Behavioral Economic Models of Household Electricity Decision Making: An Application to Energy Efficiency Program Evaluation

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ABSTRACT

How applicable are behavioral economics concepts to large-scale energy efficiency interventions in real-market settings? This paper details the application and testing of a model to evaluate and explain adoption of energy efficiency recommendations from a program in central Victoria, Australia. This study's conceptual framework integrates diffusion of innovations and behavioral economics frameworks to explain energy efficiency program participant decision-making. It does this by testing the influence of subjective assessments of the value of energy assessment recommendations, characteristics of participants and environmental context. It is proposed that these characteristics mutually motivate or prevent residential energy efficiency investment and curtailment behavior. This behavioral economics framework guided the evaluation design and construction of associated survey instruments for participants in an energy efficiency program in central Victoria, Australia. This study found that High Adopters achieved significantly higher savings than Low Adopters when compared to their respective matched control groups. Significant differences were also found between High and Low adopters with respect to the three major groups of diffusion variables. Subjective characteristics and personal characteristic measures were scored higher by the High Adopters. With respect to participant characteristics, High Adopters had higher levels of product knowledge, comprised fewer young participants, and older participants, as well as a smaller proportion of those employed, and a higher proportion of retirees. Households were more likely to be influenced by marketing communication emphasizing the cost of maintaining the status quo rather than the benefits of change. This suggests that such communication has greater persuasiveness to those already committed to adopting energy efficiency behavior, and that behavioral economics concepts have an important role in informing and improving the design, implementation and evaluation of energy efficiency programs.

Introduction

If households and industry are to be encouraged to increase energy efficiency, it is of paramount importance that energy efficiency policies are based on reliable research about not only on what policies work, but also on how policies work and under what conditions. A central economic question around energy efficiency is: can government intervention correct investment inefficiencies? Policy measures designed to address such inefficiencies include: a Pigouvian tax to create an incentive to use more environmentally friendly methods of production (Pigou, 2006); a cap and trade system (e.g., Emissions Trading Scheme) that allows trading of emissions allowances; energy efficiency subsidies and standards; and energy efficiency programs designed to foster sustainable behavior and accelerate adoption of energy-efficient technologies (i.e., market transformation). Although such measures are well recognized, a lack of credible empirical research makes it difficult to assess the extent of the energy efficiency gap and the potential influence of both independent and complementary government policy measures (Allcott and Greenstone, 2012).

Solar Cities Program

One of seven Solar Cities across Australia, the Central Victoria Solar City (CVSC) research trial encouraged residents to adopt energy efficiency technologies and services, including: home energy assessments, retrofit rebates, household solar electricity, solar hot water and in-home energy displays. The five-year study involved collecting energy meter, survey and climate data from over 2,500 households (including a control group of approximately 700 households) and assessing changes to their energy decision-making and consumption attributable to the program. The CVSC trial was funded by the Australian Government through the Department of the Climate Change and Energy Efficiency, Sustainability Victoria, the Sustainability Fund and the Central Victoria Solar City Consortium. Managed by Sustainable Regional Australia, CVSC's consortium members included Bendigo and Adelaide Bank, Central Victorian Greenhouse Alliance (CVGA), Origin (an energy retailer and Powercor (an energy distributor).

The CVSC program involved recruiting 1,873 household research participants (intervention group) and a control group of 715 households, and subsequently recording changes to their energy consumption for up to five years. Each household in the intervention group received a free walkthrough Home Energy Assessment (HEA) to identify areas of energy waste or inefficiency. Following the HEA, participants were provided with a series of recommendations to improve their household's energy efficiency and were given the opportunity to take part in one or more of the CVSC other program packages.

Purpose of the Study

The field of behavioral economics refers to the attempt to extend economic theory by providing more psychologically plausible foundations (Heukelom, 2007; Ho, Lim, and Camberer, 2006; Johnson, 2006). This study attempts to explain participant decision-making concerning the adoption of HEA recommendations. It does this by integrating diffusion of innovations and behavioral economics frameworks to explain HEA participant decision-making. In this context, the purpose of this research is to examine how energy efficiency programs influence participant behavior. Factors within the framework were used as measures of subjective assessments of the value of recommendations, characteristics of participants and environmental context to explain adoption of energy efficiency recommendations and behavior. Specifically, this research has three objectives:

1. To examine changes in electricity use attributable to the program for high and low adopters of recommendations.
2. To test how subjective assessments of recommendation value, characteristics of participants and environmental context influence adoption of energy efficiency recommendations.
3. To test the plausibility of behavioral economics concepts in explaining differences between high and low adopters of energy efficiency recommendations.

