Prospect Theory and Energy Efficiency

Abstract

Investments in energy efficiency entail uncertainty, and when faced with uncertainty consumers have been shown to behave according to prospect theory: preferences are reference-dependent and exhibit loss aversion, and probabilities are subjectively weighted. Using data from a choice experiment eliciting prospect theory parameters, I provide evidence that loss-averse people are less likely to invest in energy efficiency. Then, I consider policy design under prospect theory when there are also externalities from energy use. A higher degree of loss aversion implies a higher subsidy to energy efficiency. Numerical simulations suggest that the impact of prospect theory on policy may be substantial.

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I. Introduction

Evidence suggests that when making choices involving risk or uncertainty, people deviate from the predictions of expected utility theory. In particular, their preferences may be reference-dependent: outcomes are evaluated based on gains or losses relative to a reference point rather than on absolute consumption levels. Gains and losses may be treated asymmetrically, with losses counting relatively more than equivalent gains. The subjective probabilities assigned to outcomes may be systematically biased from the objective probabilities, and low-probability events may be over-weighted. Prospect theory (Kahneman and Tversky 1979) explains these observed behaviors.

The choice over energy efficiency investments, like buying an energy-efficient car or appliance, involves risk. There is a fixed upfront cost and the promise of energy savings, though the amount of those savings is unknown. Greene (2011) argues that loss aversion can explain the "energy paradox" or "energy efficiency gap," where individuals appear to neglect ostensibly cost-effective efficiency investments (Allcott and Greenstone 2012, Gillingham and Palmer 2014).[1] While prospect theory has been shown to predict behavior across various domains,[2] it has never explicitly been shown to predict behavior related to energy efficiency. Little is known about whether consumers' choices over energy efficiency are explained by prospect theory, nor about how policy can be designed if this is the case.

The purpose of this paper is to test whether prospect theory explains consumers' investments in energy efficiency and to see what the implications are for optimal policy design. I conduct a survey that uses a choice experiment to elicit individual-level prospect theory preference parameters, including the extent of loss aversion and probability weighting. I test whether those parameters are correlated with energy-efficiency investments, like owning an alternative-fuel vehicle or Energy Star appliance. Then, I provide a model of optimal policy, in which there are externalities associated with energy use (e.g., greenhouse gas emissions) and behavioral market failures associated with prospect theory. The model demonstrates how optimal policy depends on the degree of deviation from expected utility theory.

This paper contributes to two literatures. First, there is an empirical literature documenting, often using randomized control trials, that consumers’ energy consumption decisions appear to be motivated by social norms. Allcott and Rogers (2012) find that information provision affects energy usage: consumers who learn that their consumption levels are higher than average reduce their use, but this effect decays over time. A similar effect is found in Ayres et al. (2013), who find that both electricity

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[1] Gillingham et al. (2009) consider how various behavioral economic findings may affect energy-consumption decisions by individuals.

[2] For example, see Camerer (2004, Table 5.1), List (2004), and Tanaka et al. (2010).

and natural gas consumption are reduced after information provision, and the reduction lasts at least 7 to 12 months. Costa and Kahn (2013) observe significantly different treatment responses based on the individual's political ideology: the effect is two to four times larger for liberals than it is for conservatives. In the context of water consumption, Ferraro and Price (2013) find that information on social comparisons are more effective than technical information or savings-encouragement messages.[3] These papers do not explicitly reference prospect theory in making their empirical findings, but the finding are consistent with prospect theory if the information provision changes consumers' reference points, and consumers are averse to losses (higher energy bills) relative to those new reference points. Furthermore, most such studies do not find evidence of a "boomerang effect" from social norm-based information provision, where those who are at below-average consumption levels increase consumption after the treatment.[4] This asymmetry is consistent with loss aversion as predicted by prospect theory. To date no study has explicitly tested whether or not prospect theory can explain energy efficiency investments. The empirical evidence provided in this paper tests for such a link.

The second literature that this paper contributes to is a theoretical literature that conducts welfare analysis and studies optimal policy in an economy where consumers behave according to prospect theory. Prospect theory is a positive theory describing how individuals make choices under uncertainty. However, it raises normative questions, given that welfare analysis is not well-defined if consumers deviate from neo-classical expected-utility-maximizing behavior. More broadly, other aspects of behavioral economics raise the same set of questions.[5] More specifically, in the domain of energy and environmental policy, Heutel (2015) considers optimal policy for durable goods with externalities when consumers have quasi-hyperbolic preferences, Allcott et al. (2014) considers policy when consumers undervalue future energy costs, and Tsvetanov and Segerson (2013) consider environmental policy when consumers exhibit temptation and self-control issues.

Under prospect theory, the following general welfare question arises: what should a social planner maximize, given that consumers' preferences are characterized by loss aversion and reference-dependence? A follow-up question is: how does this maximization criterion affect optimal policy? Surprisingly, very few papers have attempted to answer these important normative questions. Kanbur et al. (2006) survey the literature on "non-welfarist" taxation, defined as the government having an

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[3] In a related context, Goldstein et al. (2008) find that social norms are more effective at getting hotel guests to reduce towel use than are appeals based on the environment.

[4] An exception is Schultz et al. (2007).

[5] Bernheim and Rangel (2009) design a theoretical framework for using revealed preferences to conduct welfare analysis under non-neoclassical models (but they do not consider the application to prospect theory).

objective function different than individuals'. Kanbur et al. (2008) consider optimal income taxation when consumers exhibit prospect theory, and they consider non-welfarist, or “paternalistic”, social welfare functions. They find that an optimal tax schedule can be discontinuous, owing to the kink in the prospect theory value function at the reference point. Jantti et al. (2014) consider optimal policy with a social welfare function that exhibits loss aversion. They examine how inequality measures may differ depending on whether preferences are reference-dependent. Dhami and Al-Nowaihi (2010) consider various social welfare functions when individuals exhibit prospect theory; all of their social welfare functions are based on maximizing expected utility, in contrast to individuals’ preferences. All of these approaches can be seen as controversial, since the planner departs from using revealed preference to guide policy. As Madrian (2014) ends her review on behavioral economics and policy: “This [assessing the social optimality of behaviorally-informed interventions] of course requires taking a stand on what is socially optimal, a task that admittedly is easier said than done.”[6]

The theory section in this paper considers optimal policy specifically in the context of energy consumption decisions when consumers behave according to prospect theory. In these markets, there already exists a market failure from the externalities associated with energy use. Under prospect theory, there is potentially a second market failure – a “behavioral” failure – if prospect theory implies that consumers are acting sub-optimally in a welfare-relevant sense.[7] This is the first paper that considers optimal policy in such an economy.[8]

This paper presents two sets of results: one empirical and one theoretical. Empirically, I find evidence that prospect theory explains people's investments (or lack thereof) in energy efficiency. I find a negative correlation between an individual's level of loss aversion and several energy efficiency investments, including owning or leasing an alternative fuel vehicle and having a high fraction of energy-efficient light bulbs. Though almost all of the relationships are of the predicted sign, the statistical

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[6] Additionally, Guthrie (2002) considers how prospect theory has been used in the law literature and in legal cases. Jolls et al. (1998) more broadly considers behavioral economics and the law. Farhi and Gabaix (2015) consider optimal tax policy in the presence of general forms of behavioral failures, though they do not explicitly model loss aversion. Apesteguia and Ballester (2015) consider the welfare implications of deviations from preference maximization.

[7] This is analogous to the dual market failures from both externalities and “internalities” modeled in Allcott et al. (2014) and Heutel (2015).

[8] Bhattacharjee et al. (1993) considers how prospect theory may affect consumer energy purchases, and Costanzo et al. (1986) offers recommendations for energy conservation based on psychology and prospect theory, but neither provides a theoretical basis by which to conduct welfare analysis. Asgary and Levy (2009) discuss how prospect theory affects policy over natural hazards and disaster planning. Knetsch (1990) considers the implications of the WTP/WTA disparity on environmental policy. See also Botzen and van den Bergh (2014) for a review of several alternatives to expected utility, including prospect theory, and their implications for climate policy.

significance is modest; out of ten estimated coefficients in the main specification, three are significantly negative at the 10% level and three more are negative with p-values less than 0.2. The results are not driven by time preferences, and they are robust to an alternate, non-parametric measure of loss aversion. A one-standard-deviation increase in loss aversion is associated with a 1.5-percentage-point increase in the probability of owning an alternative fuel vehicle.

Theoretically, I show that the standard Pigouvian prescription to price the externality at expected external costs (or benefits) is modified in the presence of prospect theory in two ways: first, based on the ratio of the true probability of achieving a cost savings and its misperceived subjective probability; and second, based on the ratio of marginal (true) utility to the derivative of the value function. Both the analytical results and numerical simulations show that a higher degree of loss aversion implies a higher subsidy to energy efficiency. Simulation results suggest that the behavioral market failure from prospect theory can be quite large, relative to the market failure from the externality.

The next section provides a model of energy efficiency demand under prospect theory that generates testable hypotheses; those hypotheses are tested in section III. Section IV provides the theoretical model of optimal policy; and section V concludes.

II. A Model of Prospect Theory and Energy Efficiency Demand

The following simple model explores how loss aversion affects investment in energy efficiency and generates testable hypotheses. The consumer decides how much energy-efficiency e to purchase (e.g., e can measure the level of energy-efficiency of an air-conditioner or the fuel economy of a car).[9] A level of e comes with a certain cost $c(e)$ and an uncertain benefit in fuel savings $b(e;\theta)$, where θ is a random variable that is realized only after e is purchased. The risk or uncertainty in energy efficiency investments has been documented and can be substantial. Mills et al. (2006) identify 10 "zones" of risk associated with energy efficiency investments, including economic factors like fuel costs and technological factors like equipment performance (see their Table 1). They also describe various methods of quantifying these risks. Jackson (2010) describes how energy efficiency investments can be managed using risk management decision tools from the financial industry.

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[9] Though the focus is energy efficiency, this or a similar model could be applied to other types of decisions, for example investments in health or health behaviors (Winter and Parker 2007).

To simplify the risk and relate it to a choice over a binary lottery (as is common in prospect theory), suppose there is a probability p that the fuel savings $b(e)$ will be realized and $1-p$ that fuel savings will be zero.

Expected utility theory predicts that the consumer will choose e to maximize

$$(1-p)U\big(w-c(e)\big)+pU\big(w+b(e)-c(e)\big),$$

where w is an endowment of consumer wealth and U is a utility function. However, prospect theory predicts that the consumer will consider the gains and the losses from the risky investment asymmetrically, and choose e to maximize:

$$\big(\pi(1-p)\big)v\big(-c(e)\big)+\pi(p)v\big(b(e)-c(e)\big).$$

The value function v is characterized by loss aversion. The probability weighting function is π, and here is assumed to be symmetric over gains and losses.

To conduct comparative statics, I assume functional forms (though later in the paper when solving for optimal policy these assumptions will not be used).[10] Assume that $v(x)=x^{\sigma}$ for gains $x>0$ and $v(x)=-\lambda(-x)^{\sigma}$ for losses $x<0$. A $\lambda>1$ represents loss aversion (a steeper slope of the value function for losses than for gains). Also assume that the probability weighting function takes the form specified in Prelec (1998): $\pi(p)=1/\exp\left[\ln\left(\frac{1}{p}\right)\right]^{\alpha}$. The parameter α represents how the probability weighting function differs from the actual probabilities. When $\alpha=1$, it is linear, but prospect theory predicts that $\alpha<1$, so that individuals overweight small probabilities.

