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The role of place attachment and environmental attitudes in adoption of rooftop solar

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ABSTRACT

Prior research on adoption of rooftop solar has investigated various economic and psychological factors contributing to or impeding adoption. One psychological factor that has been linked to environmental behavior in other settings, but not yet in the context of rooftop solar, is place attachment, an individual's sense of attachment to their community. Using a survey of over 3700 homeowners in Los Angeles County, we examine the impact of place attachment, relative to that of pro-environmental attitudes, on the decision whether to consider rooftop solar and on the decision whether to adopt it. We find that an otherwise average homeowner with pro-environmental attitudes one unit above the mean is 5.66 percentage points more likely to consider rooftop solar, while the effect of place attachment on consideration is not significant. However, among respondents who consider rooftop solar, an otherwise average homeowner with one unit stronger place attachment is 7.59 percentage points more likely to adopt, while the effect of pro-environmental attitudes on adoption is not significant. Policymakers seeking to encourage adoption of rooftop solar should contemplate leveraging place attachment, and should recognize that different policy mechanisms will be effective for homeowners in general than for those who are already considering.

1. Introduction

Policymakers are considering strategies for climate change mitigation and adaptation, many of which include the adoption of new technologies. The diffusion of such technologies depends not only on their technical and economic performance, but also on social, psychological and behavioral factors, particularly where the choice is made by individuals (Rogers, 2003). This holds for rooftop solar, which is emerging as a major strategy for decarbonization, as costs have come down (Clack et al., 2017; IPCC, 2018; Nemet et al., 2020). Absent government mandates, successful implementation depends upon wide-scale adoption by individual consumers. Some studies conclude that adoption is already quite widespread (e.g., Do et al., 2020, for the case of Vietnam), while others examine reasons why adoption has been disappointing (e.g., Dutt, 2020, focusing on Delhi). Specifically for Los Angeles, Porse et al. (2020) estimate that rooftop solar could satisfy 29% of on-site demand but that current policies interfere with realizing that level of energy output.

The decision to adopt rooftop solar is a complex one for homeowners. Many studies examine factors that influence adoption of rooftop solar (Abreu et al., 2019), including technological, spatial, and economic factors (Kwan, 2012) as well as social and psychological factors such as peer effects, social norms, and pro-environmental attitudes (Kowalska-Pyzalska, 2018; Graziano and Gillingham, 2015; Curtius et al., 2018; Bollinger and Gillingham, 2012; Wolske et al., 2020). Others focus specifically on intentions; e.g., Curtius et al. (2018) and Lau et al. (2020) examine the role of peer influence on intentions to adopt.

One factor that has not been examined in prior studies of rooftop solar adoption is the impact of place attachment, generally defined as the bond that an individual develops with a particular place where they live or regularly visit (Manzo, 2003; Lewicka, 2011; Junot et al., 2018). Research in environmental psychology suggests that place attachment is linked to pro-environmental behavior. The current study explores the contribution of place attachment, over and above environmental

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attitudes, peer effects, and other factors, in predicting both consideration and adoption of rooftop solar photovoltaics (PV). Policies that focus on providing incentives or capitalizing on peer effects but that do not take into account differences in place attachment may miss opportunities to further enhance adoption of rooftop solar.

We conducted a survey of homeowners in Los Angeles County to assess the effect of place attachment on their decision to consider and adopt rooftop solar. We distinguish between homeowners who adopted solar, those who considered but did not adopt, and those who did not consider at all. To allow for these three discrete outcomes, we used multinomial logit regression to determine the relative influence of place attachment and environmental attitudes, controlling for peer effects and other factors identified in the literature.

2. Theoretical background

Research on adoption of rooftop solar has identified a wide range of potential factors, including economic ones such as incentives, regulatory ones such as the permitting process, physical ones such as the nature of the PV technology, and social ones such as peer effects. For example, Hughes and Podolefsky (2015) find that subsidies had a substantial effect on adoption of solar PV in California. Dong and Wiser (2013) find that more streamlined permitting processes are associated with shorter project development times. Abreu et al. (2019) found that homeowners were more favorable towards an adhesive form of solar PV than towards the conventional type. A recent review (Wolske et al., 2020) of the literature on the effect of peer influence on household energy behaviours, including adoption of rooftop solar, finds solid evidence for the existence of peer effects, despite significant methodological challenges. Their review highlights the existence of both active mechanisms of peer influence, such as interpersonal communication, as well as more passive mechanisms such as normative social influences, and observes that the mechanism through which peer influence operates is not always clear. Many variations of these effects have been considered in the extensive literature on this topic. However, one factor that has emerged in the environmental psychology literature as a strong predictor of pro-environmental behavior has not yet been examined in the context of rooftop solar, namely place attachment.