Literature Review

Existing studies on household energy behavior are typically based on interdisciplinary ideas from economics, psychology and sociology. The primary purpose of such research has been to stimulate behaviors that are more energy efficient and/or will reduce energy-consuming behaviors. Despite the prevalence of research addressing such issues, understanding energy behavior still presents many complexities. Such issues include difficulties in identifying and measuring the factors that influence energy consumption and the nature of each influence on behavior. Stern (1992) suggested potential factors including psychological, social structural, economic, technological and other factors. Similarly, Abrahamse et al. (2005) proposed that energy consumption is a complex interaction between macro-level factors (e.g., technological, economic, demographic and institutional factors) and an individual's perceptions, preferences and abilities. Although such integrated models have been proposed, discipline-specific methodological approaches are still most prevalent in academia (Kierstead, 2008). This issue has raised calls for greater disciplinary collaboration to understand the behavioral and social determinants of energy use (Wilson and Dowlatabadi, 2007).

Diffusion of Innovation Theory

Many diverse concepts, variables, and processes have been defined in diffusion research in an attempt to explain what influences the decision to adopt or not adopt a new technology (Moore, 1999; Rogers, 1962). Rogers (1962) proposes that such adoption occurs as a five-step process, starting with knowledge, followed by persuasion, decision (to adopt or to reject new technology), implementation and confirmation. Marketing studies have generally applied this framework to better understand perceived characteristics of innovations and their influence on adoption or rejection (e.g. Lee, Kwon and Schumann, 2007; Moore and Benbasat, 2001). Alternatively, sociological studies have generally applied this framework to investigate the interaction between new technologies and their social context (Bruland, 1997). Wejnert (2002) argued that, historically, the literature associated with each of these factors often analyzed diffusion in isolation from the insights of other disciplines. Wejnert (2002) showed how such factors relating to the diffusion of innovations could be integrated by developing a conceptual framework derived by grouping the diffusion variables into three major components (characteristics of innovations, characteristics of innovators and environmental context) and associated sub-variables. These variables are proposed to influence adoption decision-making.

Behavioral Economics

Most human activity, including energy use, can be understood as people making decisions under some level of uncertainty. Traditionally, standard economic theory has assumed that individuals make rational, utility maximizing decisions based on all information available at the time. However, Sapsford et al. (2009) suggested that the need for a behavioral approach in economics arises whenever what is 'rationally' expected of a utility maximizing agent is not borne out in observed behavior.

Hanemann (1991) showed that the levels of compensation demanded by people with respect to environmentally related amenities were considerably higher than their willingness to pay to keep those amenities (known as the 'endowment effect'). The difference can be explained by the theory of behavior under uncertainty proposed by Kahneman and Tversky (1979). Their empirically-based model, *prospect theory*, suggests that in actual situations people predictably under-value potential gains and over-value potential losses – because they were loss averse.

Consumer decision-making and behavior are involved when it comes to energy efficiency and pro-environmental actions. Behavioral economics provide new perspectives that can inform policy design on how individuals evaluate options, make decisions, and change behavior (Hursh and Roma, 2013; Kahneman, 2003; Wilkinson and Klaes, 2008). By challenging traditional assumptions, behavioral economics provides an alternative way to model decision-making that better matches empirical observations with higher predictive power than models based purely on neoclassical assumptions (Pollitt and Shaorshadze, 2011).

Behavioral economists have identified patterns and trends in seemingly irrational consumer behavior by combining traditional economics and psychology to study consumer decision-making and motivations. In particular, Snook (2011) focused on five principles felt to be relevant to the problem of changing energy efficiency behavior. These are discussed below.

Awareness: The underlying assumption is that once people are made aware of the energy inefficiency problem and receive information on how to change their behavior, they will be willing to do so (Martiskainen, 2008). However, Geller (1981) argued that although raising awareness is a pre-requisite, there also needs to be a link with additional behavioral interventions to make the behavior change durable.

