\quad (1 - P_{a,t=2|\ a,t=1}))
\end{aligned}
$$

Each of the equations above shows that the probability of an observational state, $P(O_n)$, the probabilities of the behavior states it represents, $P(A_n)$, and the primal probabilities that represents. Since observations O_1 and O_3, shown as equation 3, are just part of the observation on the same event, A_1, these are combined. This means that there are seven observables, after combining O_1 and O_3, and four unknowns, the primal probabilities.

The equation 7 can be substituted into equation 9 and equation 4 may be substituted into equation 5. Equation 6 may also be removed since the sum of the probabilities of observed states must equal one. This leaves a fully identified system of four independent equations and four unknowns.

$$\begin{aligned}
P(O_1 \vee O_3) = P(A_1) &= (P_r P_{a,t=1})(P_r P_{a,t=2|a,t=1}) && (10)\\
P(O_4) - P(O_2) = P(A_4) &= (P_r P_{a,t=1})((1 - P_r) P_{a,t=2|a,t=1}) && (11)\\
P(O_7) = P(A_3) &= (1 - P_{a,t=1})(P_r P_{a,t=2|\ a,t=1}) && (12)\\
P(O_8) - P(O_6) &= && (13)\\
P(A_5 \vee A_6 \vee A_9) &= (1 - P_r) P_{a,t=1}((1 - P_r) P_{a,t=2|a,t=1}) + \\
&\quad (1 - P_{a,t=1})(1 - P_{a,t=2|\ a,t=1}) + \\
&\quad (1 - P_{a,t=1})((1 - P_r) P_{a,t=2|\ a,t=1})
\end{aligned}$$

Rather than solve this system of equations and find the primitive probabilities, P_r, etc., in terms of the observables $P(O_n)$, this can be solved numerically given the sample probabilities of observational state.[5] The results in this paper were found by minimizing the sum of squared deviations of the system above with the "Nelder-Mead" algorithm[NM65].

The estimated primal probabilities may be further transformed to calculate the unconditional probability of performing conservation actions in the second year.

$$P_{a,t=2} = (1 - P_{a,t=1}) P_{a,t=2|\ a,t=1} + P_{a,t=1} P_{a,t=2|a,t=1} \qquad (14)$$

Finding the sampling distribution of the primal estimates analytically is exceedingly difficult. The simplest way of determining the sampling distribution is to use the bootstrap methodology[ET93].

The next section will show the results of this analysis on the data collected during the two-year survey of California households.

4 Results

The results shown below in Table 3 are the outcome of $1,000$ simple bootstrap draws from the dataset.[6] The procedure described in the previous section allowed us to directly estimate the probability of performing a conservation action in the first year, the probability of recall, and the conditional probabilities of

[5] Earlier published results used different root finding routines and objective functions and are different from the results in this paper.

[6] An R language implementation of the estimation code is available by request from the author.

Table 3: Probability Point Estimates

Behavior	P_r	$P1$	Survey One	$P2\|N$	$P2\|Y$	P2	Survey Two
Light Bulbs	0.53	0.63	0.16	0.05	0.52	0.35	0.15
Lights Behaviors	0.62	0.85	0.52	0.21	1.00	0.88	0.43
Not using AC Behavior	0.42	0.49	0.11	0.32	0.57	0.44	0.15
Peak Behaviors	0.28	0.70	0.14	0.09	0.70	0.52	0.10
Shell Improvement	0.58	0.57	0.08	0.06	0.26	0.17	0.13
H2O Behaviors	0.28	0.70	0.14	0.07	0.70	0.51	0.10
Lg. Equip Behaviors	0.42	0.57	0.07	0.01	0.31	0.18	0.04
Appliances	0.28	0.57	0.07	0.16	0.43	0.31	0.09
Other Heat or Cool Behaviors	0.62	0.76	0.30	0.18	0.68	0.56	0.41
Sm. Equip Behaviors	0.47	0.71	0.27	0.20	0.85	0.66	0.22
Vague Behaviors	0.25	0.61	0.07	0.14	0.47	0.34	0.11

performing a conservation action the second year. Further calculations enable the determination of the unconditional probability of performing a second year conservation action.

4.1 Point Estimates of Primal Probabilities

Point estimates of the primal probabilities tell part of the story. Table 3 shows the estimated probability of performing each of the conservation actions in the first and second years as well as the conditional probabilities of performing a conservation action, and the fraction of the respondents that reported a conservation action.

The table shows that the probability of recalling a conservation action while being interviewed is not all that great. Respondents were most likely to recall changes in their lighting behavior, 62%, while only 28% recalled purchasing a new appliance. High recall probabilities are also highly correlated with the more frequently stated behaviors. The behaviors with the two highest recall probabilities, lighting reductions and generalized heating and cooling behavior, had the highest and second highest stated incidence in the first year survey, 52% and 30% respectively. The exception to this pattern are the purchasers of energy efficient light bulbs. While only 16% of the survey respondents reported purchasing CFLs or other energy efficient bulbs, they were 53% likely to recall purchasing them during the interview.

Some of the estimates are unreasonably high, e.g., large equipment behavior. Only 7% of the survey respondents reported turning off pool motors and other similar behaviors the first year, but this methodology estimates that these behaviors were performed by 57% of the population. This is highly unlikely. However, one of the hidden assumptions of the probability model is that each household is capable of performing the conservation behavior. This is a reasonable assumption for some of the conservation behaviors such as turning off the lights or purchasing CFL's, since very few households have no electric lights. However, It is not very reasonable for the large equipment behaviors; you cannot turn off the pool pump if you have no pool. Because of this assumption, some of those that did not report turning off their pool pumps, even those without pools are treated as if they forgot to report the behavior.[7]

Looking at the probabilities of performing a second year action given that the action was performed, $(P2|Y)$, and was not performed, $(P2|N)$, the first year, also enforces the notion that once people begin performing conservation actions they are likely to continue performing those actions. Conversely, those that don't are unlikely to begin. For example, of those people that purchased energy efficient light bulbs the first year, 52% purchased them the next, but only 5% of those that didn't purchase some the next year. Conservation behavior is persistent.