Strong place attachment is generally associated with pro-environmental attitudes, and under some circumstances with pro-environmental behavior at the local scale (Halpenny, 2010; Manzo and Devine-Wright, 2013), such as engagement in climate change mitigation and adaptation efforts (Scannell and Gifford, 2013; Fresque-Baxter and Armitage, 2012). Research regarding utility-scale renewable energy projects (including hydroelectric, solar, wind and tidal power) showed a strong influence of place attachment on individuals' choices to support or oppose such projects (Carlisle et al., 2014; Devine-Wright, 2011; Manzo and Devine-Wright, 2013; Devine-Wright and Howes, 2010; Vorkinn and Riese, 2011). The review by Boudet (2019) mentions that place attachment has been used to explain attitudes to several other new energy technologies. However, place attachment has not yet been linked to adoption of rooftop solar PV. While place attachment and peer influence may seem related, place attachment can play a role in neighborhoods with weak social ties between individuals. Moreover, place attachment can be strengthened or weakened by factors that have nothing to do with attitudes towards climate change or energy, hence providing a policy lever that is entirely independent from others that have been explored so far. The first contribution of our work is to explicitly examine the effect of place attachment on adoption of rooftop solar.

Research in energy policy that seeks to understand drivers of adoption of rooftop solar draws on a variety of theoretical foundations. Wolske et al. (2017) provide an integrated perspective on three commonly used theoretical frameworks: diffusion of innovations, theory of planned behavior, and value-belief-norm theory. Each of these frameworks focuses on a different subset of the overall adoption process. First, the theory of diffusion of innovations (Rogers, 2003) describes the five stages by which an individual adopts an innovation, as shown in Table 1. Research taking this perspective focuses on the extent to which rooftop solar is an innovation, meaning that homeowners need to learn more about the innovation, for instance by trial or from peers, before adopting it. For instance, Rai and Robinson (2013) find evidence that direct and indirect peer effects lead to faster adoption of solar PV. Second, the theory of planned behavior recognizes several aggregate factors, each of which the result of rational beliefs, that contribute to the intention to adopt: the individual's attitudes towards solar, perceived social norms, and the individual's ability to adopt. Abreu et al. (2019) find that the theory of planned behavior can help predict individuals' intended response to a new form of solar PV (building applied photovoltaic technology). Third, value-belief-norm theory highlights the role of values and altruism in explaining adoption of solar PV. Fornara et al. (2016) find that value-belief-norm theory can help predict individuals' intentions to adopt several forms of green energy, including solar PV.

Although all three theories recognize the distinction between intentions and adoption, the diffusion of innovation theory is the most explicit about distinguishing the multiple decision stages that an individual goes through before ultimately adopting (or not adopting) solar PV. Most studies of diffusion of rooftop solar so far either measure actual adoption, or intentions. We seek to explore whether place attachment contributes to explaining adoption, but also whether the effect (if any) is stronger in the final stage where the homeowner is deciding whether or not to adopt, or in the preceding stage where the homeowner is deciding whether or not to actively consider. For that reason, we explicitly distinguish between the Adoption stage and the Consideration stage. This focus on the differential impact of various factors on consideration versus adoption has implications for policymakers; policy levers that encourage homeowners to consider may differ from policy levers aimed at encouraging homeowners who are already considering solar to actually adopt. For instance, Palm and Lantz (2020) found that an information campaign led to a 29% increase in approved solar subsidy applications in Sweden; presumably that campaign led to an even greater increase in homeowners who at least considered solar, so perhaps a two-stage campaign with a different focus for those who had started to consider would be even more effective.

In the literature on adoption of rooftop solar, it is not common to explicitly distinguish between the consideration and adoption stages. Understanding how various factors affect each decision stage separately is important; a factor affecting ultimate adoption by only a few percentage points would translate to several million more adopters in the U. S. alone. If the factors that encourage homeowners to consider rooftop solar (or inhibit them from doing so) are different from those that ultimately drive their adoption decision, then the policy tools aimed at homeowners in general should also be different from those targeted towards homeowners who are already actively considering.

3. Methods and data

Drawing in part on the extensive literature on consumer adoption of solar PV and other environmental technologies, as well as on

Table 1
The innovation-decision process (adapted from Rogers, 2003).