The first-order condition for the choice of e is

$$\big(\pi(1-p)\big)\Big(\lambda\sigma\big(c(e)\big)^{\sigma-1}\Big)\big(-c'(e)\big)+\pi(p)\sigma\big(b(e)-c(e)\big)^{\sigma-1}\big(b'(e)-c'(e)\big)=0.$$

Comparative statics can be performed on this first-order condition to determine how the parameters of prospect theory affect behavior; details are in Appendix A. In particular, $\frac{\partial e}{\partial \lambda}<0$; that is, a higher degree of loss aversion leads to a lower level of energy efficiency investment. The intuition is that energy

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[10] In fact, some initial comparative statics can be conducted without relying on functional form assumptions. The first-order condition of the consumer's problem can be rearranged as: $\frac{b'(e)}{c'(e)}-1=\frac{\pi(1-p)v'_{loss}}{\pi(p)v'_{gain}}$, where v'_{loss} is the derivative of the value function under the loss state, and likewise for v'_{gain}. The left-hand side of this equation is independent of any subjective characteristics of the consumer. The right-hand side demonstrates the relationship between probability weighting, given by the ratio $\frac{\pi(1-p)}{\pi(p)}$, and loss aversion, given by the ratio $\frac{v'_{loss}}{v'_{gain}}$. For example, consider two individuals. One has a higher degree of loss aversion (higher $\frac{v'_{loss}}{v'_{gain}}$) while the other has a higher degree of underweighting the gain probability (lower $\frac{\pi(1-p)}{\pi(p)}$); in this case the two individuals may choose the same amount of e if these two differences perfectly offset each other.

efficiency is a risky investment with a certain loss ($c(e)$) and a risky gain ($b(e)$). The more loss-averse one is, the less she is willing to invest in that risky prospect. However, the sign of $\frac{\partial e}{\partial \alpha}$ is ambiguous and depends on the probability p of achieving the energy savings. The appendix shows that if p is small (specifically, if $p < \frac{1}{e}$), then $\frac{de}{d\alpha} < 0$. That is, suppose there is a small probability of achieving the gain. As α gets smaller than one, the consumer overweights this small probability of the good outcome. The smaller that α is, the more that the consumer overweights the probability of achieving the gain, and therefore the more that she invests in energy efficiency (so $\frac{de}{d\alpha} < 0$). By contrast, if the probability of not achieving the gain, $1 - p$, is small, then $\frac{de}{d\alpha} > 0$: the higher that α is, the more the consumer overweights the (small) probability of losing on the investment, and therefore the more the consumer invests in energy efficiency. Thus, the effect depends on whether or not the energy efficiency investment is likely or unlikely to pay off.[11]

III. Empirical Evidence

This simple theory yields testable predictions that are examined using data from a choice experiment collected in an online survey. Consumers with higher levels of loss aversion should invest less in energy efficiency. For instance, they will be less likely to install energy-efficient light bulbs like compact fluorescents or LEDs, or to replace an air-conditioning unit with an Energy-Star model. To my knowledge, no study has theoretically derived the implications of prospect theory for these classes of behaviors, and no study has empirically tested for correlations between loss aversion and these behaviors.[12]

III.A. Strategy

The three parameters σ, λ and α can be identified by observing a respondent's decisions over a series of lotteries. Following Tanaka et al. (2010), respondents are asked for preferences over pairwise lotteries, in which the expected payoff difference between the pairs of lotteries changes.[13] Table 1 lists

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[11] This result is consistent with a result from the theoretical model in Greene (2011), where it is shown that loss-averse consumers have a lower valuation of energy efficiency or of fuel economy than do non-loss-averse consumers. That model, however, focuses on the decision by manufacturers over the technological content of goods, rather than the decision by consumers over those goods.

[12] "Research demonstrating or contradicting the existence of loss aversion in consumers' decisions about the energy efficiency of energy-using durables is generally lacking." Greene, 2011, p. 616.

[13] An alternative strategy for eliciting prospect theory parameters is in Abdellaoui et al. (2008). See their discussion (p. 246) of various elicitation strategies. Also see Callen et al. (2014).

the lotteries over which subjects are asked to decide. In one series of lottery pairs, one lottery offers a small probability of a large payout (Series 1). In another series, one lottery offers a high probability of a medium-sized payout (Series 2). In the final series, lottery payouts can be either positive or negative (Series 3). Comparing the switching points between series 1 and series 2 provides a range of values for σ and α.[14] For instance, a respondent who switches in series 1 at question 9 and who switches at series 2 at question 5 makes decisions that are incompatible with expected utility theory and a power utility function ($u(x) = x^{\sigma}$). Each pair of switching points in series 1 and 2 pins down a range of values for σ and α. Comparing these estimated values with the switching point for series 3 provides a range of values for λ.

Tanaka et. al. (2010), in their sample of Vietnamese, find a mean value for $(\sigma, \alpha, \lambda)$ of (0.59, 0.74, 2.63), supporting prospect theory (loss aversion and inverted-S shaped probability weighting). Rieger et. al. (2011) survey respondents from 45 different countries and find support for prospect theory around the globe (their parameterization differs slightly from that of Prelec (1998)). While these studies identify prospect theory among participants, they do not attempt to estimate to what extent prospect theory can explain consumer behaviors.

In this survey, I test for correlations between the prospect theory parameters $(\sigma, \alpha, \lambda)$ and the energy consumption variables. Controlling for demographic characteristics, I examine whether consumers who exhibit more loss aversion (higher λ) are more or less likely to make energy-efficiency investments. Similarly, I examine whether consumers with a probability weighting that is farther from linear (lower α) are more or less likely to make energy-efficiency investments. In particular I examine energy outcomes that have been predicted to be caused by prospect theory, including purchases of energy-efficient appliances (Mayer 1995).

III.B. Survey and Data Description

I conduct an online survey of 2,045 individuals, representative of the adult US population.[15] The sample was provided by the firm Qualtrics Panels, which uses quota sampling to arrive at a representative sample based on characteristics of the population. The lottery questions described in Table 1 were asked of all participants to measure loss aversion. Respondents are paid a flat fee from

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[14] As in Tanaka et al. (2010), respondents are forced to choose a single switching point for each of the three series, rather than choosing independently for each of the 35 lottery pairs.

[15] A representative sample may not be most preferable. Alternatively, a survey could focus solely on individuals who are considering buying a new appliance or car, for example (Andersen et al. 2010). Later in this paper, I discuss results that restrict the sample to homeowners.

Qualtrics Panels for participating. Additionally, some respondents are paid based on their responses to the lottery questions in Table 1. Just 50% of respondents are chosen at random to be paid out, and of those paid out, just one of the lottery questions is randomly selected to be the payout question.[16] This method is used in previous papers that elicit prospect theory parameters using lotteries (Abdellaoui et al. 2006, Tanaka et al. 2010). Some evidence suggests that paying out based on just a random subset of lottery questions gives similar results as paying out on all of them (Starmer and Sugden 1991, Cubitt et al. 1999), though there is also theoretical (Holt 1986) and empirical (Harrison and Swarthout 2014, Cox et al. 2015) reason for being cautious.

Respondents were also questioned about their energy consumption. A series of questions were asked, predominantly drawn from the US Energy Information Administration's 2015 Residential Energy Consumption Survey.[17] Table 2 presents summary statistics of the energy-related questions. 54% of respondents are homeowners rather than renters. 54% of respondents have a high fraction (greater than 50%) of lights in their home that are energy-efficient (compact fluorescent or LED), and 73% of respondents have installed energy-efficient lightbulbs themselves. About one-fifth of respondents report having had a home energy audit performed in their home,[18] and of those about 78% have made some of the changes suggested by the audit. 82% have air-conditioning in their house, and of those, 48% have an AC unit that is certified energy-efficient by the Energy Star program, and 31% have replaced the central AC in their home since they moved in. Just about 13% of respondents report owning or leasing an alternative fuel vehicle.[19] Last, a series of questions are asked about the Energy Star certification of various appliances, and the percentage of respondents who report owning an Energy Star certified appliance range from 29% for freezers to 67% for lightbulbs.

I also ask respondents several demographic questions, which are summarized in Appendix Table A1. Each demographic variable is an indicator except for age and income. I control for all of these variables (plus the square of income) in the regressions below.

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[16] The payout question is only chosen among the first two series of lotteries shown in Table 1, since the third series involves losses and was infeasible to administer. The last lottery series is thus hypothetical. The mean payout conditional on being chosen to receive a payout was $9.28 (median = $6.00).

[17] That survey is available here: http://www.eia.gov/consumption/residential/. Some of these questions were also used in the survey in Bradford et al. (2014).

[18] This is higher than other reported values of the percentage of Americans each year that have energy audits on their homes (see, for example, Palmer et al., p. 272-273). The question in this survey asks "Has your home had an energy audit?", not specifically in the current year.

[19] Defined in the survey as either a plug-in electric vehicle (PEV), a gas-electric hybrid, or an E85 or "flex-fuel" vehicle.

Two additional sets of questions are asked for robustness checks. First, I elicit time preferences to test whether controlling for time preferences affects the results. Bradford et al. (2014) provide some evidence that time preferences, including discount factors from a $\beta\delta$ specification of preferences, are correlated with some energy consumption outcomes. I measure time preferences using the multiple price list strategy as in Meier and Sprenger (2010) and Bradford et al. (2014). Individuals are asked to make a series of choices over smaller, sooner payments and larger, later payments (e.g., choosing between $29 today and $30 in one month). From these choices, I calculate each individual's long-run discount factor δ and present bias β.[20]

Second, I ask each respondent a set of hypothetical choices about purchasing home water heaters with varying degrees of energy efficiency. Choices over water heaters were used based on Newell and Siikamäki (2015), who ask similar hypothetical questions over water heaters to elicit time preferences. The questions are designed so as to identify individuals who exhibit evidence of loss aversion. Respondents are asked to hypothetically consider buying a new water heater for their home. One question asks them to decide between keeping their current water heater, which has a 30 gallon tank and annual energy costs of $250 per year, and replacing it at no cost with a new water heater, which has a 60 gallon tank and annual energy costs of $300. Another question asks the same choice about keeping versus replacing, but the both of the characteristics of the current and new heater switched around.[21] Respondents who choose to keep the current heater for both questions demonstrate loss aversion; 19% of respondents do so.

III.C. Results

Table 3 presents summary statistics for the calculated values of the prospect theory parameters. The calculated mean value of σ is close to though slightly higher than the mean value found in Tanaka et al. (2010) among Vietnamese villagers, and the mean value of α is in fact identical to their mean value. They find $\sigma = .59$ and $\alpha = .74$ for those in the North and $\sigma = .63$ and $\alpha = .74$ for those in the South; I find $\sigma = 0.81$ and $\alpha = 0.74$. Liu (2008) for Chinese farmers found slightly lower mean values of $(\sigma, \alpha) = (.48, .69)$. My mean λ of 3.51 is nearly identical to that found in Liu (2008) (3.47) but somewhat higher

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[20] I ask the same three blocks of questions as in Bradford et al. (2014), Table 1. δ is calculated from the response to the "blue" block (5 months vs. 6 months), and β is calculated by comparing responses to the "red" (today vs. 1 month) and "blue" blocks. As with the lottery responses, consumers are restricted to choosing a single switching point from each block of questions. Each switching point yields a range of possible discount factor values, and I assign the median value within the range.

[21] In between these two questions, there are two additional distractor questions that change the tank capacity and energy costs.

than that found in Tanaka et al. (2010) (2.63) or Tversky and Kahneman (1992) (2.25), though my median value (1.61) is closer.[22]

I regress selected energy outcome variables, taken from the energy consumption variables in Table 2 described earlier, on these prospect theory parameters, controlling for the demographic characteristics presented in Appendix Table A1. Table 4 shows the results. Each of the ten columns in Table 4 presents the results from one regression, where the outcome variable is an indicator for one of the energy efficiency questions described in Table 2. The exception is column 10 in Table 4, which combines all of the questions about Energy Star appliances into a single outcome that equals 1 if the respondent answered yes to having any of the listed Energy Star appliances. In all regressions, the three loss aversion parameters σ, α, and λ are included on the right-hand side, and their coefficients and standard errors are reported.[23] All of the demographic variables listed in Appendix Table A1 (plus income squared) are also controlled for though not reported.[24]

The results support the prediction from the model about how loss aversion affects investments in energy efficiency, although for many outcomes the results are not statistically significant. The coefficients on the loss aversion parameter λ are negative as predicted in seven of the ten regressions. In two others they are zero to the third decimal point, and in just one it is positive but insignificant. Of the seven negative coefficients on λ, three are statistically significant at the 10% level, and three others have a p-value of 0.2 or lower. A higher level of loss aversion (higher value of λ) is significantly (at the 10% level) negatively correlated with having a high fraction of efficient light bulbs, replacing one's air-conditioner, and owning an alternative fuel vehicle. The magnitudes of the coefficients indicate that the relationship is modest. The standard deviation of λ is 3.867, so a one-standard-deviation increase in λ is associated with a 2.3 percentage-point increase in the probability of having a high fraction of efficient lights and a same 2.3 percentage-point increase in the probability of having replaced air conditioning.

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[22] These values are directly calculated for each individual based on his or her switching points among the three series of lotteries as described in Tanaka et al. (2010). They are not estimated using maximum likelihood methods, for example as in Harbaugh et al. (2002). See Harrison and Rutström (2008, Section 2) for a discussion of alternate estimation methods, and in particular p. 59-61 on the method used in Tanaka et al. (2010). For respondents who do not switch (which is about 50% of respondents for each series of lotteries), the values at the boundaries are used, as in Tanaka et al. (2010).

[23] The purpose of this study is to estimate the relationship between prospect theory parameters and energy efficiency investments, though several other studies examine other determinants of energy efficiency investments. For example, Nair et al. (2010) find that personal attributes affect home energy investments, Carlsson-Kanyama et al. (2005) find that home age affects home energy investments, Darby (2006) finds that "energy-conscious" people are more likely to make efficiency investments, and Diamond (2009) and Gallagher and Muehlegger (2011) study the effect of government incentives on hybrid-electric vehicle purchases.

