Adopting LEDs changes attitudes towards climate change: Experimental evidence from China

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Abstract

The adoption of low carbon technologies needs to go hand in hand with an increased awareness of climate change and its consequences and solutions. Attitudes toward climate change are influenced by a variety of factors, most notably educational attainment and exposure to climatic events attributable to climate change. However, less is known about the effect of technology adoption on climate change beliefs and support for mitigating measures. Through a longitudinal, incentivized field experiment with Chinese households, we assess attitudes toward climate change before and after adopting efficient lighting technology. The results show differential patterns of attitudinal change: while belief in the reality of climate change and willingness to adopt energy-efficient appliances increase, support for energy taxes does not. We attribute the attitudinal change to the adoption of LED light bulbs. Further evidence suggests that experience with efficient technology, rather than knowledge acquisition, drives this change. These results highlight the importance of action-initiating behavioral intervention to complement educational programs aimed at improving knowledge.

Keywords: energy efficiency, environmental attitudes, field experiment

Addressing global warming requires wide-ranging behavioral changes by individuals and households. The widespread adoption of new technologies with lower energy and carbon content is needed, as is support for the mitigation of climate change [19, 21]. To sustain both pro-environmental behavior and policy support, personal awareness of the importance and consequences of climate change is essential [39].

Countries around the world have implemented policy interventions to promote energy saving behavior and technologies, relying on both traditional market-based instruments and insights from the behavioral sciences, such as mass media campaigns, home audits, real-time information feedback, and so on [1, 2, 3, 4, 5, 6, 7, 8, 10, 17, 18, 19, 22, 24, 33, 34, 41, 42]. The underlying assumption behind such information and educational programs is that awareness and knowledge come before action. The expectation is that if people's awareness can be changed, their actions will follow. Existing research provides mixed but overall positive evidence for the direct effect of information and behavioral tools on behavioral change, at least in the short-run.

Yet little is known about the influence of behavioral change on altering attitudes and beliefs. Promoting personal awareness and knowledge of the climate change problem is challenging. A series of studies conducted by the Yale program of climate change communication, targeting mostly individuals from the US, reported that knowledge gaps and misconceptions about climate change are common. For example, only seven in ten Americans believe global warming is occurring, and only one in eight understand that almost all climate scientists (more than 90%) agree that human-caused warming is happening [30]. In this paper we aim to fill this gap by investigating whether changing people's behavior, for instance inducing the adoption of green technology, can increase their awareness of climate change, support for climate policies, and willingness to engage in subsequent action.

Our study is closely related to the social psychology literature that applies theories of persuasion to pro-environmental endeavors [9, 14]. According to this literature, the basic mechanism behind the effectiveness of persuasion in changing people's attitudes and beliefs lies in the individual's preference for consistency (PFC). Individuals with a strong PFC value personal consistency and strive to respond to most situations in a manner consistent with prior behavior [15, 23]. As Cialdini and colleagues point out, providing information may have a limited effect on beliefs when the individual's motivation or ability to think about the issue is low, which is common in practice. However, persuasion may still take place through a "peripheral route," in which cues other than the central message create a more tangential influence on the issue at hand. Bem's [11] self-perception theory, in which people observe their behavior and then infer internal reasons for it, suggests that the peripheral route can generate long-term effects once the individual begins to consider the advantages of the triggered pro-environmental behavior.

Alternative theoretical perspectives predict that behavioral change and attitudes have the opposite sign. For instance, moral licensing models argue that engaging in virtuous behavior will reduce feelings of moral obligation to further pursue similar actions and beliefs [36]. Across behaviors, studies offer evidence of both positive and negative spillover [13, 20, 26, 27, 38]. In the energy domain, patterns consistent with moral licensing, i.e. negative spillovers, have been observed between electricity and water consumption [37]. However, the evidence of spillover from behavioral change to policy support is limited. Werfel [40] finds that reporting energy saving actions lowers support for a carbon tax in Japan, a crowding-out effect which appears to be driven by the perception of sufficient progress [25, 28].