4.2 Uncertainty

The analysis presented in Section 4.1 did not take into account the uncertainty associated with those estimates. Appendix A has a full set of tables that show the sampling distributions of the previously estimated probabilities. These tables are obviously interesting from a statistical point of view, but the uncertainty is also interesting from a policy of view.

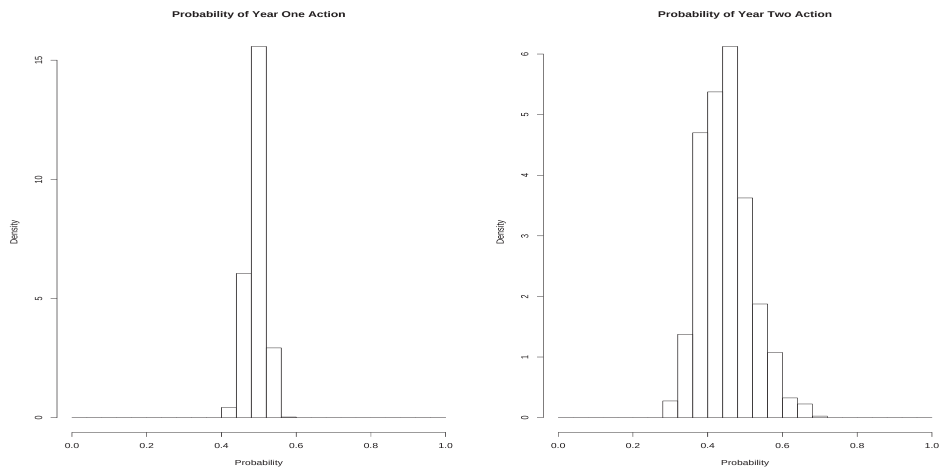
Conservation behavior changes are often not focused upon in energy efficiency programs because there is so much uncertainty about the energy savings associated with the behaviors. Widget type savings, for example, from the installation of a new air conditioner, are considered more certain, reliable, persistent, and more desirable. Unfortunately for this logic widget savings are ultimately dependent on the behaviors of the individuals that use the widgets. Installing a new energy efficient air conditioner saves no energy when the individual decides not to use it. Estimated savings from installing that air conditioner will be overstated when the individual decides to use it less frequently- even when the energy saved is greater. Uncertainty in widget type savings grows as uncertainty in conservation behaviors grow.

The uncertainties about the fraction of the population performing conservation actions are best illustrated with histograms of the parameter estimates. In each of the figures shown below the first year probabilities of conservation action are shown on the left-hand side' while on the right are the less compact second year probabilities. This is primarily because the second year probabilities include our uncertainty about the first year's behavior. A full set of figures is available in Appendix B

From a policy perspective of grid stability, the two of the most important conservation behaviors the reduction air conditioners use and peak use reduction. Air conditioning use is of course large, and highly concentrated during

[7]Removing this weakness is the topic of further research.

Figure 1: Behavior related to not using the AC at all



the peak electricity using hours of the year. Peak use describes the other non air conditioning electricity use that occurs during this high use hours. Both of these two issues get right to the heart of reliability.

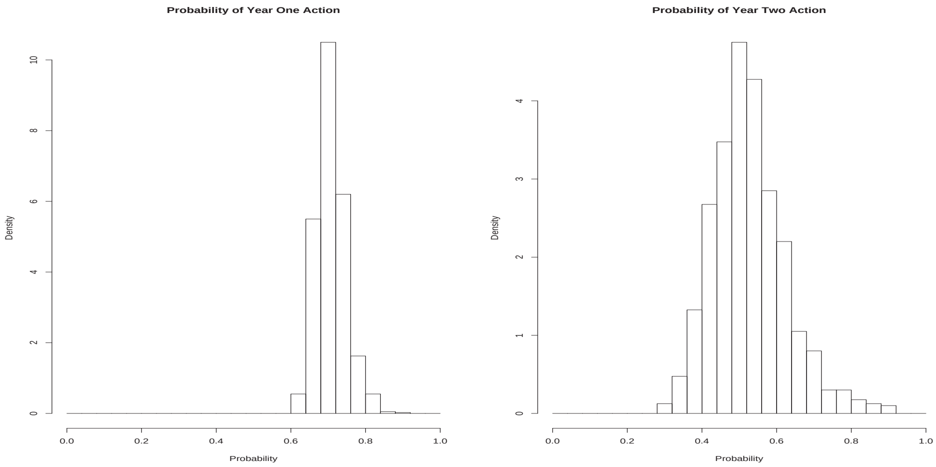
Figure 1 shows the sampling distribution of the probability that households attempting to not use the air conditioner. What is most notable is that there is greater uncertainty in the second year behavior than there is in the first year behavior. This is because there is an accumulation of uncertainty. The second year estimates reflect the uncertainty about the household behavior the previous year and the respondents ability to recall this behavior in *two* surveys. Both the year one and year two distributions are relatively compact because this behavior had a relatively high recall rate of 42%.

The figure also shows that that in the first year it is very likely that at least 40% of the households attempted not to use the air conditioner, while the lower bound in the second year was only 28%.

Figure 2 shows the similar distribution for the incidence of peak reducing behavior. The uncertainty growth is much more dramatic for this conservation behavior. The primary reason for this growth is that respondents are highly unlikely to recall these behaviors during the interview. The recall rate is only 28%, which is one of the lowest recall rates of the conservation categories.

These first and second year estimates and the uncertainty about them are not necessarily indicative of long run behavior and may represent a short-run scare or transition. Long-run behavior depends heavily on the conditional probabilities of conservation behavior, the $P2|N$ and $P2|Y$ estimates shown in table 3. The strong dependency becomes clear if conservation behavior is envisioned as a virus. The idea is that a behavior “infects” the population like a disease. Households get the bug for a while, and engage in the conservation behavior, and then ”get better”, and stop practicing that conservation behavior. In the

Figure 2: Behaviors related to using energy during off-peak hours (postpone major appliance use until evening e.g., washing, cooking, cleaning)



mean time other households have caught the bug. In this kind of model, the length of the spell of conservation behaviors for an individual household is not that important as long as the infection rate, the probability of a household picking up the behavior as new, is rather large. The long-run trend represents an equilibrium level where the same number of households stop performing the conservation action as those that are starting.