[24] The regression results are robust to not controlling for the demographic controls.

Compare those percentage correlations with the sample mean of those indicator outcomes of 54% and 31%, respectively. A one-standard-deviation increase in λ is associated with a 1.5 percentage-point increase in the probability of owning an alternative fuel vehicle, compared to the sample mean of that outcome variable of just 12.6%. The coefficients on λ thus conform to the model's prediction that $\frac{de}{d\lambda} < 0$.[25]

A caveat of this analysis is that some of these significant results may arise due to chance, since I am examining ten different outcome variables. It is unlikely that all of the results are merely due to chance, since three out of ten are significant at the 10% level and an additional three have a p-value of 0.2 or lower. I have not adjusted the standard errors or p-values using any of the conventional methods for multiple hypothesis testing, since with a large number of hypotheses these methods are very conservative, controlling the Type I error rate at the cost of substantially increasing the Type II error rate (Romano et al. 2008).[26] Alternative adjustment methods are less conservative, and some of the significant coefficients remain significant after adjusting p-values using these techniques.[27]

There is no consistent relationship across columns between the probability weighting parameter α and the energy outcomes. The theory was ambiguous about the sign of $\frac{de}{d\alpha}$. For an energy investment with a high probability of paying off, this sign is predicted to be positive. It is conceivable that this pattern of coefficients is consistent with the fact that some of these energy efficiency investments (e.g. replacing air conditioning, having efficient light bulbs) are more likely to pay off and some (e.g. a home energy audit) are less likely to, though this is speculative.

The results in Table 4 are from regressions that include all respondents with non-missing values. Alternatively, I run the regressions with just those respondents who are homeowners (Appendix Table A2), motivated by the differing incentives for renters vs. owners (Davis 2011, Gillingham et al. 2012). Also, I consider just the homeowners who have lived in their current homes for at least three years

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[25] The outcome variable from the regression reported in column 5 is having ever conducted a home energy audit. This outcome is somewhat different than the other outcomes, since it is not directly an energy efficiency investment, but rather it is an expense undertaken to get information about the types of energy efficiency investments that could be made and their expected returns. There is very limited prior research investigating the determinants of choosing to conduct a home energy audits. Two early studies, Tonn and Berry (1986) and Laquatra and Chi (1989), find that attitudes towards energy conservation affect take-up.

[26] For example, applying the Bonferroni correction means multiplying each p-value by 10, in which case none of the coefficients on λ are significant at the 10% level. The Holm-Bonferroni method adjustment is similarly conservative.

[27] Using the generalized Bonferroni method described in Lehmann and Romano (2005, Theorem 2.1) to control the k-FWE (familywise error rate), the coefficient on λ is significant at the 10% level in the regression for alternative fuel vehicle when $k = 5$.

(Appendix Table A3), to account for the fact that for people who have lived in their current homes for less time, many of these durable good purchases were likely made by the previous resident. These alternative specifications yield qualitatively similar results but with slightly higher standard errors due to the smaller sample size.

One potential confounding factor is time preference. Previous studies (Bradford et al. 2014, Newell and Siikamäki 2015) have linked discount factors to energy efficiency investments. Therefore, I re-run the regressions when also controlling for the two individual-level discount factors β and δ, calculated based on the methodology described earlier. These results, shown in Table 5, reinforce the findings from Table 4. The coefficients on λ are nearly identical to the coefficients in Table 4, where discount factors are not controlled for. Surprisingly, the coefficients on the discount factors are generally insignificant and the signs are not consistent.[28]

An alternative test avoids imposing parameterization or functional forms to calculate an individual's loss aversion parameter or other prospect theory parameters. Instead, the outcomes are regressed on a variable that represents the "switching point" among the loss aversion questions, that is, the point at which the respondent switches from option A to option B in series 3 of the lottery questions (see Table 1). These questions are constructed so that a later switching point indicates a more loss-averse individual (though the value of λ depends also on the switching points in series 1 and 2).

Table 6 presents these non-parametric regression results, where the independent variable of interest is the switching point from series 3. This takes a value between 1 (for an individual who always chooses lottery A, the least loss-averse) and 8 (for an individual who always chooses lottery B, the most loss-averse). Regressions also control for the same demographic variables as the regressions in Table 4. These results support the parametric regressions in Table 4: the negative coefficients indicate that more loss-averse individuals are more likely to make energy efficiency investments. This relationship is statistically significant at the 5% level for owning an alternative fuel vehicle and for making recommended changes after a home energy audit. Two of the coefficients that were statistically significant in the parametric regressions in Table 4, on having a high fraction of efficient lights and replacing one's air conditioner, are still negative here but no longer significant at the 10% level (p-values are .20 and .11, respectively).

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[28] The distribution of and variation in my estimates of time preference parameters β and δ are consistent with those reported in previous papers that have estimated them. For example, the mean value of δ here is 0.791, compared to 0.864 in Bradford et al. (2014) and 0.75 in Courtemanche et al. (2015).

One concern is that the evidence of loss aversion is actually evidence of "noisiness" or inattention. There is an attention filter question in the survey, asking respondents to select "C" to make sure they are paying attention, and any respondent that fails to do so is dropped entirely from all of the reported analysis. In addition to this attention filter, I can also test for the effect of inattention by exploiting the responses to the set of time preference questions described earlier. Some people's responses show evidence of a contradiction that could reflect inattention to the survey.[29] Controlling for inattention in this way, either by including an indicator variable for those respondents who demonstrate this contradiction (Appendix Table A4) or by excluding them altogether from the regressions (Appendix Table A5), yields results that are qualitatively similar to the main specification.

Finally, I consider the alternate measure of loss aversion that is based on responses to the hypothetical questions about replacing home water heaters. These responses provide a binary classification of respondents as either loss-averse (if they chose to keep their current water heater in both cases) or not loss-averse (any other combination of choices). This binary outcome shows no relationship with the parametric calculation of λ based on the lottery questions; in a regression where the outcome is the binary water loss aversion indicator from the water heater questions, controlling for the three parametric prospect theory parameters and demographics, the p-value on the coefficient on λ is .854. Furthermore, when regressing the various energy efficiency outcomes on this binary loss aversion indicator (Appendix Table A6), there is no consistent relationship between it and the outcomes. The coefficient is significantly negative at the 1% level when the outcome is making changes recommended by an energy audit, reinforcing the result from Table 6. However, the coefficient is significantly *positive* when the outcome is conducting an energy audit or replacing one's air conditioner, in contrast to the result in Table 4. Perhaps because this loss aversion measure is too coarse, or perhaps because it was based on questions that are purely hypothetical, it fails to provide additional evidence relating loss aversion to energy efficiency investments.

Overall, though the empirical results are often not statistically significant, they nevertheless provide some consistent evidence that the energy consumption behaviors of individuals are motivated in part by a choice model based on prospect theory, and in particular that those individuals who are more loss-averse are less likely to invest in energy efficiency. Given this result, I next consider the policy implications.

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[29] The contradiction arises from the three blocks of time preference questions. The "red" block (today vs. 1 month) and "black" block (today vs. 6 months) pin down a range for δ, which may contradict the δ range provided by the "black" block (5 months vs. 6 months).

IV. Policy

In this section, I consider a model of optimal policy in the context of an energy-efficiency decision made by consumers exhibiting prospect theory. The social planner seeks to maximize social welfare, and there are two potential distortions. The first is a standard market failure: externalities from the use of energy. This is modeled as a positive externality from the adoption of the energy-efficient technology, only realized in the case of cost savings. The second distortion is a "behavioral" failure caused by the consumer exhibiting prospect theory.

The first-best solution is given by the following:

$$\max_{e}(1-p)U\big(w-c(e)\big)+p\big[U\big(w+b(e)-c(e)\big)+b_{ext}(e)\big]$$

The externality from the energy efficiency investment is given by $b_{ext}(e)$, and it appears in the social welfare function, though not in the agent's utility function.[30] The first-best solution includes the consumer's utility function and is not characterized by prospect theory. This social welfare framework thus takes the form of there being a distinction between "decision" utility – that is, the subjectively perceived utility, or the utility that guides the consumer's decisions – and "experienced" utility – that is, the "true" utility, or the utility that is relevant for welfare calculations. This specification of welfare analysis is commonly used in behavioral welfare economics,[31] though there are alternatives.[32] Some empirical support for this method of welfare analysis can be found in the psychology literature in Charpentier et al. (2016), who conduct an experiment over risky gambles eliciting subjects' choices and their feelings or emotions over outcomes. They find that while choices are best modeled using a value function that exhibits loss aversion, loss aversion is not present in the function that describes feelings, which may suggest that decision utility contains loss aversion but experienced utility does not.[33]

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[30] The external benefit is separable from utility over wealth U. This avoids creating an income effect that arises in the optimal policy solutions. Results from modeling the external benefit non-separably contain this extra income effect and are available upon request from the author.

[31] For example, see O'Donoghue and Rabin (2006), Duflo et al. (2011), Heutel (2015), or Farhi and Gabaix (2015). Thaler (2016, p. 1591) summarizes: "Expected utility theory remains the gold standard for how decisions *should* be made in the face of risk. Prospect theory is meant to be a complement to expected utility theory, which tells us how people *actually* make such choices" (italics added). Farhi and Gabaix also consider an alternative to the decision vs. experienced utility welfare specification, based on misspecification of prices or taxes. Treating deviations from expected utility theory as "inadvisable" or "mistakes" goes back at least to Jacob Marschak, who in a 1950 letter to Paul Samuelson, referred to those who deviate from expected utility theory as displaying "non-Euclidean habits." (Moscati 2016, p. 229).

[32] For example, Bernheim and Rangel (2009) and Bernheim (2016).

[33] They claim their results suggest "that the asymmetric influence of gains and losses on decision making, as suggested by prospect theory, is not necessarily reflected in expected or experienced feelings." (Charpentier et al. 2016, p. 10).

The policy that the planner selects is a per-unit subsidy s to energy efficiency e. Assume that the subsidy rate s is constant so that the total subsidy payment is se (later, in subsection IV.E., I will consider the case where the subsidy rate can vary based on which state is realized). The subsidy is paid for by a lump-sum tax T, which is fixed to equal the subsidy revenues but which the consumer treats as lump sum.

The consumer acts according to prospect theory and solves:

$$\max_{e}\big(\pi(1-p)\big)v(-c(e)+se-T)+\pi(p)v(b(e)-c(e)+se-T)$$

The consumer does not consider the externality from energy efficiency, and the consumer exhibits loss aversion. Both of these deviate from the solution to the first-best problem, and so there is a potential for the social planner to intervene to increase social welfare.[34] [35]

I analyze the implication of prospect theory on policy by considering several cases. First (subsection IV.A.), I assume that the only market failure is the externality, and the consumer does not exhibit prospect theory. Then, I separately add in two aspects of prospect theory individually to isolate their effects on policy. In subsection IV.B. I assume that the consumer uses probability weighting but not loss aversion (reference-dependent preferences). In subsection IV.C., the consumer exhibits loss aversion, but not probability weighting. Then, subsection IV.D. presents the case where the consumer exhibits prospect theory, including both probability weighting and loss aversion. The remaining subsections present alternative specifications, comparative statics, and numerical simulations.

IV.A. Externality Only

To begin, consider the case where the only market distortion is caused by the externality from energy efficiency; assume that the consumer decides based on expected utility rather than on prospect theory.[36] In this case the optimal policy is to provide a Pigouvian subsidy for the positive externality.

The (unique) solution for the subsidy is:

$$s=\frac{1}{E[U']}\cdot pb'_{ext}(e^{opt})$$

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[34] A related behavioral economic effect is from framing, where the framing of a decision can affect choices (Tversky and Kahneman 1981). Here, framing choice is not a policy option, though perhaps if possible it would affect behavior (Fryer er al. 2012).

[35] A money pump (or "Dutch book") argument is often used against the plausibility of intransitive preferences like those implied under prospect theory (e.g. Azevedo and Gottleib 2012), though Rabin and Thaler (2001) and Cubitt and Sugden (2001) provide counterarguments. Here, though, the planner is benevolent, seeking to maximize the consumer's "true" utility rather than money-pump her.

[36] That is, the consumer's problem is: $\max_{e}(1-p)U(w-c(e)+se-T)+pU(w+b(e)-c(e)+se-T)$

The subsidy is equal to the expected value of the marginal external benefits ($pb'_{ext}(e^{opt})$) divided by the expected value of marginal utility $E[U'] \equiv (1-p)U'\big(w-c(e^{opt})\big) + pU'\big(w+b(e^{opt})-c(e^{opt})\big)$ (since marginal utility is different across the two states). Derivations of this subsidy and all subsequent results are in Appendix B.

