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Accelerating demand for residential solar photovoltaics: Can simple framing strategies increase consumer interest?

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ABSTRACT

Household adoption of energy-efficient and renewable energy technologies has the potential to significantly reduce emissions from electricity generation. High upfront costs, however, are often a barrier to adoption, even when costs may be offset by future energy savings. Through a series of randomized experiments, we examine whether framing strategies grounded in behavioral economics and psychology can be used to increase the financial appeal of such products. Using mock ads for residential solar photovoltaics (PV), we test four frames: gain/loss framing, temporal framing, varied savings amounts, and simple vs. detailed savings calculations. Overall, we find that reframing the financial benefits of PV does not greatly influence the appeal of solar or the likelihood to respond to the mock ads. Instead, underlying consumer motivations and predispositions (i.e., perceived social support, consumer innovativeness, and personal pro-environmental norms) are the primary factors driving interest in adopting solar. Our findings suggest that tailoring messages to targeted consumer segments may be more effective than attempts to market the financial benefits of PV to broad audiences. The results also contribute to behavioral economics and psychology research by identifying contexts under which the gain/loss framing bias and the present/future framing bias may not apply.

1. Introduction

In the United States, renewable energy technologies such as residential photovoltaics (PV) have the potential to significantly reduce greenhouse gas emissions if widely adopted. Prior assessments have determined that there is sufficient suitable roof space for solar to provide 39% of the nation's electricity demand (Gagnon et al., 2016). For residential solar to become cost-competitive with retail electricity, however, the U.S. Department of Energy projects that a 70% reduction in residential PV prices, relative to 2010 prices, to $1.60/Wdc is needed (Solar Energy Technologies Office, 2016). To date, most upfront cost reductions in PV installation have occurred on the module and hardware side. The costs of acquiring new customers, which as of 2016 comprise roughly $2500 of each sale or 10–20% of the system price (Mond, 2017), have scarcely changed since 2010.

The process of selling solar to consumers, despite strong market growth, remains relatively understudied. While several researchers have looked at factors such as the role of peer effects on consumer decision-making and adoption (Bollinger and Gillingham, 2012; Graziano and Gillingham, 2015; Palm, 2017; Rai and Robinson, 2013) and the types of events that spark initial interest in PV (Rai et al., 2016; Schelly, 2014; Sigrin et al., 2015), less is known about how to cost-effectively attract consumer attention. Prior research suggests that perceived financial benefits are a significant driver of interest in (Korcaj et al., 2015; Wolske et al., 2017), and ultimately adoption of PV (Drury et al., 2012; Kwan, 2012; Sigrin et al., 2015). It is unclear, though, whether the average consumer sees PV as financially advantageous. Given the relative novelty of PV—and of third party ownership models that allow homeowners to have solar panels without high upfront costs—many consumers may be unaware of available financing and incentives and, thus, assume that PV is not within their reach.

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The challenge of how to capture consumers' attention when upfront costs are perceived to be high is not unique to residential solar. Most energy-efficient goods require paying a price premium now for monetary savings that may pay off many years in the future. Other work has shown that people tend to overlook life cycle costs and savings when evaluating goods such as energy-efficient appliances (Gately, 1980; Hausman, 1979; Ruderman et al., 1987) and fuel-efficient vehicles (Allcott and Knittel, 2017; Lane and Potter, 2007; Rezvani et al., 2015). Because it is unclear why customers are making these seemingly "irrational" decisions not to invest in energy-efficient items (Frederiks et al., 2015; Gillingham and Palmer, 2014), simple changes in the way that solar is presented to customers—based on principles from psychology and behavioral economics—may change their attitudes towards adopting solar.

This paper presents the results of three online survey experiments designed to test the effectiveness of simple and, therefore, potentially cost-effective strategies for reframing the financial benefits of PV to be more attractive to consumers. In our first two studies, we test (1) whether mock PV ads are more persuasive when they describe the financial gains of going solar versus the money lost by not going solar, and (2) whether these gains/losses are more compelling when framed on different time scales (every month, every year, or over the total lifetime of the panels). Based on insights from these two studies, our third study explores whether reactions to the ad are a function of the amount of savings claimed and the level of detail provided about how the savings were calculated. Without details on how the savings are estimated, consumers may be skeptical of high savings claims that sound "too good to be true," especially since PV is a relatively novel and uncommon good. In each of our studies, we also compare the relative influence of the experimental conditions to that of respondent characteristics. To keep customer acquisition costs low, solar providers must weigh the tradeoffs of marketing PV broadly with a few common ads (such as those tested in our experiments) against those of targeting specific consumer segments using multiple tailored messages. Across our three studies, we find that simple framing strategies—which in theory should influence the appeal of PV—have little effect. Rather, characteristics of the individual, such as pro-environmental norms and consumer innovativeness, as well as perceptions of social support for going solar have a far greater impact on how individuals respond.

2. Studies 1 and 2: do loss frames and different temporal scales make PV more financially appealing?

Research from behavioral economics and psychology suggests that certain message framing strategies may be more effective than others. According to prospect theory (DellaVigna, 2009; Kahneman and Tversky, 1979), the pain of a potential loss is psychologically more powerful than the pleasure of an equivalent potential gain (e.g., $100 lost feels larger than gaining the same amount). As a consequence, consumers are more likely to engage in risk-seeking behaviors to avoid potential losses. Based on these principles, several researchers have argued that loss framing may be an effective strategy to promote energy-efficient goods (Frederiks et al., 2015; Gonzales et al., 1988). In the context of marketing solar panels, ads may be more effective if they highlight monies lost by *not* getting solar (i.e., wasted dollars spent on more expensive utility-generated electricity) instead of focusing on how much money could be saved by going solar; this may be especially true if consumers view adoption of solar as risky. This leads to our first hypothesis:

H1. Loss frames will be more persuasive than gain frames in generating interest in PV.

Another factor that may influence consumer attitudes is the time frame over which savings are described. Research into time discounting suggests that consumers may find PV more compelling when the benefits are framed on a near-term monthly timescale rather than longer time frames such as annual or total lifetime savings. Generally speaking, people prefer smaller, sooner rewards than delayed, larger ones (DellaVigna, 2009; Frederick et al., 2002), especially under circumstances of uncertainty or risk. Furthermore, the benefits of PV may be perceived as larger when framed as multiple, monthly gains instead of as a single total gain (Smith and Nagle, 1995). Likewise, losses that occur each month could be perceived as more painful (and therefore more motivating) than one bundled loss (Johnson et al., 1999; Kahneman and Tversky, 1979; Thaler, 1985).