Social Norms: These may be characterized by common or average behavior that is socially desirable or undesirable (Cialdini, et al., 2006). Ariely (2011) suggested that social rewards can be more influential than financial rewards because individuals have a relatively higher concern about self-perception and how others perceive them. Loewenstein and Ubel (2010) cautioned against being overly reliant on interventions utilizing social norms, pointing out that the energy savings generated tend to be small. They argued that traditional mechanisms, such as a carbon tax, would be far more effective as they would increase the price of carbon in line with its true social and environmental cost.

Goal Setting: The setting of goals alone does not seem to be effective in reducing energy use. Several studies have shown that more effective results can be achieved when goal setting is combined with a commitment to reduce energy use and/or by providing feedback about savings performance (Abrahamse, et al., 2007; Becker 1978; McCalley and Midden 2002).

Framing: The way in which information is presented (i.e., framed) affects one's choice, and has been found to be significant in choices involving uncertainty. Tversky and Kahneman (1981) showed a significant discrepancy in the choices in the context of framing, even when the probabilities and payoffs were the same. Snook (2011) claimed that financial costs, defaults and reference points were key features of framing relevant to perceptions of energy efficiency. Some examples of the relevance of framing are indicated below:

- Customers struggle with discounting investments over long periods of time, which makes it difficult to frame financial costs with respect to energy efficiency investments as, typically, the energy savings tend to occur in the future while the costs are incurred upfront.
- Providing an opt-out option (where customers are automatically program participants, in contrast to an opt-in option where customers have to choose to participate in a program) as a default option will be more likely to encourage participation because customers show a strong tendency to not use resources (times) to opt-out (Houde and Todd (2010).
- It is important for reference points to be realistic if they are to be used by customers to compare their behavior. Ariely (2011) suggested that one way to effectively use a reference point as a framing tool on quarterly energy bills would be to break out energy use into total consumption and a discretionary range. This would provide consumers with a better sense of what scale of energy efficiency is achievable, thereby enabling the customer to better visualize their opportunity for action.

Learning: This represents a behavioral objective that flows from information and works to change behavior by establishing cause and effect in the mind of the consumer. Feedback, information in response to behavior, is a particularly important type of learning in the household energy efficiency field. Fischer (2008) found that immediate feedback increases the awareness of the impact of individual behavior and builds a foundation for learning. Existing household energy efficiency feedback mechanisms include: monthly or quarterly electricity bills; in-home displays; and smart meters. In communication, simple, salient, and personally relevant information has been shown to be more effective than detailed, technical, and factual information (Wilson and Dowlatabadi 2007). Stigler (1961) found that there was a cost associated with the provision of information, and that the cost was the mental effort required to process that information. The idea that too much information was, in fact, detrimental overturned the previously held belief that more information is better.

Kempton and Montgomery (1982) found that consumers use simple heuristics to assess their energy consumption, which leads to systematic underinvestment in energy efficiency. They concluded that this was an example of "bounded rationality," when people adapt known methods to solving new problems, even if the known methods are not optimal for the new situation. Sapsford, et al (2009) noted that the study of heuristics and habits has consistently shown that, in reality, these sub-optimal behaviors radically influence decision-making. While not necessarily detrimental to behavioral change, habits are also barriers to behavioral change and become particularly relevant when behavioral change would be beneficial. For example, Tversky and Kahneman (1974) found that heuristics and habit effects are actually exacerbated by uncertainty. Such empirical studies lend support to the often quoted 'when in doubt, stick to what you know'.

Allcott and Mullainathan (2010) called for a concerted effort by researchers, policy-makers, and businesses to do the "engineering" work of translating behavioral science insights into scaled interventions, moving continuously from the laboratory to the field to practice. They argued that such an effort would have high economic returns. Pollitt and Shaorshadze (2011) also discussed how behavioral economics applies to three areas of energy policy including consumption and habits, investment in energy efficiency, and provision of public goods and support for pro‐environmental behavior. While concluding that behavioral economics seems unlikely to provide the magic bullet to reduce energy, they suggested it offers new suggestions as to where to start looking for potentially sustainable changes in energy consumption. Accordingly, the following study integrated behavioral economic concepts to empirically test the applicability of concepts from this field to better understand energy efficiency program participant decision-making.

