Geoengineering and Licensing:
In Search of a Climate-Relevant Moral Hazard

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Abstract

As climate predictions become more dire and traditional mitigation strategies become less viable, climatologists have been developing geoengineering technology to directly intervene on the climate through 'solar radiation management' and 'carbon dioxide removal'. Some are concerned that the perceived availability of geoengineering options will weaken the public's commitment to mitigation efforts. However, so far, lab studies have not shown a direct effect of geoengineering awareness on mitigation behaviors. Across seven experiments (N = 1,985) I investigated various circumstances that might afford a risk for geoengineering to jeopardize two facets of the public's commitment to mitigation: 1) feelings of urgency about mitigation efforts and 2) motivation for pro-environmental behavior. I do not find compelling evidence that feelings of urgency for mitigation nor pro-environmental behavior are immediately diminished after reading neutral prompts about geoengineering technologies. I describe the 7 experiments and results, then draw from psychology theory to discuss the implications and contextualize this investigation within the wider discussion about the moral-hazard threat.

*Keywords***:** climate change, geoengineering, goal licensing, goal pursuit.

Climate change continues to threaten future generations' necessary resources and way of life. With greenhouse emissions continuing to rise and potentially catastrophic consequences approaching, global mitigation goals will no longer be feasible using traditional mitigation strategies such as carbon-emission limits and energy conservation. Accordingly, climate scientists have been developing technology to directly intervene on climate change by intentionally manipulating the Earth's systems – a set of options referred to as 'geoengineering'. Geoengineering involves two primary approaches: minimizing solar radiation (Solar Radiation Management, or 'SRM') and removing carbon dioxide from the atmosphere (Carbon Dioxide Removal, or 'CDR). While these technologies are promising, climatologists have stressed that geoengineering alone cannot combat climate change. In order to meet global climate goals, people must continue traditional mitigation efforts in addition to implementing geoengineering technologies. But how will the prospect of these technologically advanced geoengineering options affect the public's commitment to mitigation efforts?

With growing public interest in these climate options, policymakers and climatologists must determine how to communicate with the public about geoengineering technologies. Their challenge is to balance transparent risk communication and continued scientific and technological development while still maintaining crucial support for traditional mitigation efforts. As geoengineering options increasingly become part of the conversation, many policymakers and researchers have warned of a potential 'moral hazard' - that the availability of geoengineering options poses more harm than benefit by jeopardizing the public's motivation for mitigation efforts (Anderson & Peters, 2016; Morrow, 2014). Efforts to develop geoengineering have been criticized by experts who argue that, by producing a false sense of a climate safety-net, the mere availability of geoengineering technologies would have consequences for global warming that the technologies themselves are not capable of offsetting (Lin, 2013; Schneider, 2001).

This moral hazard prediction fits in line with a common 'licensing' phenomenon observed in goal pursuit, wherein significant progress on a goal can make the pursuer feel justified in reducing their effort (Fishbach & Dhar, 2005; Fishbach, Zhang, & Koo, 2009). Goal licensing is a relatively common outcome of goal progress, so it is reasonable to expect geoengineering developments to cause a licensing effect in mitigation efforts. However, empirical evidence so far has been mixed on whether the prospect of geoengineering weakens the public's resolve for mitigation efforts (Campbell-Arvai, Hard, Raimi & Wolske, 2017; Fairbrother, 2016; Kahan, Jenkins-Smith, Tarantola, Silva, & Braman, 2015; Merk, Pönitzsch, & Rehdanz, 2016; 2019; Raimi, Maki, Dana, & Vandenbergh, 2019). Some researchers have found evidence that geoengineering can influence beliefs about climate change, but have not identified a direct relationship between geoengineering and pro-environmental behavior (Campbell-Arvai et al., 2017; Raimi et al., 2019).

In an effort to further inform policy and engineering decisions, the current research expands the scope of the search for circumstances that might afford a moral hazard to the public's commitment to mitigation. Building on past lab studies, I test new conditions and dependent variables for evidence that geoengineering poses a threat to the public's environmental concern and pro-environmental behavior.