In addition, how consumers evaluate PV adoption may depend on how they mentally account for the benefits of PV. Framing the benefits of solar in a way that comports with this mental accounting may therefore be important. For example, solar may be seen as a means to lower monthly energy bills, in which case expressing benefits (or losses) in terms of monthly savings would allow easy juxtaposition. Alternatively, PV may be seen as an additional source of income or as a long-term financial investment (Stern et al., 2018), leading people to be primarily interested in annual or overall savings, respectively. This leads to our second hypothesis:

H2. The time frame of solar benefits (i.e., monthly vs. annual vs. lifetime) will affect interest in PV.

As a confounding factor, construal level theory (CLT) suggests that people develop different mental representations (or "construals") of situations depending on their perceived psychological distance (Trope and Liberman, 2010, 2003). These construal levels influence what information is considered in a given decision-making context (Trope et al., 2007). Psychologically distant situations, such as events that are perceived to occur in the future, activate high-level construals that are abstract and low-in detail. Under these circumstances, people tend to focus on identity-related goals, the desirability of an action, and *why* they might do a behavior. By contrast, temporally near events activate low-level construals that are more concrete and detail-rich. Under these circumstances, decision-makers focus on the feasibility of an action and *how* they might do the behavior.

Several researchers have proposed an interaction between gain/loss framing and temporal distance, where the effectiveness of a gain/loss frame depends on whether it is aligned with the present/future construal level of the message (Chang et al., 2015; White et al., 2011). Loss framed messages tend to provoke negative emotions and prime thoughts of how to take action, which may be particularly compatible with present-focused, low-level construal messages that encourage individuals to think concretely about how they might act. By contrast, gain-framed messages that highlight the desirable outcomes of acting may be compatible with future-oriented, high-construal level messages. White et al. (2011) found, for example, that college students reported greater intentions to recycle if messages described either what would be gained in the future by recycling or what might be lost in the near term by not recycling. Chang et al. (2015) similarly demonstrated that college students had greater intentions to buy an environmentally-friendly dish detergent if they either read about the environmental benefits of the soap 'each year in the future' or the negative environmental consequences of not using the soap 'this year.'

In the present study, messages that describe the lifetime consequences of having solar may evoke higher-level construals than messages that describe the near-term monthly (or annual) consequences. If different temporal frames lead to different construal levels, then we might expect an interaction between gain/loss framing and the temporal scale of the message. This leads to our first research question:

RQ1: Is the effect of gain/loss frames on interest in PV moderated by the time scale on which savings (losses) are conveyed?

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Finally, while reframing the financial benefits of solar may have advantages for generating new interest in PV, it is important to consider the impact of this approach relative to other possible outreach strategies. To keep customer acquisition costs low, solar providers must weigh the tradeoffs of spending marketing dollars on a general marketing campaign aimed at a broad audience versus tailoring messages to specific consumer segments. For example, past research suggests that individuals who feel a moral obligation to act on behalf of the environment as well as those who naturally seek out novel products may be more likely to pursue innovative energy goods (Jansson, 2011; Jansson et al., 2011; Labay and Kinnear, 1981; Wolske et al., 2017). This leads to our second research question:

RQ2: What is the effect of the mock ads on interest in PV relative to that of respondent characteristics?

2.1. Methods overview

Between April and June 2016, we conducted two online survey experiments to investigate how the financial benefits of PV might be reframed to increase consumer interest in solar. In each study, homeowners of single-family homes were recruited via Qualtrics online survey panels from select U.S. states known to have burgeoning solar markets. Quotas based on U.S. Census data were used to approximate the age, education, and gender distributions found in each state. Individuals who participated in one study were prevented from participating in the other study.

Both experiments followed the same basic procedure. After answering demographic screening questions, participants were told that they would be evaluating an ad for a new brand and product. They were then randomly assigned to see one of six solar PV ads according to a 3 × 2 between-subjects experimental design. Following exposure to the ad, participants rated their interest in PV using a series of Likert-scale questions that gauged their likelihood of responding to the ad as well as their perceptions of how appealing solar seemed. Additional items measured covariates that have been shown in past research to influence interest in PV (Wolske et al., 2017). These include feelings of moral obligation to address energy issues and climate change (pro-environmental norms), consumer innovativeness, perceived social support for going solar, and perceptions about the suitability of one's home. Toward the end of the survey, participants saw the ad again and completed manipulation checks.

2.2. Study 1

Participants were homeowners of single-family homes (N = 1,112) recruited from Arizona, California, New Jersey, and New York – four of the largest PV markets in the United States. After removing individuals who already had solar panels (N = 30), the final sample comprised 1,082 homeowners, with 243 participants in Arizona, 277 in California, 277 in New Jersey, and 285 in New York.

2.2.1. Materials

Participants within each state were randomly assigned to see one of six solar PV ads according to a 3 (temporal frame: monthly, annual, or 25-year lifetime) × 2 (gain/loss frame) between-subjects experimental design. Temporal frames varied according to whether the financial benefits of solar (or losses associated with not going solar) were described on a monthly, annual, or 25-year lifetime basis. Gain frames emphasized potential solar savings with two statements: "Go Solar! You could be saving money on your bills" and "With solar, you could save ($67 each month for the next 25 years)/($804 each year for the next 25 years)/($20,100 over the next 25 years). The loss frame emphasized how consumers might be wasting money with their current utility: "Don't Have Solar? You could be losing money on your bills," followed by "Without solar, you could be wasting ($67 each month for the next 25 years)/($804 each year for the next 25 years)/($20,100 over the next 25 years; see Fig. 1 and Supplementary Material). In all conditions, the frames were designed so that individuals, if desired, could multiply the provided numbers to arrive at the total savings (losses) over the 25-year lifespan of the PV system—thereby making the total savings (losses) claimed across the six ads economically equivalent. To make the monetary values relevant, we calculated state-specific financial savings and losses based on state-wide average electricity rates (US EIA, 2016), the estimated solar generation for a 5 kW_{DC} PV system, recent technology costs (Cole et al., 2016), and existing state and federal PV incentives (DSIRE, 2017) for each state.