In this paper, we contribute to the literature in three ways. First, we test the alternative predictions of the preference for consistency and moral licensing theories, and show how the former is consistent with our findings. Namely, we show that adopting low carbon technology leads to a positive change in attitudes toward climate change. Second, we acknowledge that attitudes are multifaceted, as are the policies aimed at tackling climate change, which range from carbon pricing to renewables subsidies and energy efficiency mandates, and show that attitudinal change does not occur equally across these different policy realms. Specifically, attitudes improve more significantly for policies related to technology adoption and change, which are more directly linked to the behavioral change our intervention focuses on. Third, we provide suggestive evidence that experience with green technology, rather than cognitive awareness of its benefits, leads to attitudinal change and subsequent action.

We use efficient lighting in China as a setting for an incentivized, longitudinal field experiment. We test whether receiving LED light bulbs changes household attitudes toward climate change and its policy solutions. China is the world's largest CO_2 emitter. It has set new domestic energy and carbon intensity targets, including policies aimed at decreasing energy consumption and emissions from the booming residential building sector. Chinese people are generally aware of climate change, and more so if they have higher levels of education and exposure to climatic events attributable to global warming [16, 25, 28]. This paper reveals the extent to which Chinese households support CO_2 emission reduction policies and what can affect their support. Studying policy-driven attitudinal change can provide useful insights when evaluating long-term policy effects.

Climate attitudes and their evolution

We conducted two waves of an experiment and survey over the course of three months to evaluate changes in attitude toward climate change (see **Materials and Methods** for Sample and Procedure). Through an online survey platform, we recruited 1,268 participants at baseline, and managed to survey 585 of them again after three months. In addition, at that follow-up we recruited 261 new participants to capture any exogenous time trends in attitude due, for instance, to seasonal change, national awareness campaigns on climate change, etc. Compared to the national averages, highly educated and high-income individuals are over-represented in our sample. See *SI Section A* for summary statistics on the different samples and the corresponding national averages. Our results demonstrate no differential attrition based on attitudes toward climate change or other traits when comparing baseline and follow-up samples, and no significant differences between follow-up and newly recruited participants.

At baseline, each participant was given a small gratuity (of CNY 30, approximately USD 4.5). We elicited each participant's willingness to pay (WTP) for an LED light bulb through incentivized pairwise choices between LED and CFL light bulbs: we drew one of these choices at random for each of the participants, and sent their selected light bulb to the address they had provided, subtracting the corresponding price from their gratuity (see *SI Section H* and *I* for further explanation of the payment scheme and the exact wording of the questions). Of the 585 follow-up survey participants, 267 received an LED light bulb, 69 received a CFL light bulb, 11 reported that they did not know what type of light bulb they had received, 130 did not receive a light bulb due to giving an imprecise address, and 108 did not provide their postal address.

During both waves, 585 participants completed a questionnaire containing a set of questions measuring their beliefs, attitudes, motivations, values, policy preferences, and actions concerning climate change, including energy efficiency and conservation behavior, consumer behavior, and political behavior. We drew these questions from a questionnaire developed by Yale University's Program on climate change communication [29]. To the best of our knowledge this is the most comprehensive questionnaire on climate change attitude, and has been used in the US, India, China, and other countries [12, 28, 31] (see *SI Section B* for the full text of the 31 questions). In addition, we checked participants' knowledge of the energy cost and environmental benefits of LED light bulbs (see *SI Section F*).

We classify the 31 questions on climate change attitudes into 10 main categories, indicating whether participants believe that climate change is occurring (C1), think humans are responsible for climate change (C2), believe that the impact of climate change is severe (C3), feel that mitigating action is urgent and possible (C4), are likely to call for policy change (C5), are likely to use green modes of transportation (C6), are likely to purchase energy-efficient (EE) appliances (C7), support taxes on electricity and gasoline (C8), support international cooperation against climate change (C9), and support the introduction of renewable and efficiency standards (C10). The categories thus refer to general beliefs about climate change (C1 to C4), actions that can be taken to mitigate climate change (C5 to C7), and support for policies that target climate change (C8 to C10). We create indicators for each category by summing up participants' answers to the corresponding questions (see *SI Section B*). Figure 1 shows how the answers in each category changed between the baseline and the follow-up surveys (N=585).