This is the standard Pigouvian result, and it achieves the first-best. It ignores the consumer exhibiting prospect theory.

IV. B. Externality and Probability Weighting

Next, assume that the consumer exhibits probability weighting.[37] The first-best is achieved with the following policy:

$$s = \frac{1}{E[U']} \cdot \left[\frac{\pi(1-p)}{\pi(p)} - \frac{1-p}{p}\right] U'\big(w-c(e^{opt})\big)\pi(p)c'(e^{opt}) + \frac{\pi(p)b'_{ext}(e^{opt})}{E[U']}$$

Here, expected marginal utility is evaluated based on the weighted, not true, probabilities: $E[U'] \equiv \pi(1-p)U'\big(w-c(e^{opt})\big) + \pi(p)U'\big(w+b(e^{opt})-c(e^{opt})\big)$. The second term is identical to the optimal policy in the case without probability weighting, except that marginal benefit is multiplied by the weighted probability $\pi(p)$ rather than the true probability.[38] The first term is an additional correction for probability weighting. The term in brackets $\left[\frac{\pi(1-p)}{\pi(p)} - \frac{1-p}{p}\right]$ is positive whenever the low state is overweighted relatively more than the high state is overweighted (or when the high state is underweighted relatively more than the low state is underweighted). For instance, it is positive if you overweight the probability of the low state ($\pi(1-p) > 1-p$) and underweight the probability of the high state ($\pi(p) < p$); this weighting can be called "pessimistic." Under a symmetric (gain vs. loss) inverse-S shaped weighting function (e.g. from Prelec (1998)) where small probabilities are overweighted, a pessimistic weighting will occur when the probability of the low state occurring is small.

Assuming pessimistic weighting, the first term in the expression for s is positive. Because the consumer underweights the true probability of achieving a benefit from the energy efficiency investment, optimal policy subsidizes energy efficiency (at a higher rate than just marginal external benefits). With optimistic weighting, where the consumer relatively overweights the probability of the benefit being realized, this first term is negative. Probability weighting creates a term in the optimal subsidy of the opposite sign as the part addressing the externality.

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[37] That is, the consumer's problem is $\max_e \pi(1-p)U(w-c(e)+se-T) + \pi(p)U(w+b(e)-c(e)+se-T)$.

[38] This result is analogous to Proposition 2.2 in Fahri and Gabaix (2015), which shows that the Pigouvian tax is "modified" when consumers misperceive taxes.

In the case where there is just an externality and probability weighting, it is easy to see that the optimal set of policies is used to eliminate the distortion from both of these effects. The policy prescriptions are analogous to those from other models of misoptimization, for instance from undervaluation of future costs (Allcott et al. 2014) or tax salience (Chetty et al. 2009).

IV.C. Externality and Loss Aversion

Here, suppose that the consumer's beliefs over the probabilities are true, but that the consumer optimizes according to a value function rather than a utility function. The value function is a function of the gains and losses relative to a reference point, and thus it excludes the initial wealth level w. The value function can be asymmetric about the reference point, leading to loss aversion.

The consumer's problem in this case is:

$$\max_{e}(1-p)v(-c(e)+s\cdot e-T)+pv(b(e)-c(e)+s\cdot e-T)$$

In the first half of this maximand, with probability $1-p$ the cost savings are not realized, and the consumer treats the expenditure on energy efficiency $c(e)$ as a loss. Although there is also a subsidy that the consumer receives and a lump-sum tax, the net payment is zero and so will not move this from a loss to a gain. In the second half, with probability p the cost savings are realized and the consumer treats this is a gain (that is, $b(e)-c(e)+s\cdot e-T>0$).

While the consumer uses a reference-dependent value function that can exhibit loss aversion, the first-best outcome is defined based on the utility function, which is not reference-dependent and does not feature loss aversion. Define the marginal utility and the marginal value function at the optimum, for either a loss or a gain, in the following way:

$$v'_{loss}\equiv v'(-c(e^{opt})+s\cdot e^{opt}-T)$$
$$v'_{gain}\equiv v'(b(e^{opt})-c(e^{opt})+s\cdot e^{opt}-T)$$
$$U'_{loss}\equiv U'\big(w-c(e^{opt})\big)$$
$$U'_{gain}\equiv U'\big(w+b(e^{opt})-c(e^{opt})\big)$$

Given these definitions, the unique policy that yields the first-best outcome is:

$$s=\frac{v'_{gain}}{E[v']}\cdot\left[\frac{v'_{loss}}{v'_{gain}}-\frac{U'_{loss}}{U'_{gain}}\right]\cdot(1-p)\cdot c'(e^{opt})+\frac{1}{E[v']}\cdot\frac{v'_{gain}}{U'_{gain}}pb'_{ext}(e^{opt})$$

Here the denominator is the expected value of the marginal value function, not marginal utility: $E[v']\equiv(1-p)v'_{loss}+pv'_{gain}$. The second term, again, directly addresses the positive externality. It is modified by the factor $\frac{v'_{gain}}{U'_{gain}}$. If this ratio is greater than one, then the consumer's perceived marginal value is greater than the social planner's marginal utility, and so the part of the subsidy addressing the externality is greater than it otherwise would be. The first term is an additional component addressing loss aversion. The expression in brackets $\left[\frac{v'_{loss}}{v'_{gain}} - \frac{U'_{loss}}{U'_{gain}}\right]$ will tend to be positive under loss aversion.[39] A loss-averse consumer is less likely to invest in energy efficiency given the possibility of experiencing a loss, and this positive term in s compensates for that.

In this expression, both market failures – from the externality and from loss aversion – affect the optimal policy design, and the subsidy can mitigate both market failures. Next, I turn to the most complete case, in which there is a positive externality and the consumer is both probability weighting and exhibiting loss aversion.

IV.D. Externality and Prospect Theory

Finally, assume that all of the features of prospect theory are present, as well as the externality. The consumer's problem is

$$\max_e \pi(1-p)v(-c(e)+s\cdot e-T)+\pi(p)v(b(e)-c(e)+s\cdot e-T)$$

The subsidy that induces the first-best outcome is

$$s=\frac{1}{E[v']}\cdot\left[\frac{\pi(1-p)v'_{loss}}{\pi(p)v'_{gain}}-\frac{(1-p)U'_{loss}}{pU'_{gain}}\right]v'_{gain}\cdot\pi(p)\cdot c'(e^{opt})+\frac{1}{E[v']}\cdot\frac{v'_{gain}}{U'_{gain}}\pi(p)b'_{ext}(e^{opt})$$

Here the expected value of the marginal value function is taken using the weighted probabilities: $E[v'] \equiv \pi(1-p)v'_{loss}+\pi(p)v'_{gain}$. This expression combines the insights from the previous two expressions for optimal subsidies, in which just one feature of prospect theory was present. For instance, when there is no probability weighting (i.e. when $\pi(p)=p$), then this expressions reduces to the expression from the previous section with just reference-dependent preferences.

The sign and magnitude of s depend both on the degree of probability weighting (the relative magnitudes of $1-p$ and $\pi(1-p)$) and the distortion from reference-dependent preferences (the difference between v'_{loss} and U'_{loss}). It is possible that the two distortions created by prospect theory just cancel each other out. This would occur if $\pi(1-p)v'_{loss}=(1-p)U'_{loss}$ and if $pU'_{gain}=\pi(p)v'_{gain}$. Whether or not this holds, or whether in fact the two distortions operate in the same direction, depends on the parameterization of the functions.

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[39] For example, under a simple specification of loss aversion where U and v are identical for gains but v exhibits loss aversion under losses, then this is positive (since $v'_{gain}=U'_{gain}$ and $v'_{loss}>U'_{loss}$).

The results in this most general model show that the distortions created by prospect theory require that the standard Pigouvian response to externalities be altered. In addition to a term in the optimal subsidy that remedies the market failure from the externality, there is a term to accommodate the behavioral failures created by prospect theory. In general, the sign of these additional terms are unknown and depend on parameter values.

IV.E. State-Dependent Subsidies

Next, assume that the subsidy rate can depend on the realization of the state. The planner sets two subsidy rates, s_{LO} and s_{HI}, corresponding to the state where the energy efficiency benefit is not realized (the "LO" state, with probability $1-p$) and to the state where it is realized (the "HI" state, with probability p). The lump-sum tax is required to just offset the subsidy payments so is also state-dependent: T_{LO} and T_{HI}. The consumer's problem is

$$\max_{e} \pi(1-p)v(-c(e)+s_{LO}\cdot e-T_{LO})+\pi(p)v(b(e)-c(e)+s_{HI}\cdot e-T_{HI})$$

The planner chooses the subsidies to maximize expected utility conditional on the consumer's response. In this case, though, there is not a unique solution for the optimal policies s_{LO} and s_{HI}. There are two policy instruments, but the planner needs to induce only one scalar (e) to its optimal level, so the planner has one extra degree of freedom.

Instead, there are a continuum of solutions. One can consider, though, a constrained policy. In particular, suppose that the subsidy is constrained to be zero in the low (no energy savings) state; a subsidy can only be made if the energy savings are actually realized. In this case, the optimal policy is:

$$s_{LO}=0$$

$$s_{HI}=\left[\frac{\pi(1-p)v'_{loss}}{\pi(p)v'_{gain}}-\frac{(1-p)U'_{loss}}{pU'_{gain}}\right]\cdot c'(e^{opt})+\frac{1}{U'_{gain}}\cdot b'_{ext}(e^{opt})$$

The second term in the expression for s_{HI} is the standard Pigouvian solution of pricing at marginal external damages.[40] The first term remedies the distortion caused by prospect theory. Consider the term in brackets (which also appears in the optimal state-independent subsidy in the previous section). With no probability weighting, this term is positive when the consumer is loss-averse. With no loss-aversion, this term is positive whenever the low state is overweighted relatively more than the high state is overweighted (e.g. under a pessimistic weighting). If both of these conditions hold, then this

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[40] In the case where there are state-dependent subsidies but the only market failure is the externality (equivalent to section IV.A. but with state-dependent subsidies), then an optimal policy solution is $s_{LO}=0$; $s_{HI}=\frac{1}{U'_{gain}}\cdot b'_{ext}(e^{opt})$.

term is positive, increasing the optimal high-state subsidy relative to the Pigouvian case. If one but not both hold, then these two features of prospect theory are working in opposite directions in terms of their effect on the optimal subsidy.

Another constrained state-dependent subsidy fixes the low-state subsidy to exactly equal the marginal cost of energy efficiency at the optimum ($c'(e^{opt})$). The optimal set of subsidies under this constraint is:

$$s_{LO} = c'(e^{opt})$$

$$s_{HI} = \frac{1}{U'_{gain}} \cdot b'_{ext}(e^{opt}) - \frac{1-p}{p} \frac{U'_{loss}}{U'_{gain}} c'(e^{opt})$$

The high-state subsidy contains the same term to correct the positive externality, plus a modified term to correct for prospect theory. There are two reasons for considering this particular constrained state-dependent policy. First, it happens to be independent of the probability weighting function π. Second, I show in Appendix C that this policy corresponds to the optimal policy in the case of heterogeneity.

IV.F. Comparative Statics

I consider how parameter values affect the optimal subsidies. To conduct this comparative static analysis, I impose the functional form on the value function described earlier in Section II: $v(x) = x^{\sigma}$ for gains $x > 0$ and $v(x) = -\lambda(-x)^{\sigma}$ for losses $x < 0$. The parameter λ represents the degree of loss aversion; a higher λ means more loss aversion. I examine how the optimal subsidy s is affected by the value of λ.

First, consider the case of state-dependent subsidies from the previous subsection (IV.E.), and consider the first solution presented, where $s_{LO} = 0$. The relationship between that s_{HI} and λ is given by:

$$\frac{\partial s_{HI}}{\partial \lambda} = \frac{\pi(1-p)}{\pi(p) v'_{gain}} c'(e^{opt}) \cdot \frac{\partial}{\partial \lambda} v'_{loss} = \frac{\pi(1-p)}{\pi(p) v'_{gain}} c'(e^{opt}) \cdot \sigma\left(e^{opt^{\gamma}}\right)^{\sigma-1} > 0$$

In the expression for s_{HI} from subsection IV.E., the second term is independent of λ. In the first term, the only part that depends on λ is v'_{loss}, which is positively related to λ. Thus, for a more loss-averse individual, the optimal high-state subsidy must be higher. This is because in this constrained solution where $s_{LO} = 0$, the high-state subsidy must address the behavioral failure caused by loss aversion as well as that caused by the externality.