2.2.2. Measures

2.2.2.1. Intention to respond to ad. Participants rated their likelihood of responding to the ad using five items on a 7-point scale from 1 = *Very unlikely* to 7 = *Very likely,* with *Undecided* as the midpoint. Items included doing a web search to learn more about solar, doing a web search for the company listed in the ad, looking into the costs of solar panels, visiting the company's website, and clicking on the ad. The five items formed a reliable scale (Cronbach's α = 0.97).

2.2.2.2. Attitude toward PV. Three items measured the overall appeal of PV using 7-point bipolar scales. These included an item about the general appeal of PV (from 1 = *Extremely unappealing* to 7 = *Extremely appealing*), beliefs about how the costs and benefits of solar compare (1 = *Costs definitely outweigh the benefits* to 7 = *Benefits definitely outweigh the costs*), and whether respondents thought getting solar panels would have a negative (bad) or positive (good) impact on their household finances (from 1 = *Very negative* to 7 = *Very positive)*. These three items were averaged to form a scale of PV appeal (α = 0.83).

2.2.2.3. Construal-level check. After viewing the ad a second time, participants were asked to describe the financial benefits of solar panels on two 7-point semantic differential scales: *happen in the near future/happen in the distant future, occur right away/occur later.* These two items were averaged (r = 0.65) into a temporal distance scale, which we used to examine whether the temporal manipulations changed the perceived construal levels of the ads.

2.2.2.4. Co-variates and socioeconomic variables. Pro-environmental personal norms (α = 0.81), perceived home unsuitability, and perceived social support for getting PV (α = 0.73) were measured using items from Wolske et al. (2017). Consumer innovativeness was measured using two scales, Consumer Novelty Seeking (CNS; α = 0.91), and Consumer Independent Judgment Making (CIJM; α = 0.84) which were likewise adapted from past work (Jansson, 2011; Wolske et al., 2017).

We additionally controlled for state of residence, age, gender, education, and subjective socioeconomic status (SES). Subjective SES was

Fig. 1. Mock ad from Study 1 showing annual gain frame for California.

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measured with the MacArthur Scale of Subjective Social Status, which past research has shown to be correlated with objective measures of household wealth and financial security (e.g, Singh-Manoux et al., 2003) and a better predictor of well-being (Adler et al., 2000). The scale shows participants an illustration of a 10-rung ladder that is described as representing people in the United States. The top rung of the ladder represents people who are "the best off, those who have the most money, most education, and best jobs," while the bottom rung represents the people who have "the least money, least education, and worst jobs or job." Respondents were asked to indicate on which rung of the ladder they felt they belonged. Finally, to approximate electricity consumption, which people tend to self-report inaccurately, we also controlled for square footage and household size. For individuals who indicated that they did not know the square footage of their homes ($N = 87$), we used mean substitution based on state of residence to replace missing values.

2.2.3. Effects of ads on interest in PV

We predicted that consumers would respond more positively to loss-framed messages (H1) and that their perceptions of solar would be influenced by the temporal framing of the ad (H2). Both hypotheses were tested using two-way independent ANCOVAs, controlling for state of residence. Effect sizes are given using omega squared and partial eta squared (small = 0.01; medium = 0.06; large = 0.14). We found little evidence in support of H1. While loss frames had a marginally significant advantage over gain frames on attitudes toward PV, the effect size was very small ($M_{loss} = 4.74$ vs. $M_{gain} = 4.59$, $F(1,1073) = 3.19$, $p = 0.074$, $\omega^2 = 0.002$); no main effects were observed for gain/loss framing on likelihood of responding to the ad ($F(1,1073) = 1.47$, $p = 0.226$, $\omega^2 < 0.001$). H2 was also unsupported: the temporal frames did not significantly influence either outcome (Attitudes: $F(2,1073) = 0.883$, $p = 0.414$, $\omega^2 = 0.00$; Respond to ad: $F(2,1073) = 1.44$, $p = 0.237$, $\omega^2 < 0.001$).

We also did not find evidence that the effect of the gain/loss frames depends on the perceived temporal distance of PV's benefits (R1), as the interactions between the gain/loss and temporal frames were not significant for either outcome (Attitudes: $F(2,1073) = 0.037$, $p = 0.964$, $\omega^2 = -0.002$; Respond to ad: $F(2,1073) = 0.63$, $p = 0.533$, $\omega^2 = -0.001$). To understand these results, we looked to our construal-level check, which asked participants to rate whether the benefits of PV would occur soon or in the distant future. Contrary to our expectations, the temporal frames did not change perceptions of when the benefits of PV would accrue. On average, participants in the monthly, annual, and lifetime conditions all perceived the financial benefits of PV as occurring slightly more in the distant future (Means between 4.41 and 4.63 on 7-point scale; $F(2, 1073) = 2.23$, $p = 0.108$, $\omega^2 = 0.002$). While we did observe a marginally significant interaction between the temporal and gain/loss frames on this measure ($F(2, 1073) = 2.83$, $p = 0.060$, $\omega^2 = 0.003$), post-hoc testing yielded only one significant difference between the annual gain and annual loss frames ($M = 4.57$ and $M = 4.22$, respectively, $p = 0.038$, $\eta_p^2 = 0.004$).

2.2.4. Effects of socio-economic and psycho-social characteristics on interest in PV

To examine the effects of the ads relative to the socio-economic and psycho-social characteristics of participants (RQ2), we used a series of nested regressions, controlling for socio-economic variables (including state of residence) in step 1 of the model, psycho-social variables in step 2, the experimental conditions in step 3, and the interactions between conditions in step 4 (Table 1). Socio-economic variables accounted for 12% of variance in attitudes toward PV. Favorable attitudes toward PV were positively associated with household size, square footage, subjective socioeconomic status, and being male. Adding personal dispositions and beliefs about solar to the model significantly increased R^2 by 34%. Believing that important peers would support the decision to go solar was the strongest predictor of positive attitudes toward PV, followed by consumer novelty seeking (a measure of innovativeness), and having strong pro-environmental personal norms. Adding the experimental treatments and the interactions between them did not significantly improve the fit of the model.