We observe a generalized increase in scores in the follow-up survey across all ten categories. The differences over time are statistically significant for the belief that climate change is happening, the belief that its impact is severe, the likelihood of making green transport choices, the willingness to purchase EE appliances, and support for new efficiency standards (Wilcoxon signed rank tests, p = 0.0001, 0.0019, 0.0457, 0.0003, and 0.0093, respectively). [1] These results indicate that the choice of light bulb intervention increased concerns related to the adoption of pro-environmental technology and the willingness to support efficiency standards, but not the willingness to support energy taxes. Our results are not consistent with recent evidence of crowding-out between reporting energy saving actions and support for a carbon tax in Japan [40]. Attitudes unrelated to climate or energy, such as opinions on the role of government, peace, and inequality, did not change between baseline and follow-up (Wilcoxon signed rank test, p=0.1739).

[1] To control for multiple-hypothesis testing and false positives, we implement Bonferroni correction. All changes in attributes remain significant except for the likelihood of making green transport choices.

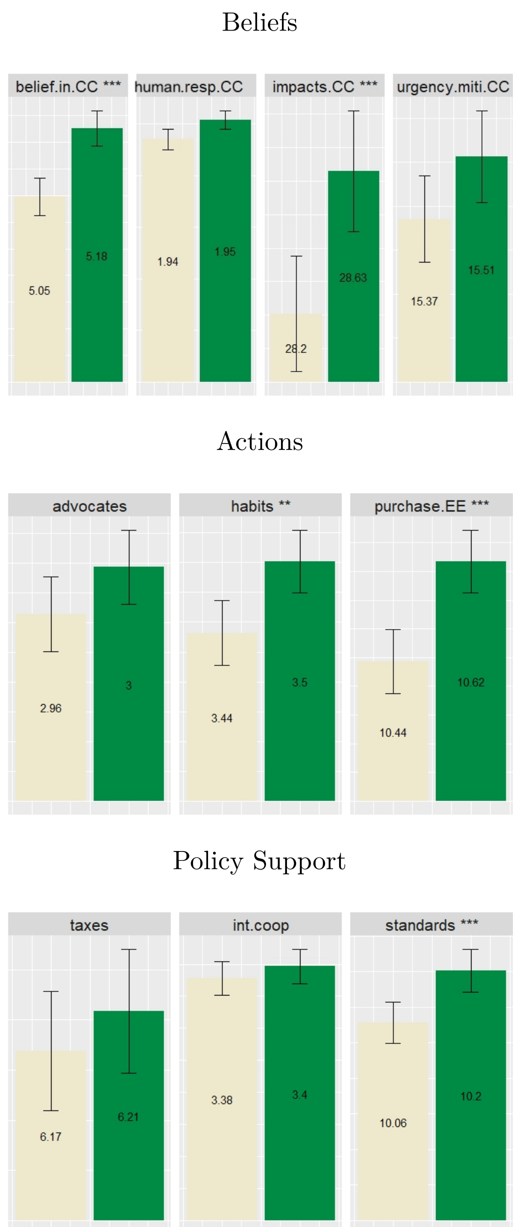

Figure 1: Climate change attitudes over time. The bars show baseline means (yellow/light) and follow up means (green/dark). Error bars show standard errors. Significance of Wilcoxon signed rank test: < 0.01 ***; < 0.05 **; < 0.1 *.

Sources of change

During the study, participants received an LED or CFL light bulb, depending on their WTP, except for those who did not leave a valid postal address. We now examine whether the changes in attitude between baseline and follow-up can be attributed to receiving an LED light bulb. We generate a dummy variable equal to one if the participant reported receiving an LED at follow-up, which was true for 267 participants. We consider these subjects as treated. We then consider all participants who did not receive an LED as the untreated subjects (N=318 in total), including those who received a CFL (N=69), those who could not remember the type of light bulb they received (N=11), those who did not receive a light bulb due to leaving an imprecise address (N=130), and those who did not leave their postal address (N=108).