Next, consider the optimal state-independent subsidy from subsection IV.D. The derivative with respect to λ is complicated by the fact that λ affects the denominator $E[v']$.

$$\frac{\partial s}{\partial \lambda} = \left[\frac{\partial}{\partial \lambda}\frac{1}{E[v']}\right] \cdot \left\{\left[\frac{\pi(1-p)v'_{loss}}{\pi(p)v'_{gain}} - \frac{(1-p)U'_{loss}}{pU'_{gain}}\right] v'_{gain} \cdot \pi(p) \cdot c'(e^{opt}) + \cdot \frac{v'_{gain}}{U'_{gain}} \pi(p) b'_{ext}(e^{opt})\right\}$$
$$+ \frac{1}{E[v']}\pi(1-p)c'(e^{opt})\frac{\partial}{\partial \lambda}v'_{loss}$$

The second part of the above expression represents the direct effect of λ on the optimal subsidy s, which is the effect on v'_{loss} in the expression for s. This term is positive; a more loss-averse person requires a higher subsidy to get her to invest in energy-efficiency. The first part of the above expression (multiplied by $\frac{\partial}{\partial \lambda}\frac{1}{E[v']}$) comes from the fact that the entire expression for s is divided by $E[v']$, which contains v'_{loss} and is therefore a function of λ. The term in the curly brackets is just the optimal subsidy multiplied by $E[v']$. This entire first part of the expression simplifies to $\frac{-1}{E[v']} s\pi(1-p)\sigma\left(e^{opt\gamma}\right)^{\sigma-1} < 0$. In other words, this indirect effect of λ on the optimal subsidy works in the opposite direction as the more intuitive direct effect. Whether it dominates and yields a net counterintuitive effect depends on the parameterization, which will be explored in the numerical simulations below.

IV.G. Additional Specifications

Appendix C presents two additional specifications. First, I allow for heterogeneity across individuals. Second, I allow for more than two possible outcomes and use cumulative prospect theory to model consumer choice.

IV.H. Simulations

Finally, I provide numerical simulations of optimal policy. I impose assumptions on functional forms and parameter values, described in Appendix D, and numerically solve for policy. In the literature, there are two types of numerical policy simulations that serve two different purposes. First and most obviously, numerical simulations can be used to quantify theoretical results. For instance, while a theory provides an expression for an optimal tax, the simulation is used to provide a value in dollars for the tax rate. In these simulations, it is important that the model is as realistic as possible and well-calibrated to the market in question.[41]

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[41] In the context of environmental policy under behavioral anomalies, two papers that provide simulations of this sort are Allcott et al. (2014) and Heutel (2015). Both provide simulations of the automobile market when consumers are irrational (inattentive to energy costs or present-biased), and both provide careful calibrations of the US automobile market and consumer preferences, including behavioral biases. Both simulations provide numerical calculations of optimal policy variables, like fuel taxes or fuel economy standards.

Another type of numerical simulation serves a different purpose. Rather than providing realistic quantitative numbers, these simulations are meant to explore how the policy outcomes relate to certain parameter values. That is, the simulations provide a form of comparative statics of the theory, numerically rather than theoretically. In these simulations, it is not important to calibrate the model to a particular market or to use real-world calibrated preference parameters. Instead the value is in seeing how policy variables change along with these arbitrary parameter values. For example, O'Donoghue and Rabin (2006) provide numerical simulations of a model of optimal "sin taxes," when consumers are present-biased. Their simulations consider different values for parameters describing the demand elasticity and the degree of present bias among consumers, and they present optimal taxes under each set of parameter values. This type of simulation can even be described as a "back-of-the-envelope" calculation.

The simulations presented here are of the second type of simulation, as in O'Donoghue and Rabin (2006). That is, the simulations are not meant to reflect any particular real-world market, nor are they calibrated to previously-estimated parameters. Therefore, their interpretation should still be seen as *qualitative* rather than as *quantitative*.

The appendix describes the functional form assumptions and most parameter values. Here, I describe the most important parameter values and results. In the base case, I set the loss aversion parameter $\lambda = 2$, which is roughly equal to the median value found in the empirical results here and to the mean value found in Tversky and Kahneman (1992). Since $\lambda > 1$, this indicates loss aversion. A larger value for λ means more loss aversion. The probability weighting parameter $\alpha = 0.75$, roughly equal to the mean value found in this paper and in Tanaka et al. (2010) and Liu (2008). Since this is less than one, it indicates that people overweight small probability events. A lower value of α means more overweighting of small probability events. The probability p of achieving energy efficiency benefits is set to 0.75, so that consumers overweight the probability of *not* achieving these benefits.

Given these parameter values and the parameter values and functional forms described in the appendix, I solve for optimal subsidies to energy efficiency under different specifications of consumer behavior, corresponding to the previous subsections in this section of the paper. The results are summarized in Table 7. The first row presents the results under the base-case parameter values. In the second panel, I vary the degree of loss aversion λ, and in the bottom panel I vary the degree of probability weighting α. The energy efficiency values e^* are expressed as a percentage of the first-best level. Subsidy values s^* are expressed as a percentage of the cost of energy efficiency at the first-best level $c(e^{opt})$.

Under the base case, the energy efficiency level e^* chosen by the consumer who exhibits expected utility theory is 89.87% of the first-best level.[42] The difference is solely due to the externality from energy efficiency. When a consumer exhibits prospect theory, the energy efficiency level chosen is lower: just 28.00% of the first-best level. Under this base-case parameterization, the scale of the market failure due to prospect theory (in terms of the consumer deviating from the first best) is larger than the market failure due to the externality.

The last four columns present optimal subsidy values under different assumptions about consumer behavior. When the consumer exhibits expected utility theory, so that the only market failure is from the externality, the optimal subsidy is 25.73% of the cost of energy-efficiency at the first-best level $c(e^{opt})$.[43] That is, the policymaker subsidizes about one-fourth of the cost of the energy efficiency investment to counteract the market failure from the externality. In the next column, I assume that the consumer exhibits probability weighting but not loss aversion, as in subsection IV.B. Here the subsidy is about twice as high as in the previous column, 59.08% of the cost of the investment. In the second-to-last column, the consumer exhibits reference-dependent preferences and loss aversion but no probability weighting. Here, the optimal subsidy is larger than the cost of energy-efficiency itself. That is, the consumer is paid to invest in energy efficiency. Loss aversion is so strong that an enormous subsidy is required to overcome it. Lastly, the final column shows the optimal subsidy when consumers exhibit prospect theory, including both probability weighting and loss aversion. Again, the subsidy rate is higher than 100% to ensure the first-best level of energy-efficiency.

The rest of Table 7 explores comparative statics over the degree of loss aversion and the degree of probability weighting. When loss aversion λ is varied, a higher value of loss aversion (higher λ) results in a lower level of energy efficiency e^*. When $\lambda < 1$ so that consumers are gain-averse rather than loss-averse, then the energy efficiency level chosen is slightly higher than it is in the case under EUT. As consumers are more loss-averse, the optimal subsidy gets higher. When consumers are gain-averse, the optimal subsidy is negative (a tax on energy efficiency) under loss aversion only, though it becomes slightly positive when probability weighting is also included. When probability weighting α is varied, a larger overweighting of small probabilities (smaller α) results in a smaller value of energy efficiency chosen e^* and a larger subsidy necessary to correct the market failure. When $\alpha > 1$ so that the

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[42] The quantitative values of these outcomes are arbitrary; the first-best energy efficiency level is 0.195, and the consumer's choice under EUT is 0.176.

[43] This value is 0.141, and the optimal subsidy is 0.0363.

consumer actually underweights the small probability of not achieving energy savings, then the optimal subsidy is slightly negative to overcome the market failure operating in the opposite direction.

As mentioned earlier, the simulation results in Table 7 are not meant to be taken as serious quantitative policy recommendations since the parameterization is (intentionally) arbitrary. Nevertheless, the magnitudes of the results suggest that the market failure arising from prospect theory may be quite large and in particular may be larger than the market failure arising from the externality.

V. Conclusion

I examine how prospect theory affects people's choices to invest in energy efficiency, and to what extent this affects optimal energy policy. Using data gathered from an online survey featuring a choice experiment to elicit evidence of prospect theory, I find that people who are more loss averse are less likely to undertake energy efficiency investments like buying a fuel-efficient car or energy-efficient light bulbs. I develop a theoretical model to conduct welfare analysis under the assumption that people's choices over energy efficiency are explained by prospect theory. The standard Pigouvian policy of pricing externalities is modified under prospect theory to account for consumers' deviations from maximizing their true utility. Optimal policy addresses both the market failure generated by externalities and the “behavioral" market failure generated by loss aversion.

Both the empirical and theoretical results point to the importance of incorporating prospect theory into energy policy evaluation and design, but both sets of results could be extended. Further research could address the importance of various assumptions. Empirically, the current set of results is from a very small sample from an online survey, so replicating the survey with additional respondents would be beneficial. The current results are based solely on hypothetical questions; running a survey in which questions are tied to actual payments may mitigate hypothetical bias. Lastly, the current survey design uses choice experiments over money lotteries to elicit preference parameters and survey questions to gather energy consumption decisions; an alternative approach is to use choice experiments over energy consumption options to elicit preference parameters, and use those results to explore how prospect theory affects energy consumption.[44]

The theoretical policy results use a number of assumptions that could be relaxed. First, the main specification is a representative agent model, consumer heterogeneity is only addressed through a simple extension modeling two types. Given that loss aversion or other prospect-theory based

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[44] A similar methodology is used by Newell and Siikamäki (2015) to elicit time discounting parameters in the context of energy-efficiency investments.

parameters may be different across the population, targeted policies that account for heterogeneity may improve on the policy responses.[45] Second, the model considers only a limited set of policy options; other policies could be modeled. For instance, the policymaker may be restricted as to how high a subsidy could be or how it could be structured. In this case, the policy may not be able to achieve the first-best outcome, but the model can solve for second-best policies. Additionally, there may be other policies available besides subsidies, including efficiency standards. Third, though the motivating example is energy efficiency investments, the model could also apply to other risky decisions that can be characterized by prospect theory, for example, decisions over health investments or health insurance. Fourth and finally, the model only considers the behavioral failures caused by prospect theory. There are other alternatives to expected utility theory besides prospect theory for modeling decisions under risk, for example, rank-dependent expected utility (Quiggen 1982) and regret aversion (Loomes and Sugden 1982). Furthermore, there are other sets of behavioral failures, for instance, those caused by time-inconsistent preferences (Laibson 1997). The relationship between prospect theory and other behavioral failures could yield further policy refinements.

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[45] Alloctt et al. (2014) consider targeting policies when consumers are heterogeneous in their undervaluing of energy costs.

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Table 1 – Prospect Theory Lottery Questions (from Tanaka et al., 2010)

Series 1				Series 2				Series 3			
Option A		Option B		Option A		Option B		Option A		Option B	
30%	70%	10%	90%	90%	10%	70%	30%	50%	50%	50%	50%
$8	$2	$13.60	$1	$8	$6	$10.80	$1	$25	–$4	$30	–$21
$8	$2	$15	$1	$8	$6	$11.20	$1	$4	–$4	$30	–$21
$8	$2	$16.60	$1	$8	$6	$11.60	$1	$1	–$4	$30	–$21
$8	$2	$18.60	$1	$8	$6	$12	$1	$1	–$4	$30	–$16
$8	$2	$21.30	$1	$8	$6	$12.40	$1	$1	–$8	$30	–$16
$8	$2	$25	$1	$8	$6	$13	$1	$1	–$8	$30	–$14
$8	$2	$30	$1	$8	$6	$13.60	$1	$1	–$8	$30	–$11
$8	$2	$37	$1	$8	$6	$14.40	$1				
$8	$2	$44	$1	$8	$6	$15.40	$1				
$8	$2	$60	$1	$8	$6	$16.60	$1				
$8	$2	$80	$1	$8	$6	$18	$1				
$8	$2	$120	$1	$8	$6	$20	$1				
$8	$2	$200	$1	$8	$6	$22	$1				
$8	$2	$340	$1	$8	$6	$26	$1				

Table 2: Summary Statistics of Energy Survey Questions

Homeowner	0.5379	Alternative Fuel Vehicle	0.1260
	(0.0110)		(0.0073)
	[2045]		[2040]
High Efficient Lights	0.5389	Energy Star Windows	0.2978
	(0.0110)		(0.0101)
	[2045]		[2045]
Installed Efficient Lights	0.727	Energy Star Refrigerator	0.5760
	(0.0099)		(0.0109)
	[2040]		[2045]
Thermostat	0.8714	Energy Star Freezer	0.2851
	(0.0074)		(0.0100)
	[2037]		[2045]
Programmable Thermostat	0.5673	Energy Star Dishwasher	0.3345
	(0.0118)		(0.0104)
	[1754]		[2045]
Energy Audit	0.2045	Energy Star Clothes Washer	0.4758
	(0.0089)		(0.0110)
	[2039]		[2045]
Audit Changes	0.7778	Energy Star Clothes Dryer	0.4386
	(0.0205)		(0.0110)
	[414]		[2045]
AC in home	0.8241	Energy Star Water Heater	0.3976
	(0.0084)		(0.0108)
	[2035]		[2045]
Energy Star AC	0.479	Energy Star Light Bulbs	0.6694
	(0.0123)		(0.0104)
	[1664]		[2045]
AC replaced	0.3143		
	(0.0114)		
	[1661]		

Notes: This table presents the mean value, the standard error of the mean (in parentheses), and the number of non-missing responses [in brackets] for each listed variable.