For intentions to respond to the ad, socio-economic variables accounted for 15% of variance. Again, household size, subjective socio-economic status, and being male were positively associated with responding to the ad while age was negatively correlated. Adding in psycho-social variables accounted for an additional 30% of variance. Consumer innovativeness (as measured by consumer novelty seeking) was the strongest predictor of responding to the ad, followed by perceived social support and pro-environmental norms. Believing that one's home was unsuitable for solar was negatively correlated with intentions to respond. Unexpectedly, consumer independent judgment making was also negatively correlated. This latter finding may reflect that individuals most interested in solar are "early majority adopters" (Rogers, 2003) who, while interested in novel products (as measured by consumer novelty seeking), are still influenced by the opinions of others. Neither the main effects for the experimental conditions nor the interactions between them significantly improved the fit of the model.

2.2.5. Study 1 discussion

In summary, we did not find support for either H1 or H2. Whether the financial benefits of going solar were framed as a gain or loss did not lead to appreciable differences on attitudes toward PV or intentions to respond to the ad. One potential explanation for this result is that part of our loss frame described how consumers could be "wasting" money without solar. It is possible that "wasting" did not evoke feelings of loss aversion. The results of Study 1 also suggest that there are no advantages to framing the financial benefits of PV on a particular time scale. However, this finding may be a consequence of our efforts to make the frames economically equivalent. As each of the three temporal frames – monthly, annual, and lifetime – described how the benefits of PV would accrue for "the next 25 years," participants in all three conditions may have been inclined to think about the benefits of PV long-term, resulting in a higher-level construal. This explanation would also account for why we did not observe differences on our construal level measure or see interactions between the gain/loss and temporal frames (RQ1). Finally, Study 1 suggests that characteristics and beliefs of the consumer play a major role in determining interest in PV. In particular, individuals who tend to seek out novel goods, have strong feelings of moral obligation to protect the environment, and those who believe their peers would support the decision to go solar are more likely to believe that PV is beneficial and respond to the ad.

2.3. Study 2

In Study 2, we addressed the potential shortcomings of Study 1 by making the following modifications: we removed the "25 year" language from the monthly and annual frames in an attempt to activate different construal levels; we changed the loss frames to describe what participants could be "losing" without solar instead of describing what they were "wasting;" and we limited the sample to homeowners in California and New York to reduce variability and enhance statistical power ($N = 1{,}054$). After removing individuals who already had PV ($N = 25$) or failed an attention check ($N = 56$), the final sample size was 973, with 480 participants in California and 493 participants in New York.

2.3.1. Effects of ads on interest in PV

As in Study 1, we looked for differences between treatments on the overall appeal of PV and the likelihood of responding to the ad using

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Table 1
Summary of hierarchical regressions to predict attitudes toward PV and intentions to respond to the ad.

	Appeal of PV							
	Step 1		Step 2		Step 3		Step 4	
	b	SE	b	SE	b	SE	b	SE
Constant	5.09***	0.29	1.50***	0.35	1.57***	0.36	1.59***	0.36
Age	−0.02***	0.00	−0.01***	0.00	−0.01***	0.00	−0.01***	0.00
Gender (female)	−0.10	0.08	−0.04	0.07	−0.04	0.07	−0.04	0.07
Education	−0.01	0.03	−0.02	0.02	−0.02	0.02	−0.02	0.02
Household size	0.11**	0.03	0.04	0.03	0.04	0.03	0.04	0.03
Square footage	0.06*	0.03	0.04†	0.02	0.04†	0.02	0.04†	0.02
SES rung	0.08***	0.03	−0.01	0.02	−0.01	0.02	−0.01	0.02
AZ	0.04	0.12	−0.02	0.09	−0.02	0.09	−0.02	0.09
NJ	−0.14	0.11	0.02	0.09	0.02	0.09	0.02	0.09
NY	0.02	0.11	0.14	0.09	0.14	0.09	0.14	0.09
Pro-environ. personal norm			0.19***	0.03	0.19***	0.03	0.19***	0.03
Social support			0.42***	0.03	0.42***	0.03	0.42***	0.03
Home not suitable			−0.05*	0.02	−0.04†	0.02	−0.04†	0.02
Consumer Ind. Judg.Making			−0.01	0.04	−0.02	0.04	−0.02	0.04
Consumer Novelty Seeking			0.23***	0.04	0.23***	0.04	0.23***	0.04
Gain frame					−0.10	0.06	−0.14	0.11
Annual frame					0.03	0.08	0.04	0.11
Lifetime Frame					−0.05	0.08	−0.11	0.11
Gain × Annual							−0.02	0.15
Gain × Lifetime							0.12	0.15
R^2	0.13		0.47		0.47		0.47	
R^2 *change*	–		0.34***		0.002		<0.001	
R^2_{adj}	0.12		0.46		0.46		0.46	
F	17.22***		67.29***		55.69***		49.33***	
	Likelihood of responding to the ad							
	Step 1		Step 2		Step 3		Step 4	
	b	SE	b	SE	b	SE	b	SE
Constant	4.78***	0.39	0.88†	0.48	0.86†	0.49	0.88†	0.49
Age	−0.03***	0.00	−0.01**	0.00	−0.01**	0.00	−0.01**	0.00
Gender (female)	−0.41***	0.11	−0.32***	0.09	−0.33***	0.09	−0.33***	0.09
Education	−0.05	0.04	−0.05	0.03	−0.04	0.03	−0.04	0.03
Household size	0.20***	0.05	0.10**	0.04	0.10**	0.04	0.10**	0.04
Square footage	0.06	0.04	0.03	0.03	0.03	0.03	0.03	0.03
SES rung	0.13***	0.03	−0.01	0.03	−0.01	0.03	−0.01	0.03
AZ	0.07	0.16	−0.01	0.13	−0.01	0.13	−0.01	0.13
NJ	−0.34***	0.15	−0.16	0.12	−0.16	0.12	−0.16	0.12
NY	−0.12	0.15	0.08	0.12	0.08	0.12	0.08	0.12
Proenviron. personal norm			0.18***	0.04	0.18***	0.04	0.18***	0.04
Social support			0.39***	0.04	0.39***	0.04	0.39***	0.04
Home not suitable			−0.13***	0.03	−0.12***	0.03	−0.12***	0.03
Consumer Ind. Judg.Making			−0.13*	0.06	−0.13*	0.06	−0.13*	0.06
Consumer Novelty Seeking			0.56***	0.06	0.57***	0.06	0.57***	0.06
Gain frame					−0.11	0.09	−0.15	0.15
Annual frame					0.18	0.11	0.14	0.15
Lifetime Frame					0.03	0.11	0.01	0.15
Gain × Annual							0.09	0.21
Gain × Lifetime							0.04	0.21
R^2	0.15		0.46		0.46		0.46	
R^2 *change*	–		0.31***		0.003		<0.001	
R^2_{adj}	0.15		0.45		0.45		0.45	
F	21.51***		64.37***		53.41***		47.72***	

† $p < 0.08$.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

two-way ANCOVAs, controlling for state of residence. Despite the updated language in the loss frame, no main effects were observed for the gain/loss conditions for either attitudes toward PV ($F(1,966) = 1.10$, $p = 0.296$, $\omega^2 < 0.001$) or intentions to respond to the ad ($F(1,966) = 0.14$, $p = 0.707$, $\omega^2 = 0.00$). Likewise, the main effects for the temporal frames were not significant (Attitudes: $F(2,966) = 2.00$, $p = 0.136$, $\omega^2 = 0.002$; Respond to the ad: $F(2,966) = 0.23$, $p = 0.78$, $\omega^2 = -0.002$).