Receiving an LED is not purely random, but is affected by the endogenous WTP and possibly other unobservable characteristics of the participant. For this reason, any comparison between subjects receiving or not receiving an LED could be affected by selection bias. We thus use propensity score matching (PSM)[35] to build a sample of treated and untreated subjects similar on all observable characteristics to reduce potential sources of bias. We match each LED recipient to a non-recipient according to baseline WTP, baseline knowledge of the energy cost and environmental benefits of LED light bulbs, LED light bulb ownership, and demographic characteristics (income, age, university degree, an indicator for having children, and gender). This procedure generates a matched sample of 410 of the 585 participants, with 205 LED recipients in the treated group and 205 non-recipients in the control group. After matching, receiving an LED is no longer correlated with WTP and individual traits. Thus, we can consider LED receipt as exogenous and evaluate its impact on attitudes toward climate change (see *SI Section C* for details of the PSM).[2]

[2] We conduct sensitivity checks on the effects of potential unobservables. We also test the robustness of our results to two alternative matching calipers, each with 1000 iterations

It is reasonable to believe that the four sub-groups in the untreated group are not equally comparable to the treatment group. More specifically, assuming that the incentive-compatible WTP elicitation method reveals a true preference with each decision, and that subjects are equally satisfied with each choice they made, the first sub-group is then considered as a valid control group.[3] However, the participants in sub-group three who left an imprecise postal address and thus did not receive the light bulb may be disappointed, and have different attitudes toward climate change as a result of this disappointment. Similarly, sub-group four participants who did not leave us their postal address may care more about their privacy, which may also be related to their climate change attitude. The third sub-group differs from the first in that they did not receive any light bulb. If not receiving the light bulb they asked for affects their climate change attitude, we should observe a difference in attitudinal change between sub-groups one and three. Similarly, if trust in the experimenters is related to climate change attitude, we should observe differences in the baseline climate change attitude between sub-group four and the participants who left an address. We use Friedman tests to establish whether these three sub-groups show the same attitudinal change in all attributes, and detect no difference in any of them ($p>0.1$ for all attributes).[4]. Further, regarding participants who have stronger privacy con-

(see **Materials and Methods** for the analysis and *SI Section C* and *E*).

[3]It is required that given a level of WTP, receiving one type of light bulb rather than another is not associated with systematic differences in satisfaction, welfare, attitudes toward the researchers, or other variables that might also affect our outcomes of interest. Asking for subjects' satisfaction with the received light bulb in the follow-up surveys would only partially solve this issue: in fact, it is possible that subjects who received a CFL would report lower satisfaction not due to a direct effect of the bundled delivered to them, but as a result of experiencing the CFL and not liking it. If subjects receiving a CFL were systematically less satisfied with the quality of the product, not ex-ante, but after having experienced its lower quality relative to an LED, this would introduce a bias in our results.

[4]Except for the attribute "habits" where $p=0.0658$. "Habits" was elicited by asking "how are you willing to bike, ride public transit or walk one more day per week?" Post-hoc comparisons reveal that the mean change of the three sub-groups are 0.0682, -0.0111, and

Table 1: Climate attitudes impacts of receiving a LED

	Change in 'Belief in CC'	Change in 'Purchase EE'
Received LED	0.1805**	0.3122***
	[0.0847]	[0.1186]

The table reports average treatment effects of receiving a LED. Standard errors are in parentheses. Significance of Wilcoxon signed rank test: < 0.01 ***; < 0.05 **; < 0.1 *.

cerns, we test if they differ in baseline attitudes from the combined treated group and the others in the untreated group. Wilcoxon tests confirm that they do not differ significantly (p>0.1 for all attributes).[5] In the following analysis we pool the participants in the four sub-groups together.

Wilcoxon signed rank tests on the matched sample reveal that the changes in some climate attitude categories can be explained by receiving an LED. Specifically, receiving an LED increases both the belief that climate change is occurring and the likelihood of purchasing EE appliances, the two dimensions of attitudes that increased most between baseline and follow-up. The self-reported likelihood of buying EE appliances is not just cheap talk: we find it strongly correlated with an incentivized WTP for LED at follow-up (Pearson Correlation, $\rho = 0.16$, p=0.0000). Other attitudes are not significantly affected by receiving an LED.