Licensing

Ultimately, the moral hazard that some climatologists anticipate is that as the public learns about geoengineering advancements, support for mitigation efforts and commitment to pro-environmental behavior will decrease. More specifically, the fear is that the public will erroneously infer that geoengineering will 'solve' climate change, which would then weaken the public's resolve for mitigation via diminished feelings of climate threat and/or decreased motivation for mitigation. This moral-hazard threat of geoengineering is one case of a general motivational threat that has plagued mitigation efforts, wherein some pro-environmental activity decreases subsequent pro-environmentalism. For example: when receiving weekly feedback on their water usage, people use less water but then increase their electricity consumption (Tiefenbeck, Staake, Roth & Sachs, 2013); people are less motivated to behave pro-environmentally immediately after making a pro-environmental donation (Meijers, Verlegh, Noordewier, & Smit, 2015); and farmers who adopt climate-friendly practices become less supportive of mitigation policies (Weber, 1997). Accordingly, there is good reason to expect that the advancement of geoengineering technologies will produce a similar response in the public.

It is useful to characterize this response as 'licensing', wherein making progress on a goal causes the goal to seem less demanding, thereby resulting in decreased motivation toward the goal (Fishbach & Dhar, 2005). Here, I regard climate change mitigation as a goal, defined as a cognitive representation of a desirable objective and motivation toward that end-state (Hull, 1932; Kruglanski et al., 2002). As with any other goal, climate change mitigation consists of goal-directed motivation, progress towards an objective, and coordination with competing simultaneous goals. Accordingly, motivation for the mitigation of climate change bears fundamental goal properties (Nash et al., 2017) and a geoengineering-prompted moral hazard constitutes a motivational threat.

When in goal pursuit, people monitor their progress toward their goal and allocate their effort across multiple goals (Carver & Scheier, 2001; Gollwitzer, 1990; Hull, 1932). In pursuing multiple goals, people can infer that substantial progress on one goal indicates that the goal now requires less work and that they may reduce their efforts in favor of another goal – the 'licensing effect' (Dhar & Simonson, 1999; Fishbach & Dhar, 2005; Fishbach, Eyal & Finkelstein, 2010). For example, after going to the gym, a dieter might indulge in a rewarding dinner or take the next day off from exercise in order to run errands. Similarly, after learning about geoengineering advances, an environmentally-conscious commuter who regularly bikes to work might opt to save time and effort by driving instead.

A number of internal and contextual factors influence whether and when goal licensing occurs (Fishbach et al., 2009). When people are evaluating their goal progress, they can be influenced by the immediate framing of the goal (Fishbach & Dhar, 2005), their emotional feedback (Fishbach et al., 2010), commitment certainty (Koo & Fishbach, 2008) and the presentation of choices (Fishbach & Zhang, 2008). These and other factors contribute to a dynamic self-regulatory process by which multiple simultaneous goals are coordinated. For example, when a studying session is framed as "making progress in academics" as opposed to "feeling committed to academics," students were more likely to prioritize a non-academic goal after the studying session by socializing with friends (Fishbach & Dhar, 2005). Similarly, when initial commitment to a green energy program is minimal, as opposed to more substantial via higher monetary investment, households are more likely to subsequently increase their energy consumption after their participation in the pro-environmental program (Jacobsen, Kotchen, & Vandenbergh, 2012).

Accordingly, while some climatologists anticipate a moral hazard in response to geoengineering advancements, an assumption underlying this fear is that the introduction of geoengineering options constitutes a situation that is conducive to licensing effects for mitigation motivation. More precisely, it is that some properties of geoengineering technologies make their advancement particularly likely to cause the public to infer that sufficient progress has been made toward climate change mitigation to justify curtailing efforts. In this work, I test this assumption and examine the potential for geoengineering to afford licensing effects in commitment to mitigation.