Table 3: Summary Statistics of Prospect Theory Parameters

	σ	α	λ
Mean	.8088	.7359	3.508
Median	.7500	.6000	1.613
Standard Error	.0109	.0077	.0855

Notes: This table presents the calculated values of the prospect theory preference parameters, calibrated based on individuals' responses to the survey lottery questions described above.

Table 4: Regression Results

	(1) High Efficient Lights	(2) Installed Efficient Lights	(3) Thermostat	(4) Programmable Thermostat	(5) Energy Audit
σ	-0.045*	-0.024	-0.029*	0.026	0.036*
	(0.024)	(0.021)	(0.016)	(0.026)	(0.019)
α	0.048	-0.019	0.029	-0.006	-0.042
	(0.032)	(0.029)	(0.020)	(0.035)	(0.026)
λ	-0.006*	-0.002	-0.003	-0.004	0.000
	(0.003)	(0.003)	(0.002)	(0.003)	(0.002)
N	1,843	1,838	1,835	1,578	1,838

	(6) Audit Changes	(7) AC	(8) AC Replaced	(9) Alternative Fuel Vehicle	(10) Any Energy Star Appliance
σ	-0.009	0.019	0.003	0.005	0.010
	(0.042)	(0.019)	(0.025)	(0.016)	(0.013)
α	0.039	0.036	0.043	0.009	-0.005
	(0.058)	(0.024)	(0.033)	(0.021)	(0.018)
λ	-0.009	0.000	-0.006*	-0.004**	0.001
	(0.006)	(0.002)	(0.003)	(0.002)	(0.002)
N	371	1,833	1,497	1,840	1,843

Notes: Heteroskedasticity-robust standard errors are in parentheses. Regressions also control for all of the demographic variables presented in Table A1 (plus income squared), and a constant. *** p<0.01, ** p<0.05, * p<0.1

Table 5: Regression Results Controlling for Time Preference

	(1) High Efficient Lights	(2) Installed Efficient Lights	(3) Thermostat	(4) Programmable Thermostat	(5) Energy Audit
σ	-0.045*	-0.025	-0.029*	0.025	0.039**
	(0.024)	(0.021)	(0.016)	(0.026)	(0.019)
α	0.048	-0.020	0.029	-0.006	-0.042
	(0.032)	(0.029)	(0.020)	(0.035)	(0.026)
λ	-0.006*	-0.002	-0.003	-0.004	-0.000
	(0.003)	(0.003)	(0.002)	(0.003)	(0.002)
δ	0.004	0.007	-0.011	0.012	-0.067
	(0.055)	(0.048)	(0.036)	(0.058)	(0.044)
β	-0.001	-0.001	-0.002	0.011	-0.026**
	(0.017)	(0.015)	(0.012)	(0.018)	(0.013)
N	1,843	1,838	1,835	1,578	1,838

	(6) Audit Changes	(7) AC	(8) AC Replaced	(9) Alternative Fuel Vehicle	(10) Any Energy Star Appliance
σ	-0.012	0.020	0.003	0.004	0.009
	(0.042)	(0.019)	(0.025)	(0.016)	(0.013)
α	0.039	0.037	0.042	0.008	-0.006
	(0.057)	(0.024)	(0.033)	(0.021)	(0.018)
λ	-0.009	-0.000	-0.006*	-0.004*	0.001
	(0.006)	(0.002)	(0.003)	(0.002)	(0.002)
δ	0.046	-0.031	-0.000	0.040	0.016
	(0.094)	(0.040)	(0.055)	(0.032)	(0.033)
β	-0.037	-0.002	-0.007	0.006	-0.002
	(0.037)	(0.013)	(0.016)	(0.010)	(0.010)
N	371	1,833	1,497	1,840	1,843

Notes: Heteroskedasticity-robust standard errors are in parentheses. Regressions also control for all of the demographic variables presented in Table A1 (plus income squared), and a constant. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 6: Non-Parametric "Switching Point" Regressions

	(1) High Efficient Lights	(2) Installed Efficient Lights	(3) Thermostat	(4) Program-mable Thermostat	(5) Energy Audit
Switching Point	-0.005	-0.004	-0.003	-0.005	0.001
	(0.004)	(0.004)	(0.003)	(0.005)	(0.003)
N	1,843	1,838	1,835	1,578	1,838
	(6) Audit Changes	**(7) AC**	**(8) AC Replaced**	**(9) Alternative Fuel Vehicle**	**(10) Any Energy Star Appliance**
Switching Point	-0.018**	-0.001	-0.007	-0.005**	0.001
	(0.008)	(0.003)	(0.004)	(0.003)	(0.002)
N	371	1,833	1,497	1,840	1,843

Notes: Heteroskedasticity-robust standard errors are in parentheses. Regressions also control for all of the demographic variables presented in Table 2 (plus income squared), and a constant. *** p<0.01, ** p<0.05, * p<0.1

Table 7: Numerical Simulation Results

α	λ	e^*, consumer with EUT %	e^*, consumer with PT %	s^*, consumer with EUT %	s^*, consumer with prob. weighting only %	s^*, consumer with loss aversion only %	s^*, consumer with PT %
Base Case							
0.75	2	89.87	28.00	25.73	59.08	135.94	176.82
Varying λ							
0.75	0.8	89.87	91.10	25.73	59.08	-11.16	17.99
0.75	1	89.87	74.96	25.73	59.08	19.34	52.02
0.75	1.5	89.87	45.67	25.73	59.08	83.98	122.21
0.75	2	89.87	28.00	25.73	59.08	135.94	176.82
0.75	2.5	89.87	17.53	25.73	59.08	178.63	220.51
Varying α							
0.25	2	89.87	8.05	25.73	154.19	135.94	280.78
0.5	2	89.87	16.72	25.73	100.79	135.94	224.56
0.75	2	89.87	28.00	25.73	59.08	135.94	176.82
1	2	89.87	40.74	25.73	25.73	135.94	135.94
1.25	2	89.87	54.09	25.73	-1.75	135.94	100.26

Notes: Other parameter values and functional forms are described in Appendix D. Energy efficiency values e^* are expressed as a percentage of the first-best level. Subsidy values s^* are expressed as a percentage of the cost of energy efficiency at the first-best level $c(e^*)$.

Appendix – For Online Publication

Appendix A: Comparative Statics of Theoretical Model

Here I provide the details of the comparative static results presented in Section II of the text. First, I demonstrate that $\frac{\partial e}{\partial \lambda} < 0$. Call the first-order condition F:

$$F \equiv \big(\pi(1-p)\big)\left(\lambda\sigma\big(c(e)\big)^{\sigma-1}\right)\big(-c'(e)\big) + \pi(p)\sigma\big(b(e)-c(e)\big)^{\sigma-1}\big(b'(e)-c'(e)\big) = 0$$

The implicit function theorem tells us

$$\frac{\partial e}{\partial \lambda} = \frac{-\,{}^{\partial F}/_{\partial \lambda}}{{}^{\partial F}/_{\partial e}}$$

The denominator of this expression is the second-order condition of the optimization problem, which is assumed to be negative to ensure an interior maximum. The numerator is $\frac{\partial F}{\partial \lambda} = \big(1-\pi(p)\big)\sigma\big(c(e)\big)^{\sigma-1}\big(-c'(e)\big) < 0$. Therefore, $\frac{\partial e}{\partial \lambda} < 0$.

Second, I solve for the effect of α on e. From the implicit function theorem:

$$\frac{\partial e}{\partial \alpha} = \frac{-\,{}^{\partial F}/_{\partial \alpha}}{{}^{\partial F}/_{\partial e}}$$

The numerator in this expression (excluding the minus sign) is $\frac{\partial F}{\partial \alpha} = \frac{\partial \pi(1-p)}{\partial \alpha}\left[\lambda\sigma\big(c(e)\big)^{\sigma-1}\big(-c'(e)\big)\right] + \frac{\partial \pi(p)}{\partial \alpha}\left[\sigma\big(b(e)-c(e)\big)^{\sigma-1}\big(b'(e)-c'(e)\big)\right]$. The expression multiplying $\frac{\partial \pi(1-p)}{\partial \alpha}$ is negative, and the expression multiplying $\frac{\partial \pi(p)}{\partial \alpha}$ is positive. Given the Prelec (1998) specification of the probability weighting function, $\pi(p) = 1/\exp\left[\ln\left(\frac{1}{p}\right)\right]^{\alpha}$, the derivative $\frac{\partial \pi(p)}{\partial \alpha} = -\pi(p)\left[\ln\left(\frac{1}{p}\right)\right]^{\alpha}\ln\left[ln\left(\frac{1}{p}\right)\right]$. This is positive whenever $p > \frac{1}{e}$ and negative whenever $p < \frac{1}{e}$. Likewise, $\frac{\partial \pi(1-p)}{\partial \alpha}$ is positive whenever $1-p > \frac{1}{e}$ and negative whenever $1-p < \frac{1}{e}$.

Simple arithmetic manipulation of these conditions leads to three cases. First, when $p < \frac{1}{e}$ (so that $1-p$ must be greater than $\frac{1}{e}$), then $\frac{\partial \pi(p)}{\partial \alpha} < 0$ and $\frac{\partial \pi(1-p)}{\partial \alpha} > 0$, so that $\frac{\partial e}{\partial \alpha} < 0$. Second, when $1-p < \frac{1}{e}$ (so that p must be greater than $\frac{1}{e}$), then $\frac{\partial \pi(p)}{\partial \alpha} > 0$ and $\frac{\partial \pi(1-p)}{\partial \alpha} < 0$, so that $\frac{\partial e}{\partial \alpha} > 0$. Third, when $\frac{1}{e} < p < 1-\frac{1}{e}$, then $\frac{\partial \pi(p)}{\partial \alpha} > 0$ and $\frac{\partial \pi(1-p)}{\partial \alpha} > 0$, so the sign of $\frac{\partial e}{\partial \alpha}$ is ambiguous and depends on the magnitudes of the other terms in the expression above for $\frac{\partial F}{\partial \alpha}$.

Appendix B: Derivations of Optimal Subsidies

Here I provide derivations/proofs of the expressions for optimal subsidies presented in Section IV of the text.

The planner's problem is to choose a policy s to maximize expected utility conditional on the consumer's response to the policy. The lump-sum tax T is constrained to just equal subsidy expenditures and thus not modeled as a choice variable.

Externality Only

In this case, presented in subsection IV.A., the consumer's first-order condition is

$$(1-p)U'\big(w-c(e^*)\big)\big(-c'(e^*)+s\big)+pU'\big(w+b(e^*)-c(e^*)\big)\big(b'(e^*)-c'(e^*)+s\big)=0$$

The planner's problem is thus

$$\max_{e,s}(1-p)U\big(w-c(e)\big)+p\big[U\big(w+b(e)-c(e)\big)+b_{ext}(e)\big]$$

such that the consumer's first-order condition holds. The subsidy and lump-sum tax need not appear in the planner's maximand since they are constrained to exactly offset and thus do not affect social welfare. The planner's problem can be written as a Lagrangian:

$$\begin{aligned}&(1-p)U\big(w-c(e)\big)+p\big[U\big(w+b(e)-c(e)\big)+b_{ext}(e)\big]\\ &\qquad+\lambda\big[(1-p)U'\big(w-c(e)\big)\big(-c'(e)+s\big)+pU'\big(w+b(e)-c(e)\big)\big(b'(e)-c'(e)+s\big)\big]\end{aligned}$$

The first-order conditions to this Lagrangian are, with respect to e, s, and λ, respectively:

$$(1-p)U'\big(w-c(e)\big)\big(-c'(e)\big)+p\big[U'\big(w+b(e)-c(e)\big)\big(b'(e)-c'(e)\big)+b'_{ext}(e)\big]+\lambda[SOC]=0$$

$$\lambda\big[(1-p)U'\big(w-c(e)\big)+pU'\big(w+b(e)-c(e)\big)\big]=0$$

$$(1-p)U'\big(w-c(e)\big)\big(-c'(e)+s\big)+pU'\big(w+b(e)-c(e)\big)\big(b'(e)-c'(e)+s\big)=0$$

Here the solution to the planner's problem for energy efficiency is simply denoted as e. The term in brackets in the first equation labeled SOC is the second derivative of the consumer's maximand with respect to e, i.e. part of the second-order condition of the consumer's problem. For brevity (it involves relatively complicated expressions of second derivatives) it is not reported here. Also, it is unnecessary to report, since the second equation above implies that $\lambda=0$ (because $U'>0$ and $p\in(0,1)$). Therefore, the SOC term drops out of the first first-order condition, and it then becomes identical to the expression describing the first-best outcome. That is, policy can achieve the first-best. The remaining two first-order conditions can be solved for s (substituting in for $(1-p)U'\big(w-c(e)\big)\big(-c'(e)\big)$) to arrive at the expression in the text.