Through which channel does an LED light bulb work to change attitude toward climate change and conservation behavior? One possible explanation is experience with the LED light bulb. We test this conjecture by asking participants whether they installed the light bulb they received. Among

-0.2121, respectively. However, any of the two sub-groups are not significantly different from each other (Wilcoxon unpaired test, p>0.1 for all)

[5]Except for the attribute "habits" where p=0.0082. Participants who have left an address reported higher willingness to "bike, ride public transit or walk one more day per week" than those who did not.

the 205 participants in the matched sample who received an LED, 194 reported installing it, 75 of whom also reported that most of the light bulbs in their home were LEDs; 119 said they owned mostly CFL, incandescent, or unknown light bulbs. We test whether the 119 "late adopters" of LED light bulbs were influenced more by the received LED light bulb than the 75 "early adopters". As expected, late adopters have lower scores for willingness to purchase EE appliances in the baseline survey compared to the early adopters (Wilcoxon rank sum test, p=0.0022). However, in the follow-up survey after adopting the LED, the two groups are no longer distinguishable (p=0.1973). Thus, "late adopters" show a greater change in willingness to purchase EE appliances as a result of LED adoption than "early adopters" (Wilcoxon rank sum test, p=0.0249). We find no difference in the belief in climate change (Wilcoxon rank sum test, p=0.9463). This evidence suggests that a new experience with LEDs may influence attitudes.

Another possible mechanism that could drive the observed attitudinal change is a change in knowledge of LED benefits resulting from LED ownership. It is possible that those who received LED light bulbs also acquired more knowledge. We measure knowledge both in terms of energy savings and environmental impact using two multiple choice questions (see *SI Section F*). Receiving an LED increases knowledge of the energy savings from using LED light bulbs, but not of the corresponding impact on the environment (Figure 2). The results are robust to different PSM calipers. These results are consistent with the information subjects obtain from the LED package, which reports energy savings with respect to CFL and incandescent light bulbs (see *SI Section G*). However, we find no correlation between knowledge (either of cost or environmental impact) and changes in "Belief in CC" (Pearson Correlation, ρ=-0.01 and -0.03, p=0.8067 and 0.5834, respectively), or in "Purchase EE" (Pearson Correlation, ρ=0.06 and 0.06, p=0.1895 and 0.2218, respectively).

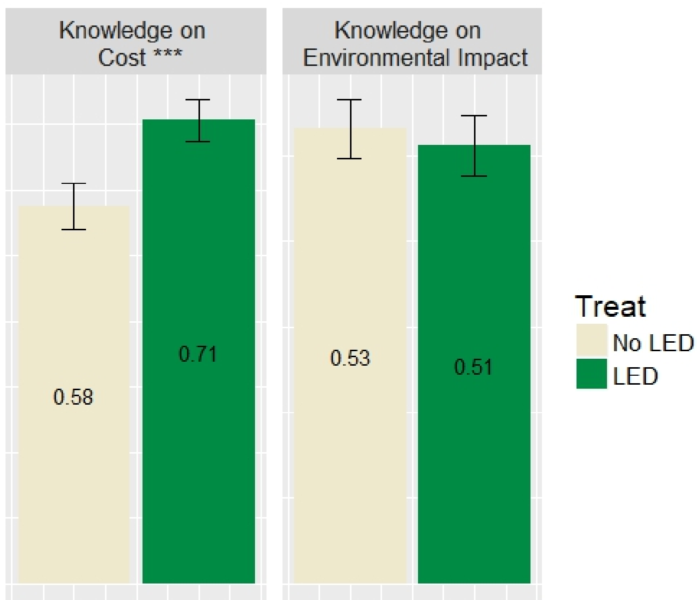

Figure 2: Knowledge on benefits of LEDs. The bars show the proportion of correct asnwers on LED costs (left panel) and environmental benefits (right panel), for subjects who didn't receive the LED (yellow/light) and those who did (green/dark).Error bars show standard errors. Significance: < 0.01 ***; < 0.05 **; < 0.1 *.