Decision stage	Definition
Knowledge	The individual becomes aware of the innovation but does not actively seek information about it.
Consideration (Persuasion)	The individual actively pursues information about the innovation and forms attitudes about it.
Adoption (Decision)	The individual engages in evaluation of the innovation and decides whether to adopt.
Implementation	The individual puts the innovation to use.
Confirmation	The individual continues to evaluate the innovation and confirms (or revises) their decision.

environmental attitudes among consumers and consumer decision-making, we conducted a survey of residents of Los Angeles County. The survey was deployed online through Qualtrics on commercial panels of survey respondents who were screened for being homeowners in Los Angeles County. Efforts were made to target solar adopters for over-sampling, which we then adjust for through the demographic weighting of observations in the regression analyses. The survey was deployed from April 13, 2018 through May 11, 2018.

3.1. Survey design and key variables

Our key outcome variable is a trichotomous measure of consideration and adoption of residential solar. This measure was constructed from two questions: "Have you considered installing solar panels at your place of residence?" and, for respondents who answered yes, "Have you installed solar panels at your place of residence?" Given the possibility of individual heterogeneity in interpretation of what it means to "consider" installing solar panels, we leveraged other questions to assess the robustness of our results to alternative measurement strategies, which we discuss in detail toward the end of this section.

Our measure of place attachment is an average of respondents' level of agreement with eight statements drawn from McAndrew (1998), such as "I feel part of what is going on in this area," and "I could not be happy living in one place the rest of my life," using a 5-point Likert scale. The full list of questions can be found in Table S1 in the Supplemental Information. We confirmed the reliability of the index by calculating Cronbach's alpha, which was 0.68, comparable to the alphas McAndrew (1998) reports for the two subscales of place attachments in his study (0.79 and 0.70).

Our measure of environmental attitudes combines three questions on environmental attitudes (see Table S2 in the Supplemental Information), drawn from existing studies of solar adoption (Sigrin and Mooney, 2018; Jager, 2006). The index is the average of the standardized values of the three original questions, and has a Cronbach's alpha of 0.83.

With regards to socio-economic and demographic characteristics, we control for the age, household size, gender, political ideology, pre-tax household income, race, retirement status, and parental status of respondents. Political ideology was based on whether the respondent identified themselves as liberal, conservative, moderate, or neither. The income variable was based on responses to the question where respondents were asked to place themselves into five bins: $36,474 or less; $36,475-$49,735; $49,736-$64,735; $64,736-$86,622, or $86,623 or more. Race of the respondent was coded as White, Black, Asian, or other. Retirement status and parental status were coded as dummy variables.

In addition, we control for the number of years they have lived in their current house and how long into the future they expect to live there. We also control for physical characteristics of their house and household items, including the physical size of the living space in their house, whether they own various appliances associated with high energy consumption, and what power provider they are served by. The living space was in square feet, binned into 20 categories from 500 or less through 5000 or more. With regards to high energy appliances, respondents were asked whether they owned air conditioning, a swimming pool, or a hot tub, and these responses were added up, for a range from 0 to 3. Although there were 9 power providers total among the respondents, the vast majority were served by either Southern California Edison or Los Angeles Department of Water and Power.

Finally, we control for the factors that can potentially shape the respondents' decision about adoption of solar power, including whether they drive a low emissions vehicle, potential peer effects, economic considerations, aesthetic considerations, and knowledge about solar power in their decision. Ownership of low-emissions vehicle was coded based on whether the respondent owned either an electric or hybrid vehicle. Potential peer effects were coded dichotomously based on whether respondents personally know anyone else who has adopted solar power. Respondents reported the salience of economic considerations, aesthetic considerations, and knowledge about solar power in their decision on a 100-point scale.

3.2. Survey procedure

Survey design began in late 2017. Institutional review board approval was received April 5th, 2018. The survey was administered online, with Qualtrics contracted to recruit 4000 respondents. Qualtrics used existing panels of potential online survey respondents and administered screening questions to limit the responses to those residing in Los Angeles County and owning a home. Qualtrics also made efforts to over-sample likely solar adopters in order to increase the power of analyses that focus on that subset of respondents. After an initial 10% sample was collected, the survey collection was paused and analyzed. At that time the research team chose to merge two branches of the survey that separated 'recent' (less than 3 years) and 'older' (3+ years) adopters of residential solar due to concerns about lack of power. The survey collection was restarted, ultimately continuing from April 13, 2018 until May 11, 2018, with 4207 total responses in the end (including partial responses).

On September 3rd, 2018, a study plan was pre-registered with OSF, including as one of the proposed studies this analysis of the link between place attachment and residential solar adoption. The authors who prepared this study plan did not have access to the data until after the registration of the study plan.