4.3 Long-Run Trends

The long-run trend is calculated by taking the conditional probability of performing a conservation action in year 2 and finding the fraction of the population that is consistent with no change in the fraction of the population conserving. This is just a Markov process and the long-run trend can be found by either solving this system of equations for the long-run probability of a conservation action, P, or by finding the Eigen vector associated with the first Eigen value.

$$P = PP_2|Y + (1 - P)P_2|N \tag{15}$$

$$(1 - P) = P(1 - P_2|Y) + (1 - P)(1 - P_2|N) \tag{16}$$

One-off computations of this kind of Markov chain will yield a monotonic trend, ever upward or downward. Because we are constructing the probability distributions of the first year, second year, and long run fraction of the households performing the conservation action, the medians of this trend can be of almost any pattern.

Table 4 shows the quantiles of the distribution of our beliefs about long-run conservation behavior with the medians of estimated first and second year

Table 4: Long-Run Trends in Conservation Behaviors

Behavior	Year 1	Year 2	Long Run
Light Bulbs	0.63	0.35	0.11
Lights Behaviors	0.85	0.88	1.00
Not using AC Behavior	0.49	0.44	0.60
Peak Behaviors	0.70	0.52	0.28
Shell Improvement	0.57	0.17	0.08
H2O Behaviors	0.70	0.51	0.23
Lg. Equip Behaviors	0.57	0.18	0.02
Appliances	0.57	0.31	0.27
Other Heat or Cool Behaviors	0.76	0.56	0.49
Sm. Equip Behaviors	0.71	0.66	0.79
Vague Behaviors	0.61	0.34	0.26

behavior. Please note that there was insufficient variability in the sample to generate the long-run estimates of lighting behavior. The remaining estimates are subject to the caveat that they are a trend constructed from two points in time.

Most of the conservation behaviors have a downward trend. The two exceptions are the small equipment and not using AC behaviors. Both of these behaviors are on an upward trend and are expected to grow. The reason for the projected growth is that both of these conservation behaviors have a high "infection" rate, 32% of households that did not try avoiding air conditioner use in the first year will try to avoid it the second. The small equipment conservation behavior has a similarly high infection rate.

The persistence of these conservation behaviors in the population does not strongly depend on how long each household practices them; that would understate their persistence. As long as some people try it every so often it will persist in the population, much in the same way as the common cold.

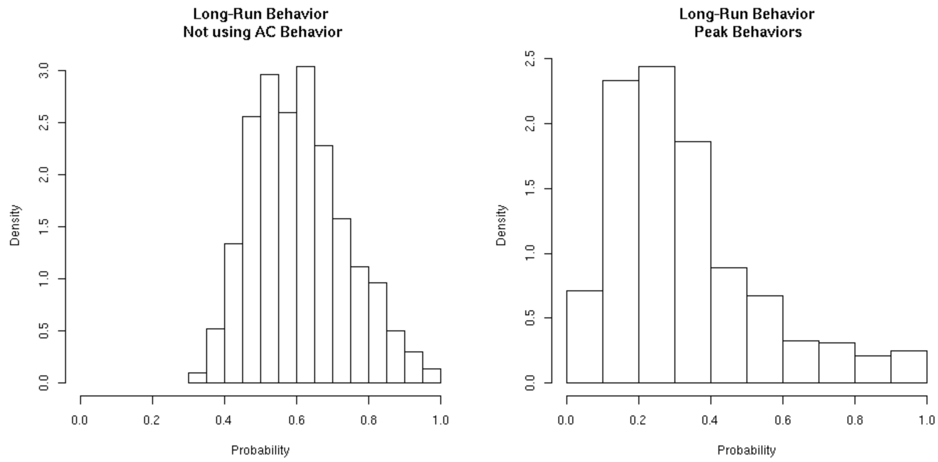
Our uncertainty about these long-run estimates is much larger than the single year estimates. A full set of these distributions for each of the conservation behaviors can be found in Appendix C.

There is a phenomenal amount of uncertainty in the long-run prevalence of these behaviors. Again, it is important to remember that the savings from energy efficient equipment is dependent on these estimates and because of that, those estimates are always more uncertain than these.

5 Summary and Conclusions

Open-responses surveys hold out the promise of greater understanding than closed-response surveys. The survey respondents can explain their point of view in their own language without the mediation of an expert's categorization and phrasing. The unfortunate side effect is that the survey respondents don't

Figure 3: Sample Long Run Distributions of Conservation Behavior



tell the interviewer everything. Because there is less prompting, conservation behaviors will be under-reported relative to their actual behavior and to the usual overstatement of closed response surveys.

By conceiving of the survey response as a compound event, performing the behavior and recalling the behavior, estimates of actual conservation behavior can be made from the data collected in our multi-year telephone survey of California residential conservation behavior. The distributions of first year, second year, and long-run probabilities of a household performing a conservation behavior were all estimated via an empirical bootstrap. In all cases, conservation behavior was estimated to be much more prevalent than a tabulation of the of the survey response data would suggest. This was particularly true of the two behaviors most closely tied to reliability, not using the air conditioner and engaging in other peak reduction behaviors.

One of the weaknesses of the method is the assumption that all households are capable of all behaviors. This assumption results in an overstatement of actual conservation behavior when this is not true. Future research is required to eliminate this unfortunate property.

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A Percentiles of Parameter Estimates

These are the sampling distribution estimates from Section 4.2. These were calculated as described, with a simple empirical bootstrap, re-sampling 1,000 times from the dataset.