As intended, removing the "25 year" language from the monthly and annual frames influenced the perceived construal level of the ad ($F(2, 966) = 14.82$, $p < 0.001$, $\omega^2 = 0.028$), with participants in the lifetime framing conditions perceiving the financial benefits of PV as occurring later in the future ($M = 4.85$) than participants in either the monthly ($M = 4.31$, $p < 0.001$) or annual frames ($M = 4.25$, $p < 0.001$). No differences were found between the monthly and annual conditions ($p = 0.953$). A main effect was also found for state, with New York residents perceiving the benefits of PV to occur slightly later

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($M = 4.57$) than California residents ($M = 4.37$, $p = 0.040$, $\omega^2 = 0.003$). Despite the lifetime framing being perceived at a higher construal level, we found no evidence to suggest that the effects of the gain/loss frames depend on perceived temporal distance (RQ1), as the interaction between the two factors was not significant for either PV attitudes (F (2,966) = 1.01, $p = 0.366$, $\omega^2 < 0.001$) or intentions to respond to the ad (F (2,966) = 1.06, $p = 0.348$, $\omega^2 < 0.001$).

2.3.2. Effects of socio-economic and psycho-social characteristics on interest in PV

We then used hierarchical regression to test the effects of the ads relative to socio-economic and psycho-social covariates (RQ2). In line with Study 1, socio-economic and psycho-social variables together accounted for 44% of variance in attitudes toward PV and 42% of variance in likelihood of responding to the ad (see Supplementary Material for full results). Adding the experimental conditions and their interactions did not improve the fit of the model for either outcome. As in Study 1, social support for going solar was the strongest predictor of believing that PV would be beneficial ($b = 0.34$, $p < 0.001$), followed by pro-environmental personal norms ($b = 0.24$, $p < 0.001$) and consumer novelty seeking ($b = 0.20$, $p < 0.001$). Consumer novelty seeking was the strongest predictor of intentions to respond to the ad ($b = 0.55$, $p < 0.001$), followed by social support ($b = 0.32$, $p < 0.001$), and pro-environmental personal norms ($b = 0.24$, $p < 0.001$). Consistent with Study 1, consumer independent judgment making was again negatively correlated with intentions to respond to the ad ($b = -0.20$, $p = 0.001$). Believing that one's home was unsuitable for solar had a small, negative effect ($b = -0.06$, $p = 0.058$).

2.3.3. Study 2 discussion

Study 2 confirms the results of Study 1: neither gain/loss framing nor temporal distance manipulations appear to influence attitudes toward PV or intentions to respond to the ad. Rather, both studies suggest that responsiveness to solar advertising is driven predominantly by underlying consumer motivations and predispositions, namely having an innate sense of curiosity about novel products, believing that others would be supportive of going solar, and feeling morally obligated to act on climate change. The design of the ad, especially the way in which the financial benefits of PV are framed, appears to be inconsequential.

3. Study 3: are consumers skeptical of PV savings claims?

Whereas Studies 1 and 2 tested strategies for making economically equivalent financial claims more appealing, Study 3 examines whether providing more information on how those financial claims are constructed impacts ad appeal. Indeed, many respondents in Studies 1 and 2 questioned the veracity of the ads' financial claims, writing in open-ended comments that they needed more details about the costs of PV to be able to fully evaluate it. When solar marketing materials make claims about the financial "savings" associated with PV, the meaning is often ambiguous. Savings could refer to the amount by which the electricity bill is reduced (gross savings), or the difference of the bill reduction and lease or loan payment (net savings). Unless ads are explicit, consumers may pessimistically assume that claims about the benefits of solar are based on gross savings and, thus, overstated. This leads to a third hypothesis:

H3. Compared to general claims of savings, ads that provide a detailed breakdown of how the savings from PV are calculated will:

a) make consumers less skeptical of the ad
b) lead to more positive attitudes about PV; and
c) result in greater intentions to respond to the ad.

In addition, we might expect that reactions toward the ad depend on (or interact with) the level of savings promised. As the level of claimed savings increases, the effect of the detailed ad may be stronger. That is, consumers may be more trusting of higher savings claims if they can see how those savings were derived. This leads to a third research question:

RQ3: Is the effect of claim type moderated by the amount of savings claimed?

To test these questions, we modified the mock PV advertisements used in Study 1 and 2, dropping the gain/loss and temporal distance manipulations altogether to focus only on annual savings, a common frame used by the PV industry (see Supplementary Material). As described below, we then varied the level of detail in the ad and the amount of annual savings claimed.

Participants were homeowners of single-family homes (N = 1,512) in Massachusetts. We selected Massachusetts as the solar market is growing, but not subject to the saturation of solar advertising common to the four states in Studies 1 and 2 (GTM Research and Solar Energy Industries Association, 2016). As in our previous studies, quotas were used to approximate the age, education, and gender distributions for the state. After removing individuals who already had solar panels (N = 39), the final sample size was 1,481.

3.1. Materials and procedure

Following a similar procedure to Studies 1 and 2, participants were randomly assigned to see one of six mock ads according to a 3 (annual savings amount: low, medium, or high) × 2 (claim type: detailed vs. simple) between-subjects experimental design. Annual dollar savings were estimated based on electricity rates, solar generation, technology costs, and current solar incentives in Massachusetts using the method described previously. High and low savings were derived as 150% and 50% of the current-day (medium) savings, respectively. The savings claim manipulation varied whether the ads explained how the projected savings from PV were derived. In the detailed savings condition, the ad illustrated how the savings claimed in the ad were calculated by subtracting annual solar lease costs from total annual electric bill savings (see Supplementary Material). In the simple savings condition, the ad only stated how much money the respondent could save each year. The savings claimed in the simple condition were the same as the net savings presented in the detailed savings condition.