We received 4207 responses. One did not indicate whether they had considered and/or adopted solar power and was dropped; others were discarded due to missing values in responses to various independent variables used in the analyses reported here. The sample used in our analyses is 3723 respondents, of which 1332 did not consider adoption of solar power, 1238 considered adoption of solar power but ultimately did not adopt, and 1153 had adopted solar at the time they responded to the survey.

3.3. Regression methods

Both the underlying theory and empirical data we have on homeowner decision-making regarding residential solar adoption suggest a trichotomous categorization of respondents: those who have actually adopted residential solar, those who have considered but have not adopted solar, and those who have not considered. Analysis of a trichotomous outcome requires the use of a statistical model that allows for multinomial choice. For the primary analysis reported in this paper, we use a multinomial logit model, which allows each coefficient to affect the relative probability of each of the three outcomes. We estimated the main model, robustness models and calculated predicted probabilities and marginal effects using both the R package mlogit (v1.01) and in Stata 15.

4. Results

4.1. Descriptive statistics

Table 2 shows the descriptive statistics for our main variables; full details are provided in Table S3 in the Supplemental Information. The two main independent variables of interest are place attachment and pro-environmental attitudes; the correlation between them is 0.26.

4.2. Main results

To explore the relative impact of place attachment, pro-environmental attitudes and other factors on decision-making regarding rooftop solar, we used multinomial logistic regression with a trichotomous outcome variable: "Not Consider," "Consider Only," and "Adopt." Interpretation of coefficient in a multinomial logistic regression is not straightforward, so we report the predicted marginal effects in

Table 2
Selected descriptive statistics.

Dependent Variables:	Total			%
Consider/Adopt Solar				
Did Not Consider	1332			35.78
Considered, but Not Adopted	1238			33.25
Adopted	1153			30.97
Total	3723			100.00
Independent Variables:	**Mean**	**SD**	**Min**	**Max**
Place Attachment Index (1 = lowest, 5 = highest)	3.44	0.63	1.00	5.00
Enviro. Attitudes Index (composite, see text)	0.023	0.86	−2.40	1.30
Peer effect (dummy variable, 1 = yes)	0.686	.46	0	1
Household Size (people)	2.82	1.64	1	20
Length of Residence at Current Home (yrs)	14.47	12.31	1	60
Expected Length of Future Residence (yrs)	9.02	9.31	0	30
Age	44.78	17.15	18	93
Number of High-Energy Appliances	1.41	0.90	0	3
Salience of Economic Beliefs about Solar Power	71.77	26.21	0	100
Salience of Knowledge about Solar Power	61.82	25.93	0	100
Salience of Aesthetics	56.90	29.16	0	100
Size of the House (categorical, by sq.ft.; see text)	7.10	4.60	1	20

Table 3
Factors in the adoption and consideration of residential solar.

	multinomial logit (marginal effects)					
	consider			Adopt		
	(consider only or adopt) vs. (not consider)			(adopt) vs.(consider only)		
	Estimate	S.E.	p-value	Estimate	S.E.	p-value
place attachment	0.0035	0.0118	0.769	0.0759	0.0219	0.001
environmental attitudes	0.0566	0.0090	0.000	−0.0351	0.0165	0.033
peer effects	0.1690	0.0133	0.000	−0.0353	0.0293	0.229
age	−0.0040	0.0006	0.000	−0.0077	0.0011	0.000
house size (sq.ft.)	0.0041	0.0017	0.012	0.0063	0.0026	0.017
knowledge about solar	0.0015	0.0003	0.000	0.0031	0.0006	0.000
high energy goods	0.0365	0.0081	0.000	0.0505	0.0140	0.000
(other controls: see Table S4 for full results)						
N (observations)	3723					
Pseudo-R2	0.2275					

Note: the estimates shown in the table are for the marginal effects derived from the multinomial logit regression included in the first column in Supplementary Table S4.

Table 3. The full regression results are shown in Supplementary Table S4.

The first column shows the marginal effects for the consideration decision between all homeowners who considered (including those who adopted) relative to those who did not consider. The second column reports the same for homeowners who adopt relative to homeowners who considered but did not adopt. Each marginal effect estimate reports the estimated effect for an average homeowner (for whom all other variables are held at the mean) of a unit change in the variable of interest. Consider for instance the marginal effect of environmental attitudes on likelihood of consideration, which is 0.0566. This means that for a homeowner for whom all other variables are at the sample mean, an increase in environmental attitudes of 1 unit is associated with a 5.66 percentage point higher probability of consideration over an otherwise identical average homeowner. Similarly, for an average homeowner who is considering solar, a 1 unit increase in place attachment is associated with an increase of 7.59 percentage points in likelihood of adoption.