Light Bulbs

Percentile	P_r	P1 (16.1%)	$P2\|N$	$P2\|Y$	P2 (15.4%)
2.50%	0.45	0.61	0.02	0.44	0.28
5.00%	0.46	0.61	0.03	0.45	0.29
10.00%	0.48	0.62	0.03	0.46	0.30
50.00%	0.53	0.63	0.05	0.52	0.35
90.00%	0.59	0.65	0.08	0.58	0.40
95.00%	0.60	0.66	0.09	0.60	0.42
97.75%	0.62	0.66	0.10	0.62	0.43

Lights Behaviors

Percentile	P_r	P1 (52.5%)	$P2\|N$	$P2\|Y$	P2 (42.5%)
2.50%	0.50	0.82	0.09	0.99	0.85
5.00%	0.58	0.82	0.11	1.00	0.86
10.00%	0.59	0.83	0.14	1.00	0.87
50.00%	0.62	0.85	0.21	1.00	0.88
90.00%	0.64	0.88	0.28	1.00	0.90
95.00%	0.65	0.89	0.30	1.00	0.91
97.75%	0.65	1.00	0.88	1.00	1.00

Not using AC Behavior

Percentile	P_r	P1 (11.0%)	$P2\|N$	$P2\|Y$	P2 (15.1%)
2.50%	0.31	0.45	0.24	0.42	0.34
5.00%	0.33	0.45	0.25	0.44	0.36
10.00%	0.35	0.46	0.27	0.46	0.37
50.00%	0.42	0.49	0.32	0.57	0.44
90.00%	0.49	0.52	0.39	0.70	0.54
95.00%	0.50	0.53	0.41	0.75	0.57
97.75%	0.53	0.54	0.44	0.79	0.60

Peak Behaviors

Percentile	P_r	P1 (13.6%)	$P2\|N$	$P2\|Y$	P2 (10.5%)
2.50%	0.20	0.64	0.03	0.53	0.36
5.00%	0.21	0.65	0.03	0.56	0.38
10.00%	0.23	0.66	0.04	0.59	0.41
50.00%	0.28	0.70	0.09	0.70	0.52
90.00%	0.34	0.76	0.16	0.82	0.65
95.00%	0.35	0.78	0.18	0.87	0.71
97.75%	0.37	0.80	0.21	0.92	0.77

Shell Improvement

Percentile	P_r	P1 (8.2%)	$P2\|N$	$P2\|Y$	P2 (13.2%)
2.50%	0.46	0.55	0.03	0.19	0.13
5.00%	0.49	0.56	0.04	0.21	0.14
10.00%	0.51	0.56	0.04	0.21	0.14
50.00%	0.58	0.57	0.06	0.26	0.17
90.00%	0.66	0.58	0.09	0.31	0.21
95.00%	0.68	0.59	0.10	0.32	0.22
97.75%	0.70	0.59	0.10	0.34	0.23

H2O Behaviors

Percentile	P_r	P1 (13.6%)	$P2\|N$	$P2\|Y$	P2 (9.8%)
2.50%	0.20	0.64	0.01	0.54	0.36
5.00%	0.21	0.65	0.02	0.57	0.39
10.00%	0.23	0.66	0.03	0.60	0.42
50.00%	0.28	0.70	0.07	0.70	0.51
90.00%	0.34	0.76	0.13	0.82	0.65
95.00%	0.36	0.78	0.15	0.86	0.70
97.75%	0.37	0.80	0.19	0.90	0.76

Lg. Equip Behaviors

Percentile	P_r	P1 (6.9%)	$P2\|N$	$P2\|Y$	P2 (4.3%)
2.50%	0.28	0.55	0.00	0.22	0.12
5.00%	0.30	0.55	0.00	0.23	0.13
10.00%	0.32	0.55	0.00	0.24	0.14
50.00%	0.42	0.57	0.01	0.31	0.18
90.00%	0.51	0.59	0.03	0.39	0.24
95.00%	0.54	0.60	0.03	0.41	0.25
97.75%	0.56	0.60	0.04	0.43	0.27

Appliances

Percentile	P_r	P1 (6.9%)	$P2\|N$	$P2\|Y$	P2 (9.0%)
2.50%	0.16	0.52	0.08	0.28	0.20
5.00%	0.18	0.53	0.09	0.30	0.21
10.00%	0.20	0.54	0.10	0.33	0.24
50.00%	0.28	0.57	0.16	0.43	0.31
90.00%	0.37	0.60	0.24	0.58	0.43
95.00%	0.39	0.61	0.27	0.64	0.49
97.75%	0.41	0.62	0.30	0.71	0.54

Other Heat or Cool Behaviors

Percentile	P_r	P1 (30.2%)	$P2\|N$	$P2\|Y$	P2 (40.9%)
2.50%	0.56	0.73	0.12	0.60	0.49
5.00%	0.56	0.74	0.13	0.62	0.50
10.00%	0.58	0.74	0.14	0.63	0.51
50.00%	0.62	0.76	0.18	0.68	0.56
90.00%	0.66	0.78	0.23	0.73	0.61
95.00%	0.67	0.78	0.24	0.74	0.62
97.75%	0.68	0.79	0.25	0.76	0.64

Sm. Equip Behaviors

Percentile	P_r	P1 (27.1%)	$P2\|N$	$P2\|Y$	P2 (22.2%)
2.50%	0.41	0.68	0.13	0.75	0.57
5.00%	0.41	0.68	0.14	0.76	0.58
10.00%	0.43	0.69	0.15	0.78	0.60
50.00%	0.47	0.71	0.20	0.85	0.66
90.00%	0.52	0.74	0.26	0.92	0.74
95.00%	0.53	0.75	0.27	0.94	0.76
97.75%	0.54	0.76	0.29	0.96	0.78

Vague Behaviors

Percentile	P_r	P1 (7.1%)	$P2\|N$	$P2\|Y$	P2 (11.2%)
2.50%	0.14	0.56	0.06	0.30	0.21
5.00%	0.15	0.57	0.07	0.32	0.22
10.00%	0.18	0.58	0.09	0.35	0.25
50.00%	0.25	0.61	0.14	0.47	0.34
90.00%	0.33	0.65	0.24	0.64	0.49
95.00%	0.36	0.67	0.29	0.72	0.57
97.75%	0.39	0.69	0.34	0.80	0.65

B Distributions of Year One and Year Two Conservation Behaviors

Figure 4: Hardware related purchased/use of new non-fixture-type appliances (refrigerator, washer/dryer, window AC, fans, etc.)