3.2. Measures

In addition to measuring attitudes toward PV ($\alpha = 0.75$) and likelihood of responding to the ad ($\alpha = 0.96$), we assessed ad skepticism. Items included whether the claims in the ad sounded too good to be true, skepticism about the benefits of PV, and if the savings from PV were too uncertain (rated from 1 = *Strongly Disagree* to 7 = *Strongly Agree)*. The three items were averaged to form a scale of Ad skepticism, $\alpha = 0.76$.

We also included a manipulation check regarding the ambiguity of the savings claimed. Participants were asked to rate the clarity of the savings described in the ad on three 7-point semantic differential scales: *vague/not vague, not clear/clear,* and *imprecise/precise.* These three items were averaged ($\alpha = 0.87$) to form a scale of Ad clarity.

3.3. Manipulation check

An analysis of variance (ANOVA) on ad clarity revealed only the expected main effect for savings claim type, with participants in the detailed savings condition perceiving the savings to be significantly

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clearer (M = 4.53) than the ads without the calculation (M = 4.15); F(1,1475) = 22.39, $p < 0.001$, $\omega^2 = 0.014$.

3.4. Effects of ads on interest in PV

We tested whether consumers would respond more positively to messages with detailed savings claims (H3) using a series of two-way ANOVAs. Contrary to our expectations for H3a, an ANOVA on ad skepticism revealed that respondents were more skeptical of the detailed ads (M = 4.31) than of the simple ads (M = 4.15, F(1,1475) = 5.73, p = 0.017), though the effect size was small (ω^2 = 0.003). No effect was found for ad amount (M_{low} = 4.19, M_{medium} = 4.22, M_{high} = 4.30; F(2,1475) = 1.09, p = 0.34, ω^2 = 0.001). We also did not find evidence of an interaction between ad type and amount (RQ2) (F(2,1475) = 1.91, p = 0.149, ω^2 = 0.002). In other words, skepticism toward the detailed and simple savings claims was not influenced by the amount of savings claimed.

Although participants were slightly more skeptical of the detailed ads, this skepticism did not appear to influence attitudes about the benefits of PV. Respondents who saw the detailed ads had more favorable attitudes about PV than those in the simple ad condition (H3b) ($M_{detailed}$ = 4.49, M_{simple} = 4.28; F(1,1475) = 10.85, p = 0.001, ω^2 = 0.007), though this effect was qualified by a significant interaction (F(2, 1475) = 3.91, p = 0.020, ω^2 = 0.009). As suggested by RQ2, when claimed savings amounts were high, participants found PV more appealing when shown a detailed ad (M = 4.67) as compared to the simple ad (M = 4.27, F(1, 1475) = 14.08, $p < 0.001$, η^2 = 0.009). When claimed savings were low, no differences were found between the two ad types ($M_{detailed}$ = 4.29, M_{simple} = 4.32, F(1,1475) = 0.04, p = 0.851). Fig. 2 illustrates this interaction.

For intentions to respond to the ad, the predicted main effect (H3c) for savings claim type was not significant ($M_{detailed}$ = 3.94, M_{simple} = 3.85; (F(1,1475) = 0.92, p = 0.338, ω^2 = 0.00, though there was a marginally significant main effect for savings amount (M_{low} = 3.80, M_{medium} = 3.84, M_{high} = 4.03; F(2,1475) = 2.46, p = 0.085, ω^2 = 0.005). We also did not find evidence of an interaction between ad type and savings amount (F(2,1475) = 1.191, p = 0.149, ω^2 = 0.004).

3.5. Effects of socio-economic and psycho-social characteristics on interest in PV

As with our previous studies, we used hierarchical regression to test the effects of the ads relative to socio-economic and psycho-social covariates (see full results in Supplementary Material). Again, personal dispositions and beliefs about solar were the strongest predictors, explaining 31% of variance in attitudes toward solar and 32% of variance in intentions to respond to the ad, after controlling for socio-economic variables. Specifically, pro-environmental norms, consumer novelty seeking, and having social support to go solar were positively associated with both outcomes, while believing that one's home was unsuitable for PV was negatively correlated. Having social support to go solar was the strongest predictor of favorable attitudes toward PV (b = 0.35, $p < 0.001$) while consumer novelty seeking was the strongest predictor of responding to the ad (b = 0.49, $p < 0.001$).