The results show that having pro-environmental attitudes and knowing people who have previously adopted residential solar are significantly positively associated with consideration of solar, but that they are not significantly associated with greater adoption of solar amongst those who consider it. (The positive significant coefficient in Table S4 compares adopters to non-considerers; the marginal effects in Table 3 compare adopters to considerers who do not adopt.) Conversely, greater place attachment is not significantly associated with consideration of solar, but amongst considerers, it is significantly associated with a higher likelihood of adoption.

While Table 3 reports the statistical significance of our key results, Fig. 1 illustrates the substantive magnitude of our findings in terms of how different levels of environmental attitudes and place attachment affect probabilities of consideration and adoption. Holding all of our other explanatory variables constant at their respective mean values, going from a relatively low level of pro-environmental attitudes (20th percentile in the environmental attitude index) to a high level (80th percentile) results in an increase of 10.7 percentage points in the likelihood of consideration (from 67.1% to 77.8%), a large and statistically significant difference. A similarly large change in place attachment (from 20th to 80th percentile) results in a non-significant increase (0.4 percentage points) in the likelihood of consideration.

However, when it comes to actual adoption of rooftop solar (among all respondents, including those who considered and those who did not consider), place attachment has a significant impact whereas environmental attitudes do not. Here, a change in place attachment from the 20th to the 80th percentile is associated with a 5.0 percentage point increase in likelihood of adoption of residential solar (from 21.0% to 26.0%). A comparable change in environmental attitudes is associated with a non-significant increase in adoption of residential solar (1.8 percentage points, from 22.1% to 23.9%). This suggests that although stronger environmental attitudes increase the probability of considering solar in the first place, it does not ultimately lead to significantly higher adoption. In other words, a homeowner who considers solar primarily for environmental reasons is less likely to follow through with adoption than a homeowner who considered solar primarily for other reasons. This is also illustrated by the negative coefficient for environmental attitudes in the adoption regression in Table 3 (which shows estimates for adoption conditional on consideration).

Many other factors increase the likelihood of both consideration and adoption of residential solar, including owning goods such as pools or

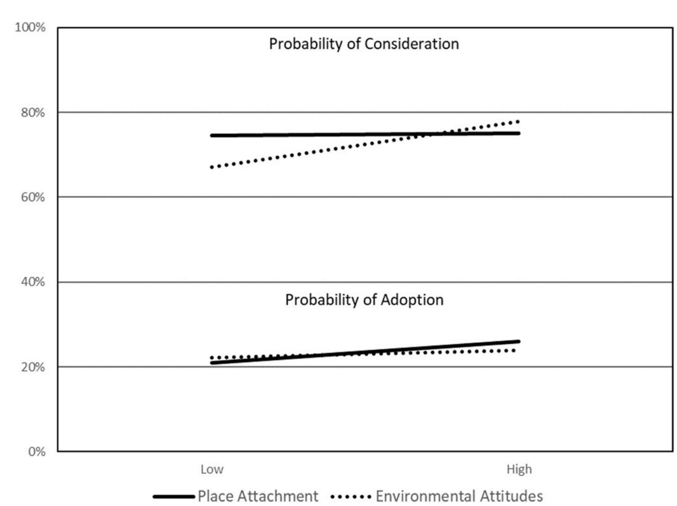

Fig. 1. Impact of environmental attitudes and place attachment on probability of consideration and adoption of rooftop solar (among all respondents).

electric vehicles that consume a great deal of electricity, knowing more about solar power, and having a larger house. Age, on the other hand, is negatively correlated with both consideration and adoption.

To summarize our main results, we find that environmental attitudes and peer effects make homeowners more likely to consider rooftop solar; however, once they are considering solar, environmental attitudes and peer effects do not lead to significantly greater adoption. Rather, among homeowners considering rooftop solar, place attachment plays a surprisingly large role in predicting actual adoption (Fig. 2). This distinction between the factors driving consideration vs. adoption has implications for policymakers, as the tools they can use to encourage consideration could differ from those aimed at encouraging adoption.