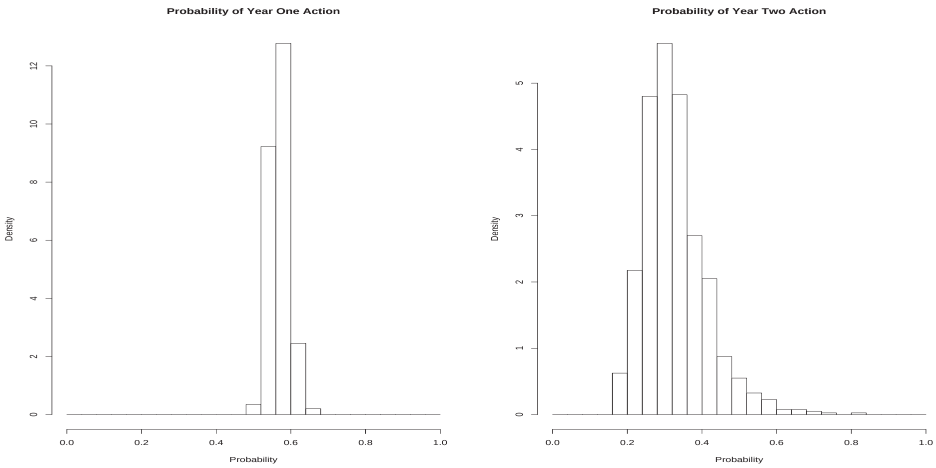


Figure 5: Behaviors related to using less water or using less hot water e.g., shorter showers, wash in cold/warm water, turn water heater down)

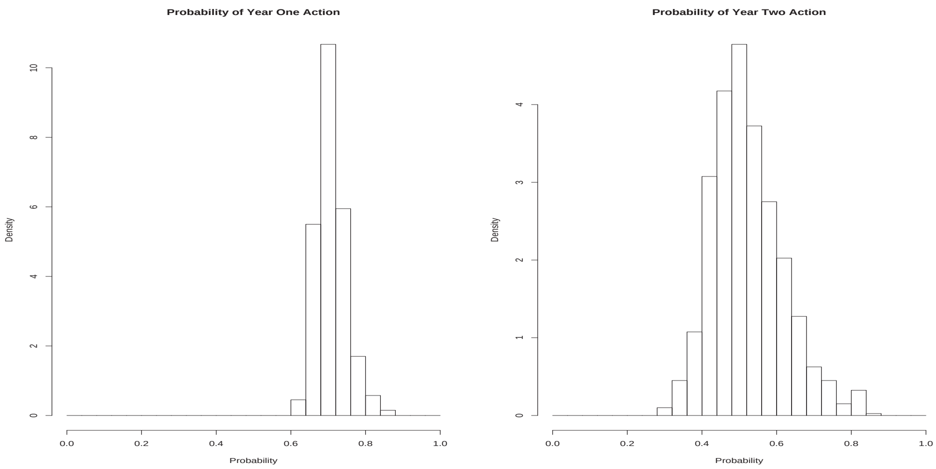


Figure 6: Behaviors related to pools, spas, and irrigation motors (turn off, use less often)

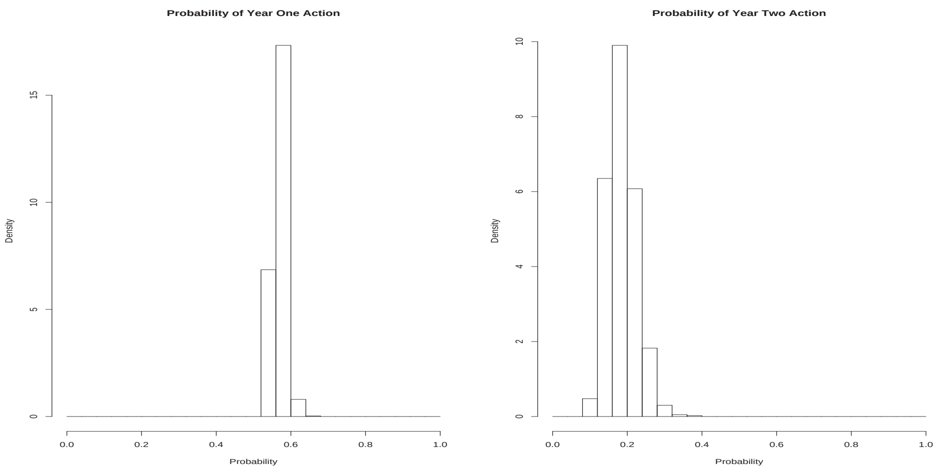


Figure 7: Hardware related purchase/use of compact florescent bulbs or other energy saving/low-watt bulbs