Externality and Probability Weighting

In this case, presented in subsection IV.B., the consumer's first-order condition is

$$\pi(1-p)U'\big(w-c(e^*)\big)(-c'(e^*)+s)+\pi(p)U'\big(w+b(e^*)-c(e^*)\big)(b'(e^*)-c'(e^*)+s)=0$$

The Lagrangian describing the planner's problem is

$$\begin{aligned}(1-p)U\big(w-c(e)\big)+p\big[U\big(w+b(e)-c(e)\big)+b_{ext}(e)\big]&\\ +\lambda\big[\pi(1-p)U'\big(w-c(e)\big)(-c'(e)+s)&\\ +\pi(p)U'\big(w+b(e)-c(e)\big)(b'(e)-c'(e)+s)\big]&\end{aligned}$$

The three first-order conditions for the Lagrangian are identical to the three conditions in the previous subsection of this appendix, except replacing the probabilities p and $1-p$ with the weighted probabilities $\pi(p)$ and $\pi(1-p)$, respectively, in the second and third condition and in the expression SOC. It remains true that the second first-order condition implies that $\lambda=0$, and thus that the first-best can be achieved. The first and third conditions can be solved for s to yield the expression in the text.

Externality and Loss Aversion

In this case, presented in subsection IV.C., the consumer's first-order condition is

$$(1-p)v'\big(-c(e^*)\big)(-c'(e^*)+s)+pv'\big(b(e^*)-c(e^*)\big)(b'(e^*)-c'(e^*)+s)=0$$

The Lagrangian describing the planner's problem is

$$\begin{aligned}(1-p)U\big(w-c(e)\big)+p\big[U\big(w+b(e)-c(e)\big)+b_{ext}(e)\big]&\\ +\lambda\big[(1-p)v'\big(-c(e)\big)(-c'(e)+s)+pv'\big(b(e)-c(e)\big)(b'(e)-c'(e)+s)\big]&\end{aligned}$$

The three first-order conditions are

$$(1-p)U'\big(w-c(e)\big)\big(-c'(e)\big)+p\big[U'\big(w+b(e)-c(e)\big)\big(b'(e)-c'(e)\big)+b'_{ext}(e)\big]+\lambda[SOC]=0$$

$$\lambda\big[(1-p)v'\big(-c(e)\big)+pv'\big(b(e)-c(e)\big)\big]=0$$

$$(1-p)v'\big(-c(e^*)\big)(-c'(e^*)+s)+pv'\big(b(e^*)-c(e^*)\big)(b'(e^*)-c'(e^*)+s)=0$$

As in the previous cases, the second condition implies that $\lambda=0$, that the the SOC term drops out of the first condition, and the first and third conditions can be solved for s to yield the expression in the text, substituting in the notation v'_{loss}, v'_{gain}, etc.

Externality and Prospect Theory

In this case, presented in subsection IV.D., the consumer's first-order condition is

$$\pi(1-p)v'\big(-c(e^*)\big)(-c'(e^*)+s)+\pi(p)v'\big(b(e^*)-c(e^*)\big)(b'(e^*)-c'(e^*)+s)=0$$

The Lagrangian describing the planner's problem is

$$\begin{aligned}&(1-p)U\big(w-c(e)\big)+p\big[U\big(w+b(e)-c(e)\big)+b_{ext}(e)\big]\\ &\qquad+\lambda\big[\pi(1-p)v'\big(-c(e)\big)(-c'(e)+s)+\pi(p)v'\big(b(e)-c(e)\big)(b'(e)-c'(e)+s)\big]\end{aligned}$$

The three first-order conditions are identical to the three conditions from the previous subsection, except replacing the weighted probabilities for the true probabilities. The second condition implies $\lambda = 0$ once again, so that the first and third conditions can be solved for s.

State-Dependent Subsidies

In this case, presented in subsection IV.E., the consumer's first-order condition is

$$(1-p)U'\big(w-c(e^*)\big)(-c'(e^*)+s_{LO})+pU'\big(w+b(e^*)-c(e^*)\big)(b'(e^*)-c'(e^*)+s_{HI})=0$$

The planner now has an additional choice variable:

$$\max_{e,s_{LO},s_{HI}}(1-p)U\big(w-c(e)\big)+p\big[U\big(w+b(e)-c(e)\big)+b_{ext}(e)\big]$$

such that the consumer's first-order condition holds. The planner's problem can be written as a Lagrangian:

$$\begin{aligned}&(1-p)U\big(w-c(e)\big)+p\big[U\big(w+b(e)-c(e)\big)+b_{ext}(e)\big]\\ &\qquad+\lambda\big[(1-p)U'\big(w-c(e)\big)(-c'(e)+s_{LO})\\ &\qquad+pU'\big(w+b(e)-c(e)\big)(b'(e)-c'(e)+s_{HI})\big]\end{aligned}$$

Now there are four first-order conditions to this Lagrangian, with respect to e, s_{LO}, s_{HI}, and λ, respectively:

$$(1-p)U'\big(w-c(e)\big)\big(-c'(e^*)\big)+p\big[U'\big(w+b(e)-c(e)\big)\big(b'(e)-c'(e)\big)+b'_{ext}(e)\big]+\lambda[SOC]=0$$

$$\lambda(1-p)U'\big(w-c(e)\big)=0$$

$$\lambda pU'\big(w+b(e)-c(e)\big)=0$$

$$(1-p)U'\big(w-c(e)\big)(-c'(e)+s_{LO})+pU'\big(w+b(e)-c(e)\big)(b'(e)-c'(e)+s_{HI})=0$$

Both the second and third conditions imply that $\lambda = 0$. This leaves two remaining conditions (the first and fourth) but three remaining unknowns (e, s_{LO}, and s_{HI}), which implies that the problem is over-determined and there are a continuum of solutions for the subsidies.

For the first solution presented in the text, assume that $s_{LO} = 0$. Then, solve the remaining two first-order conditions for s_{HI} to arrive at the expression for s_{HI} in the text. For the second solution, assume that $s_{LO} = c'(e)$, and solve for s_{HI}.

Appendix C: Additional Specifications

Heterogeneity

I consider a simple form of heterogeneity. There are just two consumers. One maximizes according to expected utility theory, while the other maximizes according to prospect theory. The positive externality market failure applies to both consumers, but the market failure from prospect theory only applies to the second consumer. The planner now has two scalars to achieve to meet the first-best allocation: the energy efficiency investments of consumer 1 and of consumer 2. Therefore, under this specification of heterogeneity, a policy with state-dependent subsidies s_{LO} and s_{HI} will uniquely achieve the first-best outcome.[46]

Formally, let consumer 1 be the expected utility maximizer and consumer 2 be the prospect theory maximizer. The first-best outcome is the solution to:

$$\max_{e_1,e_2} q\left[(1-p)U\big(w-c(e_1)\big)+p\big[U\big(w+b(e_1)-c(e_1)\big)+b_{ext}(e_1)\big]\right]$$
$$+(1-q)\left[(1-p)U\big(w-c(e_2)\big)+p\big[U\big(w+b(e_2)-c(e_2)\big)+b_{ext}(e_2)\big]\right]$$

The parameter q represents the weighting in social welfare placed on consumer 1; alternatively, there are a continuum of consumers and q is the fraction that are expected utility maximizers. The utility function, cost function, internal and external benefit functions, and wealth are allowed to differ across the two consumer types, though for simplicity here and below I omit subscripts (e.g. $b(e_1)$ and $b(e_2)$ more formally are $b_1(e_1)$ and $b_2(e_2)$, respectively).

The planner's problem is to choose e_1, e_2, s_{LO}, and s_{HI} to maximize weighted expected utility across the two consumers, constrained by the consumers' first-order conditions describing their choices in response to the subsidies. The first consumer maximizes according to expected utility theory so has a first-order condition equivalent to that in subsection IV.A. (though responding to state-dependent subsidies). The second consumer maximizes according to prospect theory so has the same first-order condition as in subsection IV.E. The planner's problem can be expressed as a Lagrangian. As in the previous cases, the first-order conditions imply that the Lagrangian multiplier is zero, so that the first-best can be achieved. The remaining first-order conditions can be used to solve for the subsidies. The optimal set of subsidies is:

$$s_{LO}=\frac{1}{\det(A_1)}p\pi(p)v'_{gain}\left[b'_{ext}(e_1)-\frac{U'_{1,gain}}{U'_{2,gain}}b'_{ext}(e_2)\right]+\frac{\det(A_2)}{\det(A_1)}\frac{U'_{1,gain}}{U'_{2,gain}}c'(e_2)$$

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[46] A trivial policy that includes a subsidy targeted to each consumer type would also achieve the first best by simply replicating the results from previous sections.

$$s_{HI} = \frac{1}{\det(A_1)}\left[-p\pi(1-p)v'_{loss}b'_{ext}(e_1) + (1-p)\pi(p)v'_{gain}\frac{U'_{1,gain}}{U'_{2,gain}}b'_{ext}(e_2)\right] - \frac{\det(A_2)}{\det(A_1)}\frac{(1-p)}{p}\frac{U'_{1,loss}}{U'_{2,gain}}c'(e_2)$$

These expressions include $\det(A_1) \equiv (1-p)U'_{1,loss}\pi(p)v'_{gain} - pU'_{1,gain}\pi(1-p)v'_{loss}$ and $\det(A_2) \equiv (1-p)U'_{2,loss}\pi(p)v'_{gain} - pU'_{2,gain}\pi(1-p)v'_{loss}$. These expressions are complicated and difficult to interpret, but both the low-state and high-state subsidies include terms that address the externalities ($b'_{ext}(e_1)$ and $b'_{ext}(e_2)$) and terms that address consumer's 2's prospect theory maximization.

These expressions can be slightly simplified by assuming that the utility functions, cost functions, benefit functions, and wealth levels of the two types are identical to each other. The only difference between the two consumers is that consumer 2 exhibits prospect theory. This implies that the two optimal energy efficiency levels are identical to each other ($e_1 = e_2 \equiv e$), although the planner still requires two instruments to achieve them. It also implies that $\det(A_1) = \det(A_2)$. The optimal set of subsidies in this case is:

$$s_{LO} = c'(e)$$

$$s_{HI} = \frac{1}{\det(A_1)}\left[(1-p)\pi(p)v'_{gain} - p\pi(1-p)v'_{loss}\right]b'_{ext}(e) - \frac{(1-p)}{p}\frac{U'_{loss}}{U'_{gain}}c'(e)$$

The first term in s_{HI} is approximately $b'_{ext}(e)$ since the term in brackets is approximately equal to $\det(A_1)$. This term represents the correction for the externality. The remaining term in s_{HI}, as well as the entire expression for s_{LO}, represent the correction for consumer 2's prospect theory behavior.

This policy is analogous to the second constrained state-dependent subsidy that was presented in section IV.E., in which the low-state subsidy is fixed at the marginal cost of energy efficiency $c'(e)$. The first term in s_{HI} is analogous to the first term in that earlier expression, though the factor in front of $b'_{ext}(e)$ is modified to account for the fact that only one consumer exhibits prospect theory. The second term here is identical to the second term from that section.

Multiple States

Next, I suppose that there more than just two (low and high) possible states. I use the cumulative prospect theory model developed by Tversky and Kahneman (1992).[47] Suppose that there are $n + m$ possible states of the world, where m states are losses (net gains from energy efficiency

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[47] When there are only two outcomes (one gain and one loss), cumulative prospect theory reduces to ordinary prospect theory.

investment are negative) and n states are gains. Denote the net private gains, not including the externality, of energy efficiency level e in state i characterized by random variable θ_i as $x_i(\theta_i) \equiv b(e;\theta_i) - c(e)$. Arrange all possible states in order from largest net losses (state $-m$) to largest net gains (state n), where the index i is negative for losses and positive for gains. That is, $i \in \{-m, \dots, n\}$. Assume that the choice of e does not affect the ordering or the sign of the outcome. The value of a prospect x_i is $v(x_i)$. Denote the decision weight given to state i based on its cumulative probability, relative to the reference point, to be π_i^- for losses and π_i^+ for gains. Following Tversky and Kahneman (1982), if p_i is the objective probability of state i, then for losses $\pi_i^- = w^-(p_{-m} + \cdots + p_i) - w^-(p_{-m} + \cdots + p_{i-1})$ for $1 - m \leq i \leq 0$ and $\pi_{-m}^- = w^-(p_{-m})$, and for gains $\pi_i^+ = w^+(p_i + \cdots + p_n) - w^+(p_{i+1} + \cdots + p_n)$ for $0 \leq i \leq n-1$ and $\pi_n^+ = w^+(p_n)$. The functions w^- and w^+ are capacity functions, which are strictly increasing functions from the unit interval to itself.