4.3. Robustness tests

To assess the robustness of our results, we explored numerous alternative model specifications and operationalizations of our main variables. First, a reasonable alternative statistical model choice that might also be appropriate would be to use a nested logit, in which the analyst assumes that the “consider” and “adopt” outcomes are ‘nested’ together, as in a sequential choice model in which a homeowner first chooses consideration and then whether or not to adopt. This model requires stronger assumptions by the analyst, even though it is also consistent with the theoretical framework of this paper. Supplementary Table S4 includes the full results for the multinomial logit summarized in Table 3 and the results of a comparable nested logit, and shows that the model choice has no substantive effects on our results. In Supplementary Table S4 we report the two “default” comparisons for our trichotomous outcome: adopters to non-considerers and those who only consider to non-considerers. These two sets of comparisons provide a full set of reported results for each model, although other comparisons can also be made.

Second, we explored whether our deliberately non-representative sample influenced our results. Naturally, the respondents to the survey do not match up neatly with the demographics of homeowners in Los Angeles County. For example, based on the data from the American Community Survey (ACS) (Ruggles et al., 2020) for year 2016, the area homeowners (and their spouses) are relatively old, with over 36% older than 60 and only 17% younger than 40. More than 45% of all the respondents to our survey, on the other hand, reported their age to be under 40 while less than 25% indicated that they are over 60 years of age. Less dramatically, women are overrepresented among our respondents (almost 60% rather than 55%), as are Asian-Americans (18.8% among our respondents vs. 14.6% among local homeowners). The distribution of income amongst our respondents also differed from the overall distribution of Los Angeles homeowners. At the top of the distribution only 44.9% among those who were willing to indicate their income reported annual household income over $86,623, vs. 49.9% among actual homeowners, and at the bottom 10.5% indicated income less than $36,474, vs. 18.2% among actual population.

In order to mitigate the potential bias from the discrepancy between our sample and actual socioeconomic distribution of the homeowners, we developed the weighting scheme for the model based on the sociodemographic characteristics of the homeowners and their spouses in Los Angeles County, on the assumption that either would have been likely respondents to the survey. Their characteristics were obtained from the 2016 ACS data, along the four dimensions of race, gender, age, and annual household income. For each group corresponding to a particular set of values along these variables, the shares of the subgroup relative to the overall population, in both the actual population and among respondents to our survey, were compared against each other. If the subgroup is under- or overrepresented in our sample relative to the overall population in our sample, they were assigned a weight to counteract the distortion so that the distribution of the fully weighted sample would match the distribution of the actual population along these four axes.

To assess robustness of our results, we estimated a model using the traditional demographic weights as described above, as well as a model with the most extreme weights (the 1% most weighted and the 1% least weighted) trimmed, to ensure that no single observation has excessive influence on the results. Both models result in comparable findings to the primary analyses reported in the paper.

Third, we varied how we classified respondents into the “not consider” and “consider” categories. For our main results we relied on respondents’ answer to the question “Have you considered installing solar panels at your place of residence?” While “adopt” is relatively unambiguous, it seems likely that there may be some heterogeneity in respondents’ understanding of the term "consider". The survey included other questions that capture explicit actions taken by nominal considerers, requiring increasingly costly action, including researching residential solar, contacting solar installers and actually getting bids. As we use increasingly strict measures of consideration, the effect of environmental attitudes on consideration weakens, but the effect of place attachment on adoption within the resulting group of considerers remains largely unchanged.

For our fourth set of robustness tests we used alternative versions of our key measures of place attachment (based on 8 questions) and environmental attitudes (3 questions). To ensure that our results are not driven by any single component of the measures, we sequentially remove individual components of each measure, reporting eight models in which place attachment is based on only seven questions and three models in which environmental attitudes are based only on two questions, all of which result in similar findings to the main analyses.