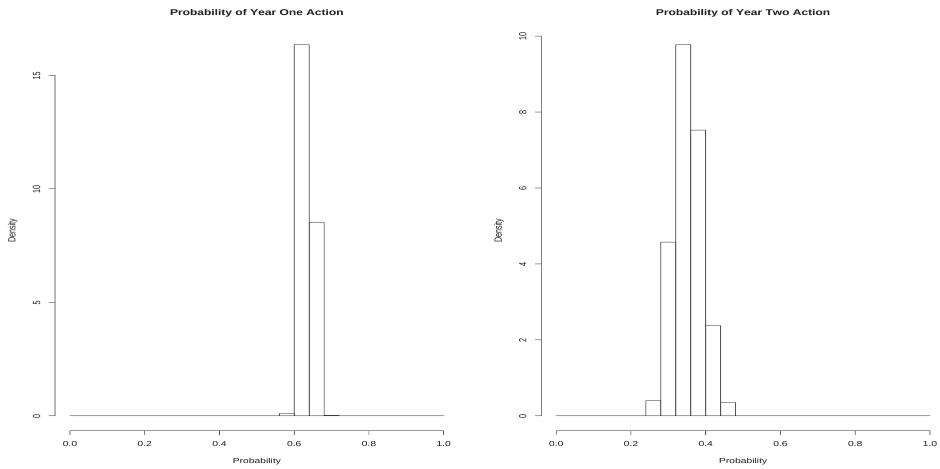


Figure 8: Behaviors related to turning off lights or using fewer lights

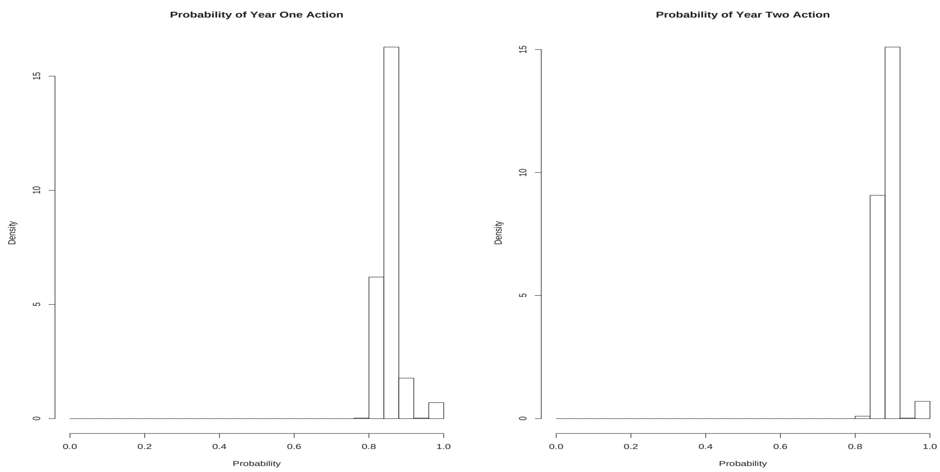


Figure 9: Behavior related to not using the AC at all

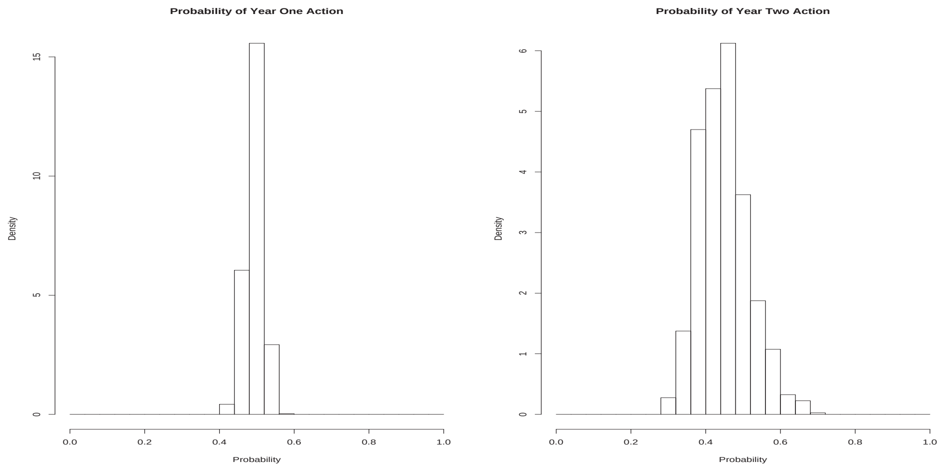


Figure 10: Behaviors related to heating or cooling other than not using the AC at all (e.g., use AC less, use ceiling fans, draw curtains, night venting, thermostat up/down)

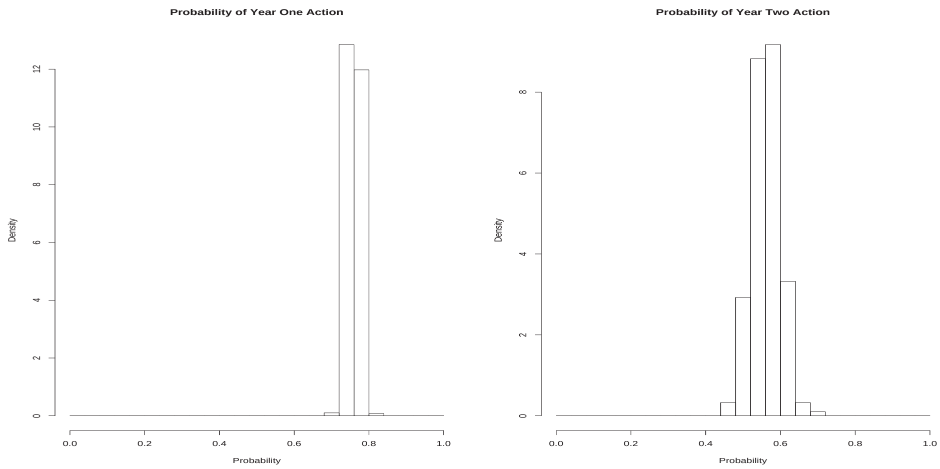


Figure 11: Behaviors related to using energy during off-peak hours (postpone major appliance use until evening e.g., washing, cooking, cleaning)

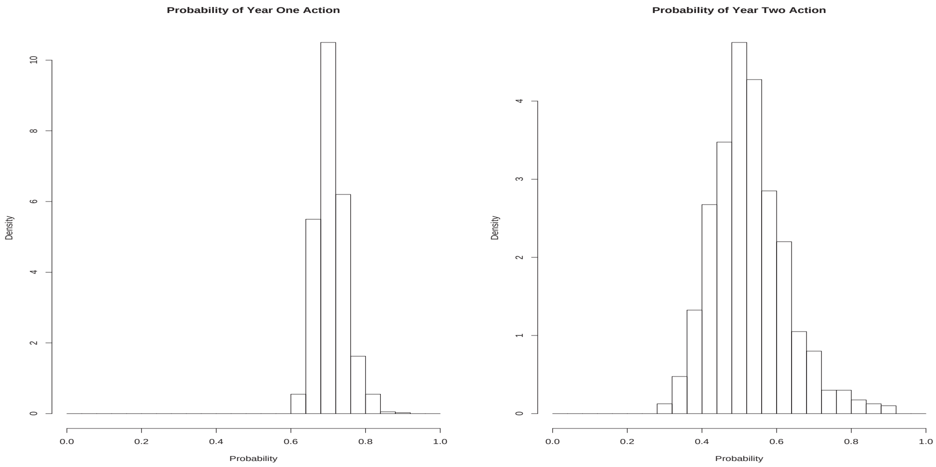


Figure 12: Hardware related one-time improvements to the house (windows, insulation, a new fixed appliance like water heater, AC, furnace, etc.)