Evaluation Design

The voluntary nature of participation in energy efficiency programs often means that a true experimental design with randomly assigned treatment and control (non-treatment) groups is not possible. As the intervention groups for the CVSC program were self-selected, and a comparison group randomly selected, a non-equivalent groups quasi-experimental design (NEGD) was adopted for this study. A simple pre-post design without a comparison group would not have allowed for testing of whether differences would have occurred without the intervention. Therefore, this study used a pre-post design with matched comparison groups to enable measurement of changes in electricity use attributable to the CVSC program. For interested readers, a more comprehensive review of the NEGD can be found in Cook and Campbell (1979).

Matched Pairs

A problem created by quasi-experimental research designs is that there may be systematic differences between the intervention and comparison groups besides intervention exposure (Stuart, 2010). To increase comparability between the evaluation's intervention and comparison groups, a matched pairs design was used. This process involved propensity score matching of intervention participants with comparison group households based on a composite of background variables and pre-program adoption of renewable energy technologies (i.e., household solar electricity and solar hot water). Matched comparison groups were used to control for confounding factors such as weather variations, gas connection, house size, number of occupants and knowledge and beliefs about energy efficiency.

Data Collection

A longitudinal design was employed, with measurements before, during and after the intervention. Historical energy consumption and climate data were collected for up to 3 years pre-intervention and at intervals throughout the remainder of the CVSC program. Data collection began in 2010, and continued until the program's conclusion in June 2013. Three major data sources were collected and monitored for this study: electricity use, participant information and climate data.

Participant information:

Two baseline surveys were conducted with all participating households when joining the program. The first of these (a self-administered mail survey) mainly focused on household characteristics such as site details, appliances, lighting, energy bills, reticulated gas[1] and other energy sources and energy efficiency measures. The second survey (either mail, telephone or web) collected information about environmental values, knowledge, views and opinions on energy use, information sources and demographic characteristics. The initial paper-based survey was required in order to obtain the required specific site details. All follow-up surveys were telephone or web-based, where demographic differences were observed, with older respondents more likely to complete the telephone version of the survey. An assessment of measurement invariance indicated that modal differences were small. Missing value analysis was applied to explore the prevalence and nature of missing data from the surveys. This process found the frequency of missing household data was small (ranging from <1% to 5%).

A post-intervention follow-up survey included questions specific to particular interventions that addressed issues of satisfaction, value, changes to housing and demographic characteristics, attitudes towards solar energy technologies, free ridership and spillover, and other items. The measures of behavioral economics concepts such as prospect theory, loss aversion, bounded rationality and social norms were presented to respondents as scenarios or statements anchored by Likert scales from 1 (strongly disagree) to 5 (strongly agree). The energy impact of participant behavior was measured using electricity meter data. Confirmatory factor analysis (CFA) was undertaken to assess the construct validity, and reliability of these measures. Because the observed attitudinal indicators were measured using ordinal Likert scales, the use of product-moment correlations are not appropriate (Jöreskog, 1990). Therefore, polychoric correlations were calculated and CFA was undertaken using a Weighted Least Squares (WLS) estimation method. The results from this analysis suggested that these scales had a plausible fit with the data (CFI>0.95, RMSEA<0.05, Raykov's ρ >0.7).

Data Analysis and Results

The following section summarizes data collected from the study and reports results of inferential statistical analyses. The purpose of the analyses was to examine how energy efficiency programs influence participant behavior and, in particular, the adoption of energy efficiency recommendations.

Adoption

Twenty eight percent of participants (n=510) receiving a Home Energy Assessment indicated that they had carried out all or most of the recommendations provided by their assessor. These were defined to be *High Adopters*. The majority of participants (66%) indicated that they had carried out some but not all of the recommendations provided, while 6% did not carry out any of the recommendations. These latter two groups were combined to allow for robust comparisons, and defined as *Low Adopters* (n=367). The major reasons mentioned for not carrying out any HEA recommendations were financial considerations (48%) and that they were planning to carry out the recommendations in the future (30%).