Moral hazard risk of geoengineering

While there is persistent concern over whether geoengineering efforts may weaken the public's resolve for mitigation efforts, lab studies so far have not provided a compelling answer. The public tends to agree that geoengineering poses a threat to mitigation support (Corner & Pidgeon, 2014) but there is little evidence that support or commitment to mitigation change after reading about geoengineering. Reading about specific types of CDR (direct air capture and "bioenergy plus carbon capture", but not reforestation) caused people to feel less threatened by climate change, but did not directly change their support for policies that support mitigation efforts – although feelings of threat were related to policy support (Campbell-Arvai et al., 2017). In a separate study, reading about SRM only undermined mitigation policy support amongst conservatives and moderates, and only when SRM was depicted as a definite and absolute solution for climate change (Raimi et al., 2019). Additionally, I conducted a conceptual replication of Campbell-Arvai et al. (2017) that produced similar results and did not indicate that prompts about geoengineering directly cause a change in policy support (Supplemental Study 1). Thus, there is evidence to suggest that geoengineering can abate feelings of fear about climate change, but no compelling evidence that a decrease in fear consistently translates into a decrease of support for mitigation.

The remainder of the research on geoengineering has yielded mixed evidence. Some researchers have argued that geoengineering efforts pose no moral hazard. In one study, reading brief prompts about geoengineering had no effect on trust in climate science or willingness to pay taxes to help with mitigation efforts (Fairbrother, 2016). In a separate study, even expert levels of familiarity with geoengineering technologies did not result in decreased support for mitigation amongst geoengineering experts compared to the public (Merk et al., 2019). In fact, although there was no effect on mitigation support, geoengineering experts viewed geoengineering as riskier compared to laypeople (Merk et al., 2019). Other studies account the case for why exposure to geoengineering may *increase* concern for climate change, but evidence to support this possibility is weak (Kahan et al., 2015; Merk et al., 2016).

So far, research has begun to characterize the potential for geoengineering to undermine the public's commitment to mitigation, but further work will clarify what circumstances afford a moral hazard and the magnitude of the risk. Open questions remain about why geoengineering awareness has changed feelings about climate change under some circumstances but not others, and about the potential for geoengineering developments to directly undermine mitigation efforts.

Current Research

Lab studies have not identified a case in which geoengineering directly undermines the public's support for mitigation. The empirical search has pursued a potential moral hazard manifested in policy support and concern about climate change. Investigations have tested three potential sources for a moral hazard response: educational descriptions of geoengineering technology (Campbell-Arvai et al., 2017; Fairbrother, 2016; Merk et al., 2016*),* persuasive narratives for and against geoengineering (Kahan et al., 2015; Raimi et al., 2019), and expert levels of experience with geoengineering (Merk et al., 2019). These sources represent some of the many contexts that can evoke climate change mitigation. Similarly, policy support and concern for climate change are a limited representation of many potential manifestations of mitigation support. However, geoengineering can pose a risk if it interferes with any of the many actions that contribute to mitigation. If geoengineering has the potential to jeopardize the public's commitment to mitigation efforts, it may manifest in policy support, water conservation, emissions reduction, electricity use, or any other form of pro-environmental resolve.

This work continues the empirical search. To do so, I first characterize climate change mitigation as a goal and examine mitigation motivation following exposure to geoengineering information. Informed by goal theory (Carver & Scheier, 2001; Dhar & Simonson, 1999) I reasoned that a moral hazard would originate in a licensing effect afforded by the advancement of geoengineering. That is, if geoengineering undermines mitigation efforts, it is primarily because the prospect of geoengineering is particularly likely to appease concerns about climate change and thereby alleviate urgency for climate change mitigation. To test this prediction, I examined whether thinking about geoengineering, prompted by politically neutral and non-persuasive media pieces, reduces feelings of urgency for mitigation (experiments 1 – 3). Then, I expected that this decrease in urgency would culminate in decreased motivation towards mitigation efforts and reduced commitment to pro-environmental behavior. Accordingly, I tested the predictions that thinking about geoengineering decrease motivation for pro-environmental behavior (experiments 4 – 7).

Further, because small differences in framing and other contextual factors can determine whether licensing effects occur or not, I examined new outcomes of interest and evoked geoengineering in different contexts in an effort to expand the search for a potential moral hazard. First, I reasoned that reactions to the prospect of geoengineering may be different when the technologies are not framed within the politically charged climate change context. Thus, I sought to observe a relatively politically neutral measure of commitment to mitigation and introduce geoengineering in science- and business-focused contexts, as opposed to the climate change contexts that have been used previously. In 7 experiments, I measure self-reported feelings of urgency for mitigation (experiments 1 – 3) and behavior to reduce carbon-emissions (experiments 4 – 7) after exposure to neutral geoengineering information in science and business media pieces.