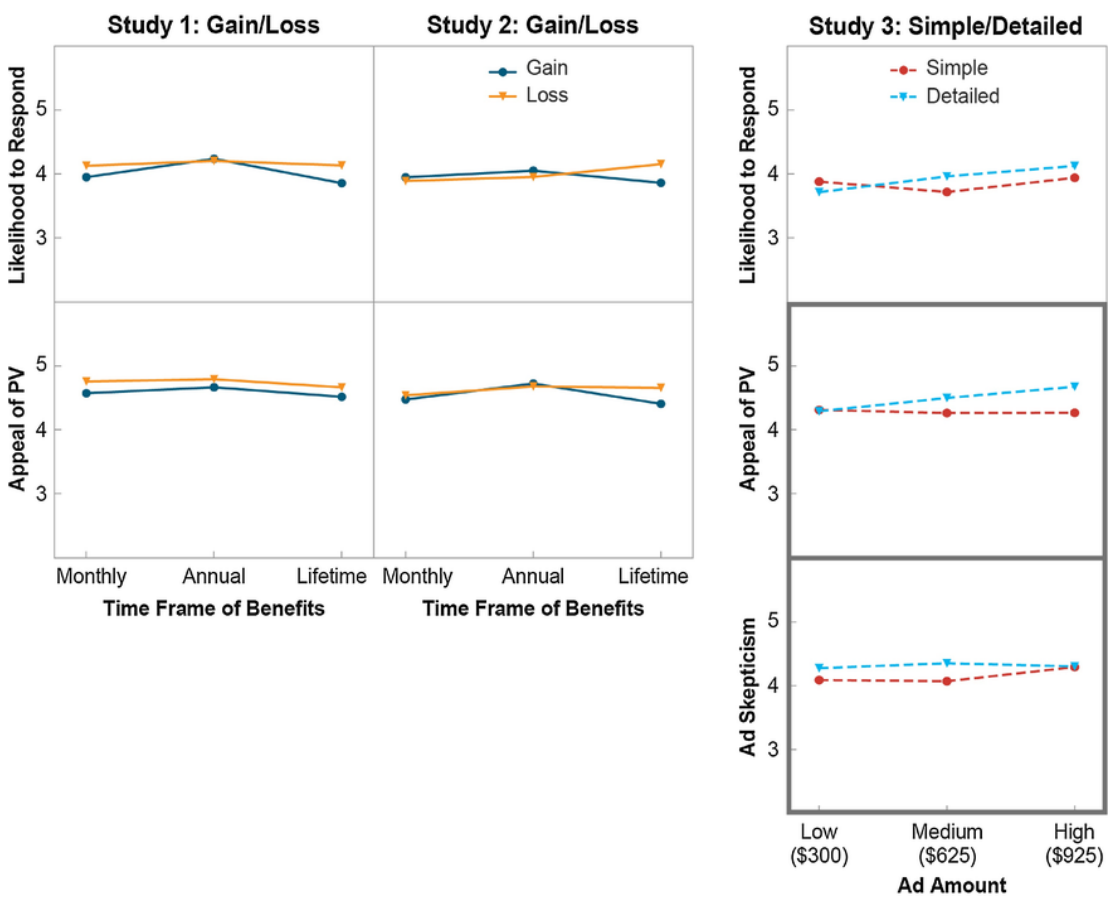

Fig. 2. Summary of results for Studies 1 through 3. Graphs with significant results are outlined in bold. In Studies 1 and 2, neither gain/loss framing nor temporal framing influenced the appeal of PV or the likelihood of responding to the ad. The interactions between these treatments were also not significant. In Study 3, the likelihood of responding to the ad was not influenced by either the amount of the ad or whether a detailed calculation was provided for the savings claim. A significant interaction was found between ad amount and ad type on the appeal of PV. In addition, participants were more skeptical of the detailed ad with the calculation than the ad with the more ambiguous savings claim.

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Adding the experimental conditions to the model for PV attitudes led to a small but significant increase in R^2 of 0.009 (F_{change} (3,1466) = 6.43, $p < 0.001$). In line with our ANOVA results, participants who saw detailed savings claims found PV more appealing than participants in the simple savings claim conditions ($b = 0.19$, $p < 0.001$). Controlling for the interactions between conditions significantly increased the fit of the model by 0.004 (F_{change} (2, 1464) = 4.11, $p = 0.017$). As we saw with our ANOVA analysis, detailed savings claims led to more favorable attitudes when the amount of claimed savings was high; no differences were found between ad types when the savings amount was low.

When predicting intentions to respond to the ad, controlling for the experimental conditions significantly increased R^2 by 0.004 (F_{change} (3,1466) = 2.99, $p = 0.030$). This effect appeared to be driven predominantly by the contrast between the high and low savings claim amounts, with participants in the former indicating that they were slightly more likely to respond to the ad ($b = 0.23$, $p = 0.013$). In line with our ANOVA results, the interactions between the experimental treatments did not improve the fit of the model (F_{change} (2,1464) = 1.54, $p = 0.214$).

3.6. Study 3 discussion

Study 3 provides mixed evidence about the effects of showing consumers a detailed breakdown of how savings are calculated. On one hand, respondents shown the detailed savings ad were slightly more skeptical of the ad's claims than those shown the simple savings claim. On the other hand, when claimed savings amounts were high, the detailed ad led to more positive attitudes about PV's benefits than the simple ad. One potential explanation for these findings is that the annual electric bill costs shown in the detailed ad may have been higher than what respondents' had experienced personally—leading respondents to question whether the savings were overstated. Nonetheless, when claimed savings amounts were high, the detailed ad may have led participants to believe that they were more likely to benefit financially from solar than participants shown the more ambiguous ad. Interestingly, the clarity of the savings claim had no effect on likelihood of responding to the ad; as with Studies 1 and 2, respondent characteristics, particularly whether they were innovative consumers, were more predictive of intentions.

4. General discussion and conclusion

In the U.S., customer acquisition costs remain a significant barrier to lowering the installed cost of residential PV and, therefore, to scaling up the market. Solar providers may find it especially challenging to attract new customers if consumers perceive PV to be financially unattractive. In this paper we use mock solar advertisements to test the effects of four different framing strategies on interest in PV: temporal framing, gain versus loss framing, savings claims with and without a detailed savings calculation, and different savings amounts. These framing strategies are appealing both because they require only small changes in the wording of marketing material—making them an inexpensive and cost-effective way to decrease customer acquisition costs—and because they are grounded in research from behavioral economics and psychology that suggest these small changes in framing can have large effects in outcomes.

Contrary to expectations, our results (see Fig. 2 for summary) show little or no effect of these various frames on the perceived appeal of PV, participants' likelihood to respond to a mock ad, and, for Study 3, skepticism toward the ads—despite having sufficient sample sizes to detect very small effects. In Studies 1 and 2, participants found PV no more attractive whether the financial outcomes of solar were described in terms of losses or gains or whether the claimed savings (or losses) were described as e.g., $67 per month or $20,100 over 25 years. These findings stand in contrast to common wisdom that loss frames may be an effective way to increase interest in low-carbon technologies (Frederiks et al., 2015; Gonzales et al., 1988) and to advice that energy metrics should be provided on expanded scales that show the cumulative benefits of energy technologies over time (Larrick et al., 2016). In Study 3, we similarly found no differences in consumer interest when ads varied the claimed savings amount from 50% to 150% of average expected savings. Taken together, these results suggest that consumers may be judging the general plausibility of the ad's claims without giving much weight to the absolute dollar amounts described. Instead, across all three studies, we find that underlying consumer motivations and predispositions (i.e., being an innovative consumer, perceiving social support to go solar, and having pro-environmental personal norms) are the primary factors driving interest in adopting solar.