[1] Reticulated gas is LPG distributed by a network of pipes connected to a storage vessel away from the customer's site (e.g., homes). Multiple customers are serviced from one storage vessel.

Change in Electricity Use

A repeated measures analysis of variance (rANOVA) was conducted to assess whether there were differences in energy use changes between High Adopters and Low Adopters compared to their respective matched comparison groups. Due to observed non-normality for the energy use measures, this analysis was undertaken on log transformations. To obtain a measure of effect, the relative change between the post-intervention and pre-intervention data was determined. This change measure represents a difference of differences (the difference between the changes in intervention and matched comparison groups for High Adopters and Low Adopters).

After matching, no significant differences in energy use were found between levels of adoption and respective matched comparison groups before the intervention. However, there were significant differences in energy use after the intervention, for both high and low adopters. This is shown in Table 1 where differences for High Adopters can be seen to be considerably more than that for Low Adopters. That is, High Adopters achieved significantly higher net savings than Low Adopters when compared to their respective matched comparison groups. A summary of absolute savings and percentages is included in Table 1.

Table 1: Net and gross changes in electricity use (kWh) by group

	High Adopters	**$\text{Comparison}_{\text{High}}$**	**Low Adopters**	**$\text{Comparison}_{\text{Low}}$**
Before	15.8	15.8	15.8	15.8
After	11.3	13.9	12.2	13.9
Gross %-Change	-29%*	-12%*	-23%*	-12%*
	4.5 kWh	*1.9 kWh*	*3.6 kWh*	*1.9 kWh*
Net %-Change	-17%*		-11%*	
	-2.6 kWh		*-1.7 kWh*	

* Significant at the 95% level

This analysis found that the gross savings for the High Adopters group was 29%, which was 17% more than that for their matched comparison group (12%). The overall decrease in energy use for the Low Adopters was 23%, which was 11% more than that for their matched comparison group (12%). Low Adopters decreased their energy use by 11% more than their matched comparison group. This suggests that changes in energy use were significantly affected by both program participation and the extent of adopting energy efficiency recommendations. The net reduction of 11% electricity use for the low adopters is similar to the overall net change observed along the eastern coast of Australia by power companies and is also reflected in the net change observed in the comparison group of this study.

Differences in Adopter Groups

High Adopters were compared to Low Adopters with respect to various diffusion variables, measured using validated scales from the literature relating to key constructs. Comparisons were made using independent samples t-tests, Mann-Whitney and Chi-Square tests. The results are outlined in Table 2.

On each of the subjective characteristics items, High Adopters scored significantly higher than Low Adopters ($p < 0.01$ in each case). As a group, the High Adopters were more satisfied with their HEA, thought it to be of higher value and quality, and had higher intentions to reduce energy use than Low Adopters.

Personal characteristics were ascertained using measures of perceived behavioral control, interest, propensity to plan and self-control. On each of these items, the *High Adopters* scored significantly higher than the *Low Adopters* ($p < 0.05$ in each case), however, the differences were not as large as evidenced by the magnitudes of the t-statistics.

Participant characteristics were made up of subjective product knowledge, age, employment status and retirement status. *High Adopters* scored significantly higher on product knowledge than *Low Adopters* ($p < 0.01$). There were significantly fewer young participants and significantly more older participants in the group of High Adopters. Similarly, there was a smaller proportion of those employed and a higher proportion of retirees in the group of High Adopters.

Table 2: Comparisons of high adopters to low adopters with respect to diffusion variables

Diffusion Variables	Test Statistic	p-value	Finding
Subjective Characteristics			
Satisfaction with HEA	t = 4.465	0.000	High adopters significantly higher than low adopters
Value of HEA	t = 4.582	0.000	High adopters significantly higher than low adopters
Quality of HEA	t = 3.977	0.000	High adopters significantly higher than low adopters
Intentions	t = 2.734	0.006	High adopters significantly higher than low adopters
Personal Characteristics			
Perceived Behavioural Control	t = 1.972	0.049	High adopters significantly higher than low adopters
Interest	t = 2.392	0.017	High adopters significantly higher than low adopters
Propensity To Plan	t = 2.163	0.031	High adopters significantly higher than low adopters
Self-Control	t = 2.047	0.041	High adopters significantly higher than low adopters
Participant Characteristics			
Subjective product knowledge	t = 2.758	0.006	High adopters significantly higher than low adopters
Age	Z = -2.222	0.026	Less 18-34 year olds and more 65+ year olds were high adopters
Employed	$\chi^2_1 = 4.597$	0.032	Smaller proportion of employed were high adopters
Retired	$\chi^2_1 = 5.997$	0.014	Higher proportion of retirees were high adopters