More precisely, I tested exposure to geoengineering under two contexts: 1) science-focused description of geoengineering advancements in popular media, and 2) business-focused description of the stock market performance of geoengineering projects. I designed 7 different materials to introduce geoengineering in politically-neutral and non-persuasive framing: 4 pop-science articles (experiments 1 – 4), 2 visual stock-market summaries (experiments 5 and 6), and 1 finance-focused business announcement (experiment 7). All materials were edited to maintain neutral language about the efficacy or potential of the geoengineering technologies they describe. Further, I compared prompting thoughts about CDR (experiments 4, 5, and 7) and SRM (experiments 1 - 4 and 7) against corresponding materials prompting thoughts about traditional mitigation efforts (experiment 1) and thoughts unrelated to climate change (experiments 2 – 7). All materials are available on the Open Science Framework at osf.io/mk2qe.

Experiment 1

Experiment 1 began the exploration of whether and when considering the prospect of geoengineering technology diminishes commitment to mitigation efforts. Here, I tested whether introducing geoengineering information in the format of a popular science media article affords a moral hazard in comparison to information about traditional mitigation efforts. Participants read an edited pop-science article from the website 'WIRED'. In the control condition, the article described transportation management strategies employed in Europe that will reduce carbon emissions and contribute to climate change mitigation. In the 'geoengineering' condition, the article described a Harvard scientist's experiments to develop Solar Radiation Management (SRM) technology. In both conditions, the article was edited for length and to maintain neutral language about the efficacy of the mitigation effort described. Following the article, participants reported their feelings of urgency for mitigation.

I predicted that participants who read about geoengineering would report lower feelings of urgency than participants who read about traditional mitigation efforts.

Method

I recruited 400 U.S adults through Amazon's Mechanical Turk ('MTurk') platform for a study on science communication methods. A pilot study (N = 80) conducted on the same platform suggested that roughly 15% of participants would not pass attention and manipulation checks. Accordingly, I aimed for a final sample size of roughly 340, which would afford 80% power to detect an effect size of at least d = 0.30.

Participants were randomly assigned to either the geoengineering or control condition. Participants viewed the 'WIRED' article for their respective condition and were required to remain on the page for at least 60 seconds before proceeding. On the next page, all participants responded to 4 comprehension checks on the material they viewed. If any of the responses were incorrect, participants were informed that at least one of their answers was incorrect, then routed to view the article and respond to the comprehension checks a second time. Participants who then responded incorrectly to any of the four questions a second time were excluded from analysis.

Following the comprehension checks, participants read a summary of the global goal to lower CO_2 production to 1.5 tons per person by 2030. Participants then reported their feelings of urgency for climate change mitigation by indicating their agreement to 9 statements, such as “This goal feels urgent to me” and “I am concerned with our progress on this goal” [-3 = strongly disagree, 0 = neutral, 3 = strongly agree] (see Appendix, table 2.2 for full scale). A factor analysis of the scale yielded a one-factor extraction (eigenvalue = 5.32, 62% of variance explained) and validity was sufficient ($\alpha = 0.92$).

In addition to comprehension checks, participants responded to two attention checks embedded within the scales (e.g. “Please select ‘strongly disagree’ for this statement”). Exclusions on the basis of failed attention checks (N = 17) and failed manipulation checks (N = 55) were roughly equal across conditions (χ^2 (1, N = 328) = 0.11, p = .74) and yielded a final sample of 328 participants ($N_{Geoengineering}$ = 167).

Participants reported their demographic information, including political orientation, measured via self-reported political orientation (1 = extremely liberal, 7 = extremely conservative) and 4 questions about their feelings toward liberals, conservatives, democrats, and republicans (1 = very much dislike, 7 = very much like; Knight, 1999; Skitka, Bauman, & Sargis, 2005). Finally, they viewed a debriefing statement before receiving their compensation.