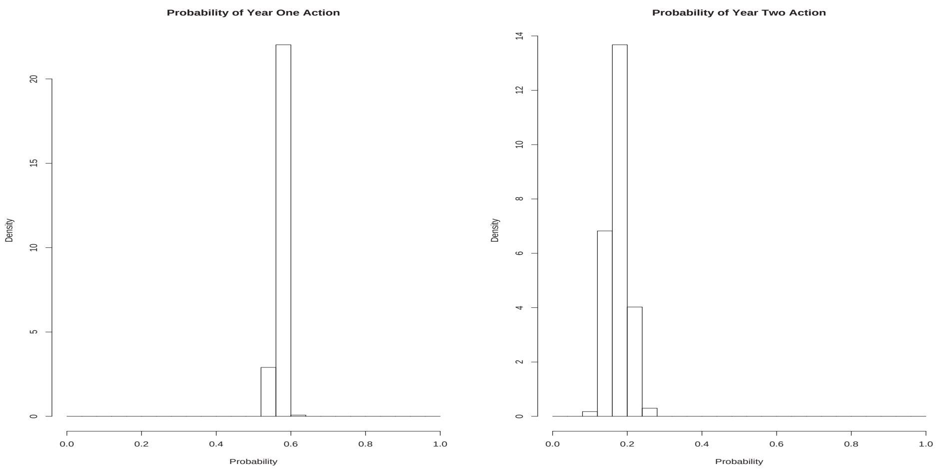


Figure 13: Behaviors related to household appliances (turn off, use less, unplug)

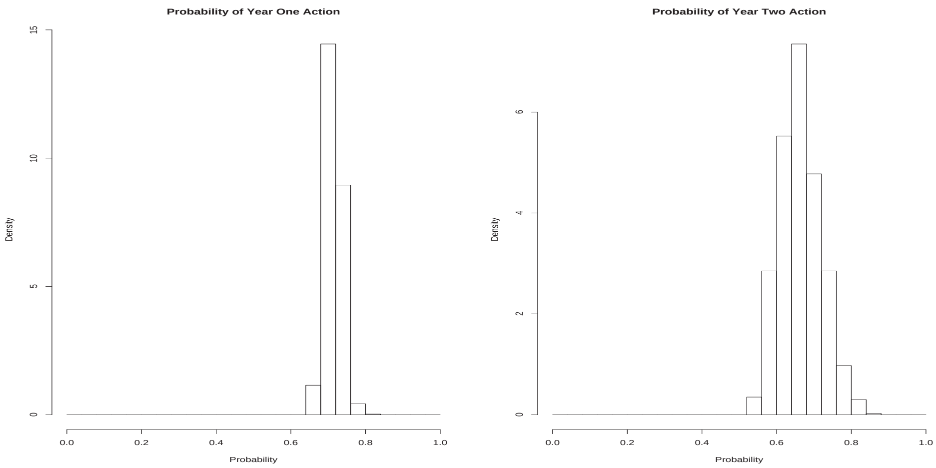
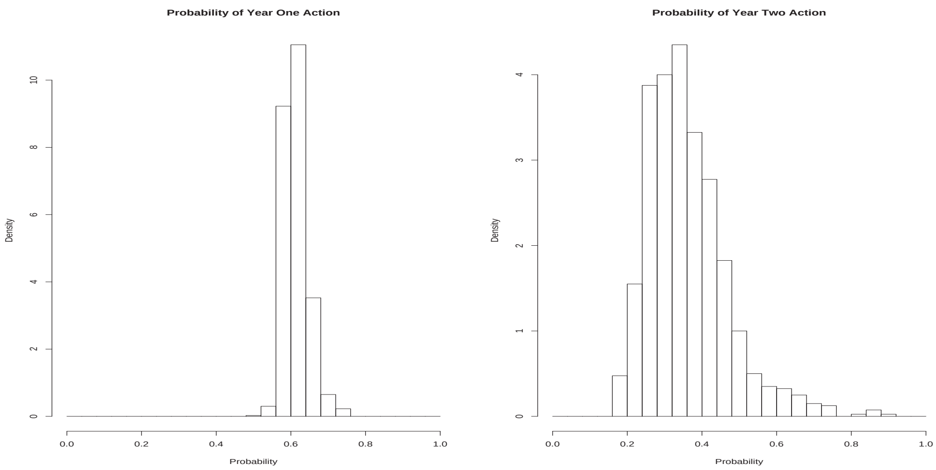


Figure 14: Behaviors stated in general terms (e.g., "over-all conserver", "be less comfortable", "use little energy")



C Distribution of Long-Run Conservation Behaviors

Figure 15: Distribution of Long-Run Conservation Behaviors (Part 1)

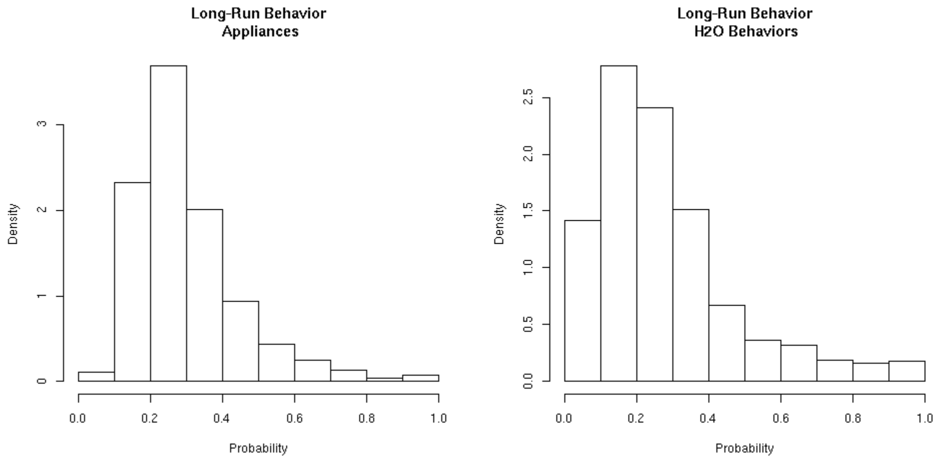


Figure 16: Distribution of Long-Run Conservation Behaviors (Part 2)