Interestingly, our findings stand in contrast to other studies that find gain/loss and temporal frames can be manipulated to promote environmental behaviors such as recycling (White et al., 2011) and intentions to purchase an eco-friendly dish detergent (Chang et al., 2015). One explanation for this discrepancy is that PV requires far greater commitment and more serious consideration than either of these actions. In contrast to recycling or buying dish detergent, consumers may always think of PV as a long-term decision, so attempts to alter this perception through temporal framing may have little effect. In addition, prior studies described the gains and losses to the environment or community, whereas we focused on the economic impacts to the participant. It is possible that economically-focused messages lead to more nuanced evaluations of losses and gains. For example, consumers may not perceive money that they have already budgeted to spend on utility-provided electricity as a loss, but rather as money that has already been spent (Thaler, 1985). This would explain why our loss frames, which emphasized what would be wasted or lost by sticking with the status quo were ineffective compared to gain frames. An alternative explanation is that consumers may still be loss averse but to the presumed upfront costs of going solar. Consumers may assume that the financial outlay for purchasing or leasing solar is greater than the potential losses associated with relying on the utility. Gamliel and Herstein (2011, pp. 155–156) similarly found that "lose if you don't purchase" frames had no advantages over "save if you purchase" frames when promoting sale goods that required an initial expenditure. Even if consumers believe that solar makes financial sense in the long run, those benefits may be overshadowed by other types of perceived costs: the time and effort of learning about solar, of finding reputable installers, of weighing different solar system packages, and of coordinating installation.

Another explanation for why our results might differ from previous studies concerns the nature of the experiment. By asking participants to evaluate an ad, we likely encouraged closer processing of ad content than if participants were to see the ad in passing while browsing on the Internet or flipping through a magazine. If the effects of prospect theory are a manifestation of quick, intuitive thinking (Kahneman, 2011), it is possible the framing manipulations would be more successful if experienced under more natural conditions. In addition, research is needed to determine whether the effects we observed hold upon repeat exposure to the ad. Some evidence indicates that repeat exposure to persuasive messaging leads to closer processing of the content (Cacioppo and Petty, 1989), especially when information is perceived to be personally relevant (Claypool et al., 2004). This might suggest that individuals who are already interested in PV are unlikely to be influenced by different framings upon repeat exposure. Conversely, when information is not personally relevant, repeated exposure to an ad can reduce analytical processing (Claypool et al., 2004), suggesting that the experimental framings might be more effective over time for individu-

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als not previously interested in solar. More research is needed to determine the boundary conditions of our findings.

Although our studies were based on hypothetical ads and homeowners' stated intentions, the findings may nonetheless have important implications for both the solar industry and for policymakers. First, our results suggest that at the current stage of solar diffusion, consumers may be inattentive to the way the financial benefits of PV are portrayed, at least in initial marketing materials. This finding not only suggests that solar providers should invest marketing research dollars in other outreach strategies, but may also have ramifications for policymakers considering how to promote available financial incentives. If consumers are not swayed by varying estimates of cumulative annual or lifetime savings, information about available incentives may be equally uncompelling, particularly for consumers who are not actively contemplating PV. To be motivating, such information may need to come from trusted sources such as solar community organizations, local electric utilities, or community members who have already adopted PV (Noll et al., 2014; Palm, 2016; Schelly, 2014; Stern et al., 2018).

Second, results from our hierarchical regressions indicate that the effects of the ads on interest in PV were minimal compared to those of consumer characteristics. Rather than attempting to create marketing messages that appeal to a broad spectrum of consumers, a better strategy for lowering customer acquisition costs may be to segment customers based on psychological characteristics and to tailor messages and outreach strategies to these segments. For example, solar providers could target innovative consumers with messaging about advances in PV technology or provide messaging about the environmental benefits of PV to consumers with pro-environmental inclinations. This is not to suggest that ads should avoid describing the financial benefits of PV altogether; rather such information may be of greater interest to individuals with a greater proclivity to adopt (Wolske et al., 2017). In this vein, policymakers might consider bundling incentives for new, related technologies, so that, for example, innovative consumers who are shopping for plug-in electric vehicles might be encouraged to consider rooftop solar.

Our results also point to the importance of perceived social support for going solar, lending credence to existing programs in the U.S. that encourage solar adoption through community group-buys (Gillingham and Bollinger, 2017; Noll et al., 2014). In locations where such programs are not feasible, solar providers might do well to highlight the increased popularity of PV in their marketing materials and to test strategies for increasing client referrals. The solar industry may also want to lend support to local solar community organizations, which can enhance peer effects by highlighting pro-solar opinion leaders, hosting workshops on the process of installing PV, and connecting consumers with existing PV adopters in the community (Noll et al., 2014; Schelly, 2014).

We caution that with each of the above suggestions, more research is needed to determine its potential efficacy and impact on customer acquisition costs. Furthermore, the results of the present studies may be specific to the current stage of the U.S. solar market, and therefore less applicable once the market fully matures. Research on diffusion of renewable energy systems indicates that as these technologies become commonplace, the factors that influence consumer decision making shift (Heiskanen and Matschoss, 2017). While early adopters of a technology may be inherently more innovative and pro-environmental and, thus, more willing to overlook the costs and risks associated with a product, mainstream shoppers may be more likely to pay close attention to issues of cost and convenience. As solar PV becomes mainstream, it is possible that gain/loss frames, perceived temporal distance, and the clarity of marketing claims will have stronger influences on consumer decision-making. Future research could also examine the heterogeneity of response among participants with different trait-level characteristics, such as cognitive reflection and need for cognition, which may predict how susceptible participants are to the ad manipulations (Frederick, 2005; Zhang and Buda, 1999).

Finally, in addition to informing residential solar PV policy, our findings contribute to the behavioral economics and psychology literature. Over the last several decades these fields have identified a number of potentially generalizable psychological biases, including several examined in the present study: loss aversion under conditions of uncertainty, temporal discounting, and under- or over-weighting information based on its perceived psychological distance. A new wave of research, including our own, is refining the situations and contexts under which those biases apply (e.g., Andreoni and Sprenger, 2012 find dynamically consistent time preferences and reasonable discounting). Specifically, our null results suggest that biases related to loss aversion and present/future frames may not apply when marketing the financial consequences of long-term energy investments. Future research is needed to tease apart the conditions under which these biases may have an effect. For example, future studies could examine how the type of gains/losses incurred (e.g., economic vs. other) influence perceptions of these goods and whether temporal frame manipulations might work with goods that have a shorter payback period (e.g., energy-efficient appliances). Gaining a better understanding of the precise situations and contexts in which these biases do and do not apply will allow us not only to better understand their underlying psychological effects, but also how we might use them to promote greenhouse-gas reducing technologies and behaviors.

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