For our fifth set of robustness tests, we decompose indices included

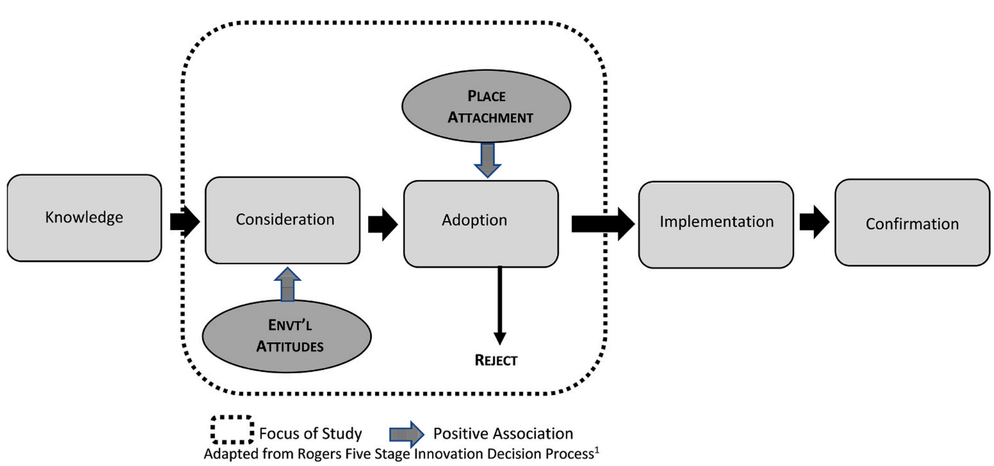

Fig. 2. Effects of place attachment and pro-environmental attitudes on innovation decision.

with the control variables. We do find some differences in simultaneous adoption of high energy appliances: installing new air conditioning is associated with both increased consideration and adoption, installing a swimming pool is significantly associated with increased adoption only, and the installation of a jacuzzi has no significant effect. Our main findings are not affected.

Finally, we check whether our core results are robust to the inclusion or exclusion of these control variables, and find that in all variations we considered our primary results for the relationship between place attachment, environmental attitudes and the consideration and adoption of residential solar remain robust.

5. Conclusions, policy implications and limitations

5.1. Conclusions

This study illustrates two important aspects of the role of psychological and attitudinal factors in the decision of whether to adopt new environmentally beneficial technology, in this case rooftop solar. First, it demonstrates that place attachment plays a meaningful part in real-world decisions regarding rooftop solar. The magnitude of the overall effect of place attachment on adoption is comparable to or greater than that of environmental attitudes and of peer effects. To some extent, this is surprising given that rooftop solar is largely concerned with a global environmental problem while place attachment is an inherently local construct (Vorkinn and Riese, 2011). Prior place attachment studies identified a spill-over effect in which place attachment to the local environment generates positive feeling towards the broader environment, increasing the likelihood of pro-environmental attitudes and behavior more generally (Halpenny, 2010; Vaske and Kobrin, 2001). However, our results suggest that something more than spill-over is occurring. Place attachment and pro-environmental attitudes impact decision-making at different stages in the rooftop solar decision process, suggesting that place attachment affects decision-making independently of pro-environmental attitudes. Further study of the mechanisms by which these factors impact the decision to adopt rooftop solar is needed to address the local attachment-global impact conundrum.

Second, our results elucidate the locus and the effect of pro-environmental attitudes, peer effects, and place attachment in the decision-making process. Prior work showed that homeowners who had pro-environmental attitudes or peers who adopted rooftop solar were themselves more likely to install it. Our results show that these effects are linked to one stage of the decision process—consideration—in which the homeowner decides whether to invest the resources into actively considering a solar system. Those pro-environmental attitudes and peer effects play little apparent role in the homeowner's subsequent evaluation of the new technology. Conversely, stronger place attachment makes homeowners more likely to adopt once they consider rooftop solar, but does not make them more likely to consider in the first place. This is in contrast to some of the work discussed in the review mentioned earlier (Wolske et al., 2020), which suggests that interacting with existing adopters may not necessarily increase the likelihood of considering rooftop solar but may increase adoption by reducing uncertainty. The review notes though that those studies rely on respondents' recollection of those influences, which may not be accurate. Clearly, parsing the locus of the effect is necessary to provide guidance to policymakers and purveyors of solar systems in crafting more nuanced policies to drive broader adoption.

5.2. Policy implications

It is well-understood that policies aimed at increasing adoption of rooftop solar PV can leverage a combination of economic mechanisms, such as incentives (e.g., Hughes and Podolefsky, 2015), and social mechanisms, such as peer effects (e.g., Bollinger and Gillingham, 2012; Wolske et al., 2020). Earlier work (such as Graziano and Gillingham, 2015) has suggested that policy-makers can leverage these peer effects when identifying neighborhoods to target for information and outreach programs. Our finding that place attachment also contributes to higher adoption of rooftop solar suggests that such neighborhoods should not be selected only based on likely attitudes towards solar PV, but also based on the overall degree of place attachment felt by individuals in the neighborhood. Scannell and Gifford (2013) found stronger climate change engagement among neighborhoods with greater place attachment. Neighborhoods that may not seem like prime candidates for policies aimed at encouraging adoption of rooftop solar may be more appealing targets when place attachment is taken into account. If neighborhoods with high place attachment include some where many residents are from minority groups, then including such neighborhoods as potential targets for outreach programs could help reduce the inequity in diffusion of rooftop solar (Reames, 2020; Sunter et al., 2019).