Results

I tested the immediate effect of geoengineering awareness on self-reported feelings of mitigation urgency. A *t*-test comparing feelings of environmental urgency in the geoengineering condition (*M* = 0.81, *SD* = 1.38) against the control condition (*M* = 0.96, *SD* = 1.50) revealed no significant effect of the geoengineering prompt $t(326)$ = -0.98, p = .33, CI 95% [-0.32, 0.11]. Means and standard errors of self-reported urgency are depicted in Figure 1.1.

In follow up analyses, I tested for an effect of political orientation. Feelings of urgency about climate change were predicted by political orientation ($F(1, 326)$ = 107, *p*

$< .001$) with feelings of urgency decreasing as conservativism increases. As such, I tested whether the geoengineering prompt had an effect on feelings of urgency when accounting for political orientation. An ANOVA with condition predicting feelings of urgency and controlling for political orientation yielded no significant effect ($F(1, 325) = 1.26$, $p = .26$). Further tests for an interaction between political orientation and condition confirmed nothing of significance ($F(1, 324) = 0.01$, $p = .92$). Thus, feelings of urgency for climate change mitigation were predicted only by political orientation and not by reading about geoengineering or any interaction between the two.

The licensing hypothesis was not supported. In comparison to only reading about traditional mitigation and adaptation options, reading about SRM technologies did not influence self-reported environmental urgency.

Experiments 2 and 3

In experiment 1, I tested a geoengineering prompt against a prompt about traditional mitigation efforts, which afforded an observation of how geoengineering compares to other mitigation efforts. In experiments 2 and 3, I sought to explore how the prospect of geoengineering compares to a more neutral control that involves no mention of mitigation efforts. Reading about climate change mitigation can prompt thoughts and preconceptions about climate change that can influence responses about feelings of environmental urgency. Thus, I sought to isolate the influence of geoengineering prompts from thoughts about other mitigation efforts. I reasoned that any context in which geoengineering reduces the public's pro-environmental commitment constitutes a threat to mitigation.

In the following two experiments, I examined the influence of geoengineering thoughts in comparison to not thinking about climate change at all. In both experiments, all participants read the same two filler pop-science articles that were not related to climate change and responded to comprehension checks for the articles. Participants in the 'geoengineering' condition then continued on to read one more pop-science article about SRM with comprehension checks. Participants in the control conditions read no further articles. In experiment 2, the article was identical to the article used in experiment 1. In experiment 3, the article was similar in length and described a group of scientists' work in developing and deploying aircraft for SRM.

I predicted that thinking about geoengineering, in comparison to not thinking about climate change, would produce lower feelings of urgency for climate change mitigation.

Method

I recruited 302 MTurk workers in experiment 2 and 303 in experiment 3. Participants were randomly assigned to either a control or geoengineering condition. Participants in the control condition read 2 pop-science articles unrelated to climate change and presented with questions to encourage comprehension of the material. Participants in the geoengineering condition read the same 2 pop-science articles, then read an additional article about SRM with accompanying comprehension questions. All participants then reported their environmental urgency using a similar 9-item scale as in experiment 1 and responded to the same attention checks.

In both studies, exclusions on the basis of failed attention checks ($N_2 = 37$, $N_3 = 39$) were equal across conditions (χ^2s < 1). Final sample sizes consisted of 265 U.S adults in experiment 2 ($N_{Geoengineering} = 130$) and 264 in experiment 3 ($N_{Geoengineering} = 151$).

Results

For experiment 2, a *t*-test determined that feelings of environmental urgency in the geoengineering condition ($M = 0.98$, $SD = 1.73$) were lower than in the control condition ($M = 1.40$, $SD = 1.58$; $t(263) = -2.06$, $p = .04$, CI 95% [-0.49, -0.01]). Thus, evidence from experiment 2 supports the prediction that reading about SRM will cause reduced feelings of urgency for mitigation efforts.

However, this effect was not detected in experiment 3, a close replication of experiment 2 ($t(264) = 0.83$, $p = .83$, CI 95% [-0.14, 0.34]). Further, the effect was in the opposite direction of that found in experiment 2: people reported non-significantly higher feelings of urgency after reading about geoengineering ($M_{geoengineering} = 1.21$, $SD_{geoengineering} = 1.82$; $M_{control} = 1.03$, $SD_{control} = 1.77$). All means and standard errors of self-reported urgency are depicted in Figure 1.1.