Conclusion

We report results from an experiment showing attitudinal change toward climate change over the course of three months, which we attribute to having received efficient LED light bulbs. Participants in the experiment became generally more concerned about climate change. However, significant attitudinal change occurred only along specific dimensions, emphasizing the multidimensional nature of perceptions about climate change and policies aimed at solving it. The driving factor appears to be the adoption and experience of new green technology rather than the acquisition of knowledge. Preference for consistency provides a theoretical framework consistent with our results. The crowding-in of experimental evidence suggests that encouraging small adopting actions by the government or other organizations can lead to subsequent behavioral change. This creates opportunities for designing policy tools that are complementary to educational programs aimed at improving knowledge.

Materials and Methods

Sample Two waves of surveys (baseline and follow-up) were administered using "www.Sojump.com," an online platform providing a nationwide sample of 2.6 million individuals in China for computer-based surveys. Respondents opted into the study by clicking the survey link on the survey list. The follow-up survey was conducted three months after the baseline: we invited all participants who had completed the baseline survey for within-subject comparisons and respondents who had not participated in the baseline for between-subject comparisons. All participants were Chinese non-students from 30 provinces/autonomous regions/direct-administrative municipalities (except for Tibet, Hong Kong, Macau, and Taiwan). Our sample differs from the representative Chinese population (see *SI Section A*) because online surveys cannot reach poorer demographic groups. [6] The baseline was conducted in August, September, and October 2016 (n=1268), while the follow-up took place in November and December 2016 and January 2017 (n=585 returning participants and n=261 newly-recruited participants).

Procedures At baseline, we elicited the willingness-to-pay (WTP) for an LED light bulb from all participants in an incentive-compatible way. Participants were given a CNY 30 gratuity and asked to spend it on the purchase of a light bulb. They were requested to choose between an LED and a CFL light bulb in a series of binary decisions in which we varied the price of the LED light bulb for each decision. For each participant, one of these binary decisions was randomly selected for implementation, and the participants thus received the type of light bulb they had selected in that decision, paid the corresponding price, and received the remaining amount (CNY 30–price) in their Sojump account. Participants with higher WTP were more likely to receive an LED than a CFL light bulb (for elicitation details see *SI Section H*). At the end of the survey we elicited the participants' attitudes toward climate change through 12 questions (31 sub-questions), together with their knowledge about the benefits of LED light bulbs, their current light bulb ownership, and demographic details (see *SI Section B*). In a few places we modified the questions on climate change attitude to fit the Chinese context; these changes are explained in *SI Section B*. In the follow-up survey, we elicited their WTP for an LED, knowledge of the benefits of LEDs, whether they installed the light bulb received, and climate change attitudes again.

At baseline, each participant received either a piece of information on the energy saving of adopting a LED or a control, and one of three pieces of information about the benefits of adopting LEDs: i.e., mitigating climate change, reducing air pollution, or unrelated information as a control. The exact wording is provided in *SI Section D*. At the end of the survey at

[6] In 2016, about 53.2% of the population had internet access. Source: National Bureau of Statistics of PRC

baseline and at follow-up, we tested participants' knowledge on the benefits of adopting LEDs (*SI Section D and F*).

Analysis Our evaluation of the impact of receiving an LED on attitudinal change suffers from an endogeneity issue, as the likelihood of receiving an LED increased with the subject's baseline WTP for LEDs. In addition, there may be differences between subjects who did and did not leave a valid postal address, whether due to privacy concerns or other reasons: indeed, those who left a valid address had a higher baseline WTP. We address such identification issues and assess the causal effect of receiving an LED on attitudinal change using propensity score matching (PSM), which matches each subject who received an LED to a subject who did not, based on the following characteristics: baseline WTP, baseline knowledge of the monetary and environmental benefits of LEDs, light bulb ownership, and demographic characteristics (income, age, university degree, an indicator for having children, and gender). Matching produces a control group that is similar to our treated group, i.e. those who received an LED (see *SI Section C*). We use a central value for the caliper of β=0.25 standard deviations, in line with the literature [32], but provide sensitivity to both the choice of caliper and the bootstrapping results of 1000 simulations (see *SI Section E*).

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