Suppose there is an externality that is state-dependent, denoted by $b_{ext,i}(e)$. When this is positive, it represents a positive externality, as in the previous model, though it could be negative for some states. The first-best outcome is given by the solution to

$$\max_e \sum_{i=-m}^{n} p_i\left[U\big(w + x_i(e)\big) + b_{ext,i}(e)\right]$$

The planner can levy a subsidy s per unit of energy efficiency e, coupled with a revenue-neutral lump-sum tax T. Under this policy, the consumer's optimization problem is

$$\max_e \sum_{i=-m}^{-1} \pi_i^- v(x_i(e) + se - T) + \sum_{i=0}^{n} \pi_i^+ v(x_i(e) + se - T)$$

By comparing the first-order condition characterizing the first-best outcome and the first-order condition characterizing the consumer's solution, it can be shown that the following subsidy induces the first-best:

$$s = \frac{1}{E[v']}\left\{\frac{\pi_k^+ v_k'}{p_k U_k'} \sum_{i=-m}^{n} p_i b_{ext,i}'(e^{opt}) - \pi_k^+ v_k' \sum_{i=-m}^{-1} \left(\frac{\pi_i^- v_i'}{\pi_k' v_k'} - \frac{p_i U_i'}{p_k U_k'}\right) x_i'(e^{opt}) \right.$$
$$\left. - \pi_k^+ v_k' \sum_{i=0; i\neq k}^{n} \left(\frac{\pi_i^+ v_i'}{\pi_k' v_k'} - \frac{p_i U_i'}{p_k U_k'}\right) x_i'(e^{opt})\right\}$$

Here $v_i' \equiv v'\big(x_i(e^{opt})\big)$, $U_i' \equiv U'\big(w + x_i(e^{opt})\big)$, and $E[v'] \equiv \sum_{i=-m}^{-1} \pi_i^- v_i' + \sum_{i=0}^{n} \pi_i^+ v_i'$. This is expressed in terms of an arbitrary excluded gain state $k \in \{1, \dots, n\}$; any gain state can be used for k. The first term in the curly brackets is the term that addresses the externality and is based on the expected value of the externality. The remaining two terms account for the probability weighting (comparing π_i to p_i) and the reference-dependent loss-averse preferences (comparing v_i' to U_i'). These terms are a generalization of the first part of the expression for s from section IV.D, where there are just two possible states.

Appendix D: Details of Numerical Simulations

I impose the following functional forms and parameter values, described in Appendix Table A7. The functional forms for utility, the prospect value function, and the probability weighting function are identical to those used in the comparative statics exercises in Section II and Section IV.F. These are standard functional forms in the prospect theory literature (e.g. Tanaka et al. 2010). The functions describing the cost and benefits (internal and external) of energy efficiency are arbitrarily chosen to be power functions, where costs are convex and benefits are concave. The coefficient of 0.01 in front of the external benefit function is calibrated to ensure an interior solution. The probability of achieving the energy savings p is 0.75. This, in addition to the assumption that the weighting parameter α in the probability weighting function is less than one, assures that consumers are overweighting the relatively small probability that the cost savings are unrealized. (In fact, while that probability $1 - p = 0.25$, the weighting probability is $\pi(1 - p) = 0.279$.)

The simulations are solved in Matlab; code is available upon request. Optimal subsidies are found both by using the first-order conditions presented in the paper and by numerically maximizing the relevant optimization function.

Appendix Table A1: Summary Statistics of Demographic Survey Questions

Age	44.92
	(0.3697)
	[2045]
Female	0.4995
	(0.0111)
	[2042]
White	0.7619
	(0.0094)
	[2045]
High School Grad	0.3065
	(0.0102)
	[2039]
Some College	0.1986
	(0.0088)
	[2039]
College Grad	0.2673
	(0.0098)
	[2039]
Postgrad Degree	0.0932
	(0.0064)
	[2039]
Married	0.4789
	(0.0111)
	[2040]
1 or 2 Children	0.3999
	(0.0109)
	[2028]
3 or more Children	0.2342
	(0.0094)
	[2028]
Income	90000
	(27000)
	[1868]

Notes: This table presents the mean value, the standard error of the mean (in parentheses), and the number of non-missing responses [in brackets] for each listed variable.

Appendix Table A2: Regression Results – Homeowners Only

	(1) High Efficient Lights	(2) Installed Efficient Lights	(3) Thermostat	(4) Programmable Thermostat	(5) Energy Audit
σ	-0.022	-0.020	-0.015	0.015	0.055**
	(0.032)	(0.026)	(0.017)	(0.032)	(0.027)
α	0.042	-0.033	0.016	-0.009	-0.042
	(0.042)	(0.036)	(0.021)	(0.044)	(0.037)
λ	-0.004	-0.005	-0.003	-0.002	0.001
	(0.004)	(0.003)	(0.002)	(0.004)	(0.003)
N	999	997	992	908	995
	(6) Audit Changes	(7) AC	(8) AC Replaced	(9) Alternative Fuel Vehicle	(10) Any Energy Star Appliance
σ	0.013	0.015	-0.024	-0.009	0.003
	(0.048)	(0.021)	(0.034)	(0.023)	(0.013)
α	-0.017	0.041	0.080*	0.019	-0.011
	(0.064)	(0.026)	(0.046)	(0.031)	(0.017)
λ	-0.007	-0.002	-0.004	-0.005*	0.002
	(0.006)	(0.003)	(0.004)	(0.003)	(0.001)
N	238	992	866	997	999

Notes: Heteroskedasticity-robust standard errors are in parentheses. Regressions also control for all of the demographic variables presented in Table A1 (plus income squared), and a constant. *** p<0.01, ** p<0.05, * p<0.1

Appendix Table A3: Regression Results – Homeowners with at least 3 Years Tenure Only

	(1) High Efficient Lights	(2) Installed Efficient Lights	(3) Thermostat	(4) Programmable Thermostat	(5) Energy Audit
σ	-0.025	-0.019	-0.018	0.017	0.043
	(0.034)	(0.028)	(0.019)	(0.035)	(0.029)
α	0.064	-0.006	0.003	-0.005	-0.039
	(0.046)	(0.040)	(0.022)	(0.048)	(0.040)
λ	-0.004	-0.005	-0.001	-0.003	0.002
	(0.004)	(0.003)	(0.002)	(0.004)	(0.004)
N	855	853	848	777	851

	(6) Audit Changes	(7) AC	(8) AC Replaced	(9) Alternative Fuel Vehicle	(10) Any Energy Star Appliance
σ	0.034	0.018	-0.036	-0.006	0.002
	(0.050)	(0.023)	(0.037)	(0.025)	(0.014)
α	0.036	0.028	0.120**	0.027	-0.005
	(0.069)	(0.030)	(0.052)	(0.033)	(0.018)
λ	-0.006	-0.001	-0.008*	-0.005*	0.001
	(0.006)	(0.003)	(0.005)	(0.003)	(0.002)
N	204	848	731	853	855

Notes: Heteroskedasticity-robust standard errors are in parentheses. Regressions also control for all of the demographic variables presented in Table A1 (plus income squared), and a constant. *** p<0.01, ** p<0.05, * p<0.1

Appendix Table A4: Regression Results – Control for Inattention Measure

	(1) High Efficient Lights	(2) Installed Efficient Lights	(3) Thermostat	(4) Programmable Thermostat	(5) Energy Audit
σ	-0.046*	-0.026	-0.029*	0.026	0.036*
	(0.024)	(0.021)	(0.016)	(0.026)	(0.019)
α	0.049	-0.019	0.029	-0.006	-0.042
	(0.032)	(0.029)	(0.019)	(0.035)	(0.026)
λ	-0.006*	-0.002	-0.002	-0.004	0.000
	(0.003)	(0.003)	(0.002)	(0.003)	(0.002)
Contradiction Indicator	-0.019	-0.024	0.005	0.003	-0.009
	(0.024)	(0.021)	(0.016)	(0.025)	(0.019)
N	1,843	1,838	1,835	1,578	1,838

	(6) Audit Changes	(7) AC	(8) AC Replaced	(9) Alternative Fuel Vehicle	(10) Any Energy Star Appliance
σ	-0.009	0.019	0.001	0.006	0.011
	(0.042)	(0.019)	(0.025)	(0.016)	(0.013)
α	0.039	0.036	0.044	0.008	-0.006
	(0.058)	(0.024)	(0.033)	(0.021)	(0.018)
λ	-0.009	-0.000	-0.006**	-0.004*	0.001
	(0.006)	(0.002)	(0.003)	(0.002)	(0.002)
Contradiction Indicator	-0.000	-0.006	-0.034	0.014	0.022*
	(0.044)	(0.018)	(0.025)	(0.016)	(0.013)
N					

Notes: Heteroskedasticity-robust standard errors are in parentheses. Regressions also control for all of the demographic variables presented in Table A1 (plus income squared), and a constant. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Appendix Table A5: Regression Results – Exclude Inattentive Respondents

	(1) High Efficient Lights	(2) Installed Efficient Lights	(3) Thermostat	(4) Programmable Thermostat	(5) Energy Audit
σ	-0.059	0.028	-0.026	0.019	0.033
	(0.037)	(0.031)	(0.025)	(0.039)	(0.031)
α	-0.038	-0.040	0.052	-0.063	-0.087**
	(0.053)	(0.045)	(0.034)	(0.058)	(0.042)
λ	-0.008*	-0.004	-0.001	-0.005	-0.004
	(0.005)	(0.004)	(0.003)	(0.005)	(0.004)
N	716	714	713	613	714
	(6) Audit Changes	(7) AC	(8) AC Replaced	(9) Alternative Fuel Vehicle	(10) Any Energy Star Appliance
σ	0.031	0.043	-0.013	-0.021	-0.013
	(0.060)	(0.029)	(0.039)	(0.024)	(0.020)
α	-0.011	0.011	0.083	-0.001	0.038
	(0.085)	(0.038)	(0.055)	(0.032)	(0.026)
λ	-0.025***	0.002	-0.007	-0.007***	0.001
	(0.010)	(0.003)	(0.005)	(0.003)	(0.003)
N	151	711	592	714	716

Notes: Heteroskedasticity-robust standard errors are in parentheses. Regressions also control for all of the demographic variables presented in Table A1 (plus income squared), and a constant. *** p<0.01, ** p<0.05, * p<0.1

Appendix Table A6: Regression Results – Hypothetical Water Heater Loss Aversion Indicator

	(1) High Efficient Lights	(2) Installed Efficient Lights	(3) Thermostat	(4) Programmable Thermostat	(5) Energy Audit
Loss Averse	-0.036	0.009	0.026	0.046	0.097***
	(0.030)	(0.027)	(0.020)	(0.032)	(0.026)
N	1,813	1,808	1,805	1,556	1,808
	(6) Audit Changes	(7) AC	(8) AC Replaced	(9) Alternative Fuel Vehicle	(10) Any Energy Star Appliance
Loss Averse	-0.181***	0.003	0.081**	0.011	-0.024
	(0.055)	(0.023)	(0.032)	(0.020)	(0.018)
N	361	1,803	1,474	1,810	1,813

Notes: Heteroskedasticity-robust standard errors are in parentheses. Regressions also control for all of the demographic variables presented in Table A1 (plus income squared), and a constant. *** p<0.01, ** p<0.05, * p<0.1

Appendix Table A7: Functional Forms and Parameter Values of Numerical Simulations

Parameter/Function	Functional Form	Parameter Value
Consumer utility	$U(c) = c^\sigma$	$\sigma = 0.6$
Prospect value function	$v(x) = \begin{cases} x^\sigma & if\ x \geq 0 \\ -\lambda(-x)^\sigma & if\ x < 0 \end{cases}$	$\lambda = 2$
Probability weighting	$\pi(p) = 1/\exp\left[\ln\left(\frac{1}{p}\right)\right]^\alpha$	$\alpha = 0.75$
Cost of energy efficiency	$c(e) = e^\gamma$	$\gamma = 1.2$
Internal benefit of energy efficiency	$b(e) = e^\zeta$	$\zeta = 0.8$
External benefit of energy efficiency	$b_{ext}(e) = 0.01e^\xi$	$\xi = 0.6$
Wealth		$w = 10$
Probability of achieving energy cost saving		$p = 0.75$