Moreover, policies need not explicitly focus on solar at all: investments in strengthening place attachment could also contribute to higher adoption of rooftop solar. Emphasis on an ideologically neutral factor such as place attachment could sometimes be more effective than a focus on climate change directly. While a recent study concluded that individuals across the ideological spectrum in the United States are adopting rooftop solar (Mildenberger et al., 2019), appeals to the environmental benefits of rooftop solar may be counterproductive for populations that are skeptical of climate change. For instance, in some such communities with relatively strong place attachment, positioning adoption of rooftop solar as a way to strengthen local resilience may be more meaningful than emphasizing the climate change benefits. Alternatively, programs aimed at encouraging adoption of rooftop solar in communities exhibiting lower level of place attachment may be less effective if they are not preceded by efforts to improve the quality of life in those neighborhoods first, to strengthen residents' place attachment; Junot et al. (2018) make a similar argument for pro-environmental behaviors more generally.

Moreover, we find that the factors that drive homeowners to start considering rooftop solar are not the same as those that drive them to adopt once they are already considering. As a result, policies that are ultimately aimed at increasing adoption should be tailored toward the decision stage the target audience is in. For example, to encourage residents to seriously investigate solar—to spend time and cognitive resources to seek out information online and in-person—policies may focus heavily on the environmental benefits of solar in education and outreach programs. Likewise, such programs would also emphasize demonstration projects and adoption by neighbors and peers to drive consideration. This is consistent with the approaches described in, among others, Jager (2006) and Palm and Lantz (2020). However, for those residents who are already actively considering, our findings suggest that stronger pro-environmental attitudes do not further increase the likelihood of adoption. Therefore, when confronted with homeowners who are already considering rooftop solar, policies should perhaps not continue to emphasize its environmental attributes, but can leverage the effect of place attachment instead. They could do so by establishing a positive link between rooftop solar and place. For example, Curtius et al. (2018) suggested that policy-makers should leverage regional hot spots where peer influence spurs faster diffusion. Once a policy-maker has stimulated interest among homeowners in such a hot spot, messaging could focus on other aspects of the neighborhood, to enhance homeowners' sense of place attachment, rather than necessarily focusing on environmental or economic aspects of solar. Decision-making is a nuanced cognitive and behavioral process; policies aimed at influencing it should be nuanced as well.

5.3. Limitations

While the survey design and statistical methods reported in this paper are fairly standard, it is important to recognize key methodological limitations.

First, these analyses rely on survey respondents whose answers we cannot independently verify. We have no reason to believe the survey respondents would be particularly likely to provide inaccurate answers to any of the questions, and we have conducted extensive robustness analyses to ensure that our findings do not rest on any single question. Still, we are working with answers provided by respondents, not objective measures of reality.

Second, the methods used here demonstrate a clear correlation between place attachment and residential solar adoption, one that is robust to alternative statistical specifications and the inclusion of a wide range of control variables, but this does not demonstrate causality. We cannot rule out that the correlation between place attachment and solar adoption is driven by other unobserved factors beyond the scope of this study. This is a common limitation when using observational data to study the link between attitudes and beliefs and behavior.

Third, we should be careful about the external validity of our study. Our findings are drawn from a survey of Los Angeles homeowners, where the environmental conditions are well-suited for solar energy production and there is a robust market for residential solar installation. It is not clear that our findings would extend to homeowners in areas in which residential solar has yet to even gain a foothold.

Finally, the policy implications we propose are speculative, and not confirmed directly by our results. For instance, to test whether greater place attachment increases adoption of solar PV, one would ideally conduct a randomized controlled trial over time where policy-makers invest in some neighborhoods but not in others, measure whether place attachment in the treated neighborhoods increased over time, and then determine whether more homeowners adopted rooftop solar in those neighborhoods than in the control neighborhoods. That is clearly unlikely to be practical, but we hope that our work will help broaden the policy toolkit by highlighting that a social factor unrelated to solar PV itself, namely place attachment, can also contribute significantly to adoption of rooftop solar.

Author contributions

CC, HH, TM, BN, and AP designed the research; CC, HH, TM, BN, and AP designed the survey; BN and AP managed the execution of the survey; HK and BN performed the statistical analysis; CC, HH, HK, TM, and BN wrote the paper. All authors reviewed the final draft.

Data availability

The subset of the survey data which were used for the analyses reported here, together with code for running, are available from the authors upon request. All responses are retained, including those that we excluded during the analysis. All variables that were used in these analyses are included; variables not used in this analysis have been excluded.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enpol.2021.112764.

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