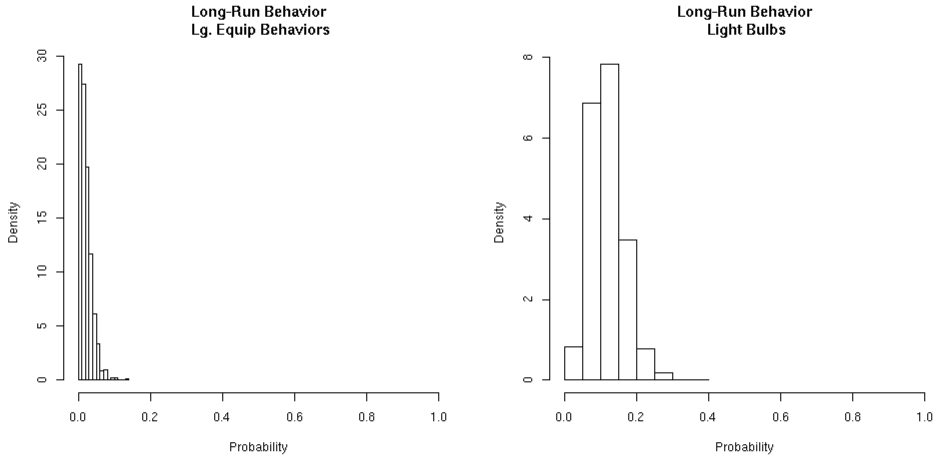


Figure 17: Distribution of Long-Run Conservation Behaviors (Part 3)

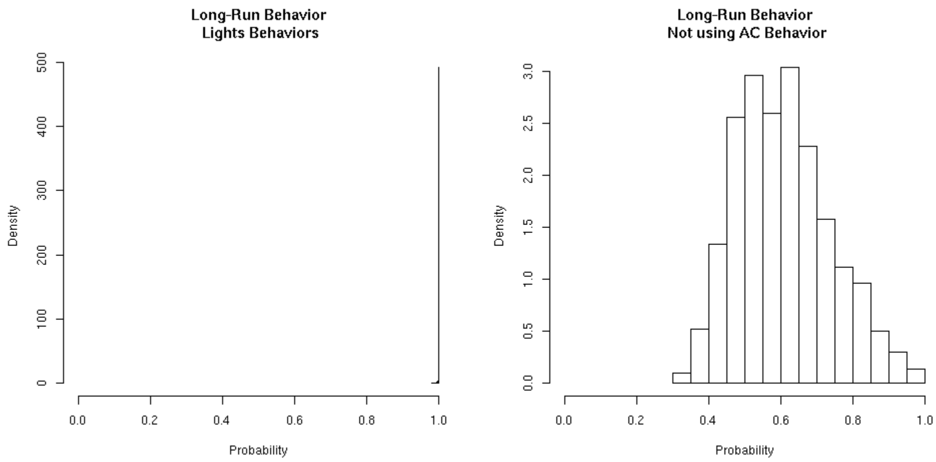


Figure 18: Distribution of Long-Run Conservation Behaviors (Part 4)

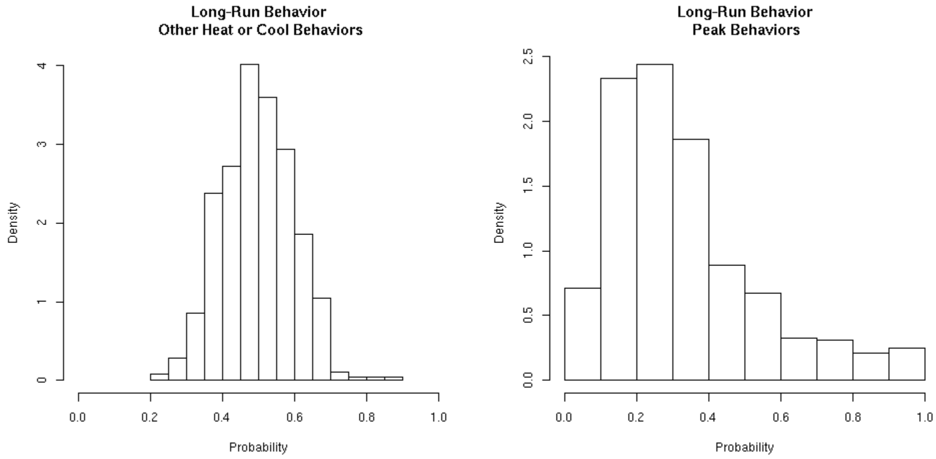


Figure 19: Distribution of Long-Run Conservation Behaviors (Part 5)

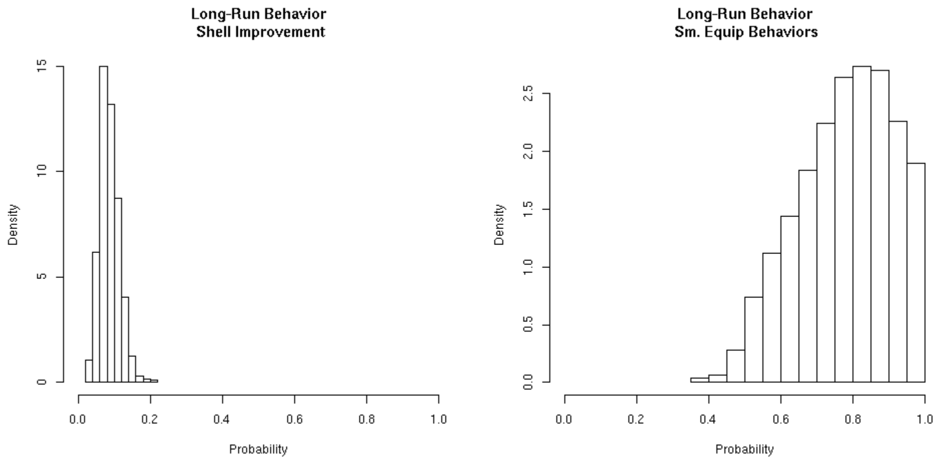


Figure 20: Distribution of Long-Run Conservation Behaviors (Part 6)