Loss Aversion

A key theory of behavioral economics is that people tend to strongly prefer avoiding losses (costs) to acquiring gains (benefits). This concept is known as loss aversion. To test the applicability of this theory to the purchase of an energy efficiency device, respondents were randomly presented with one of two hypothetical scenarios about the purchase of a Solar Hot Water system. The first scenario emphasized the benefits of purchasing a Solar Hot Water system (saving $360 a year over 6 years), while the second scenario highlighted the costs of keeping the participant's existing system (costing $360 a year more over 6 years). As indicated by Table 3, both the comparison group (77%) and the intervention group (81%) were more likely to purchase a Solar Hot Water system under the second scenario (cost emphasis). Furthermore, purchasing a Solar Hot Water system under the first scenario (benefit emphasis) was more attractive for the intervention group (67%) than the comparison group (57%). The implications of these findings for programs designed to encourage energy efficiency adoption is that households are more likely to be influenced by marketing communication that emphasizes the cost of maintaining the status quo rather than the benefits of change. The greater appeal of highlighting benefits for the intervention group than the comparison group suggests that such communication has greater persuasiveness to those already committed to adopting energy efficiency behavior.

Table 3: Costs vs. Benefits: Solar Hot Water Scenarios

		Control	Intervention
Scenario 1	A. Purchasing a $2,400 Solar Hot Water system, which will save you $360 a year over 6 years*	57%	67%
	B. Keeping your existing system*	43%	33%
Scenario 2	A. Purchasing a $2,400 Solar Hot Water system	77%	81%
	B. Keeping your existing system which costs you $360 a year more over 6 years	23%	19%

*Significant at the 95% level

Discussion

The main purpose of this study was to explain participant decision-making concerning the adoption of HEA recommendations by integrating diffusion of innovations and behavioral economics frameworks to explain HEA participant decision-making. The study is important because it has shown that diffusion of innovation and behavioral economics concepts can be integrated to better understand energy-related decision-making. It has also provided empirical evidence supporting the loss aversion theory that people tend to strongly prefer avoiding losses to acquiring gains, a key theory of behavioral economics.

This study found significant differences in energy use between levels of adoption and respective matched comparison groups after the intervention. High Adopters saved significantly more energy than Low Adopters (17% vs. 11%). On every item used to measure the diffusion variables, subjective, personal and participant characteristics, High Adopters scored significantly higher than Low Adopters.

These results provide support for Wejnert's (2002) claim that integrating the diffusion variables can significantly influence our understanding of adoption decision-making, and sheds a stronger light on the decision-making process than would have otherwise been possible under the historical approach of analyzing diffusion in isolation from the insights of others. These results also provide support for the proposal by Abrahamse et al. (2005) that energy consumption is a complex interaction between technological, economic, demographic and institutional factors, as well as perceptions, preferences and abilities of individuals.

The study found that a smaller proportion of employed participants and a higher proportion of retirees were High Adopters. This suggests a potential area for future research to explore the differences between young families and retirees, particularly in relation to behaviors associated with reducing energy usage.

Given the supportive findings relating to loss aversion, it would seem that households will be more likely to be influenced by marketing communication that emphasize the cost of maintaining the status quo, rather than the benefits of change. Such communication will have a greater persuasiveness to those already committed to adopting energy efficiency behavior.

Changes in energy use were significantly affected by both program participation and the extent of adopting energy efficiency recommendations. This has implications with regard to HEAs by developing strategies to encourage people to adopt as many recommendations as possible. Specific tailoring of such recommendations and the way in which they are presented and followed up may be critical in establishing "buy-in" on the part of the householder. This may well represent a useful area of future research for optimizing the adoption of energy efficiency technologies and behaviour.

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