The licensing prediction was partially supported in experiments 2 and 3. I found evidence for reduced feelings of mitigation urgency after reading about geoengineering, but failed to replicate the evidence in a subsequent study. Thus, in further pursuit, my next experiments tested a similar geoengineering prompt as the media piece used in experiment 2, but measure pro-environmental behavior as the outcome (experiment 4), then continue to employ different types of prompts to observe their effects on pro-environmental behavior (experiment 5-7).

Internal mini meta-analysis and equivalence testing

Experiments 1-3 revealed little and inconsistent evidence of an immediate licensing effect in feelings of environmental urgency following a geoengineering prompt. Only one of three studies - experiment 2 - detected evidence that reading about SRM reduces urgency for climate change mitigation. The effect failed to replicate in experiment 3. Thus, evidence in support of the 'licensing' hypothesis is inconsistent.

To consolidate these results, I conducted a within-paper meta-analysis. In order to integrate Supplemental Study 1 into the meta-analysis, the two statistically equivalent geoengineering conditions (M_{CDR} = 5.19, M_{SRM} = 5.37; planned contrasts ANOVA: $F(1, 281) = 0.66$, $p = .42$) were consolidated into one 'geoengineering' condition. The meta-analysis yielded a non-significant overall effect of geoengineering prompts on immediate self-reported environmental concern (random-effects; $\beta = -0.07$, CI.95: [-0.21, 0.07], $p = .23$). Results are depicted in Figure 1.2.

Because nonsignificant results do not indicate the absence of an effect, I employed equivalence testing to more rigorously test the null hypothesis (Lakens, 2017). Equivalence testing complements traditional null-hypothesis significance testing to assess whether the observed data implicate a meaningful and sizable effect. Due to the gravity of the consequences of climate change, and the significance of small effects when aggregated across a population (see Greenwald, Banaji & Nosek, 2015), I consider an effect as small as $d = \pm 0.20$ in this case to be meaningful. As such, I set the equivalence boundaries at $\Delta_L = -0.2$ and $\Delta_U = 0.2$.

An equivalence test on the effect size estimate produced by the meta-analysis indicated that the control and geoengineering groups were not statistically equivalent, given bounds of $\Delta_L = -0.2$ and $\Delta_U = 0.2$ ($Z = 1.41$, $p = .09$). That is, traditional significance tests indicated that the difference between geoengineering and control groups was not observably greater than zero, but equivalence testing indicated that the difference is not significantly smaller than an absolute effect size of $d = 0.2$. Results are depicted in Figure 1.3. Accordingly, I cannot reject the possibility that geoengineering prompts decrease concern about climate change at an absolute effect size of $d = 0.2$ or smaller.

Discussion of experiments 1-3

Experiments 1-3 did not produce overall evidence that immediate feelings of urgency for climate change mitigation are influenced by thinking about geoengineering efforts. However, an equivalence test failed to reject the possibility of a small effect ($d \leq 0.2$). Thus, these results cannot reject the possibility of a small licensing effect in response to prompts about geoengineering technology. Because climate change mitigation is a societal-level outcome - such that individual levels of commitment to mitigation aggregate into consequences for a society as a whole - it is possible that even a very small effect at the individual level can result in significant consequences at the societal level, a point I return to in the general discussion. Accordingly, I acknowledge the potential that geoengineering technologies may have an important effect on the public's concern for climate change that I was unable to detect in experiments 1-3.

Pro-Environmental Behavior

Experiments 1-3 revealed little evidence for a direct licensing effect in self-reported feelings of urgency in response to the prospect of geoengineering. Given the considerable attitude-behavior gap in the context of climate change (Vermeir & Verbeke, 2006), self-reported attitudes about climate change and pro-environmental behaviors are not tightly correlated. Accordingly, it's likely that changes in pro-environmental behavior don't necessarily mirror changes in attitudes about climate change – but both are important contributors to mitigation efforts. Following this reasoning, it is possible that geoengineering poses a motivational threat that isn't detectable in self-reported attitudes about mitigation but manifests in pro-environmental behavior. The following 4 experiments investigate this possibility.

In past research on geoengineering, pro-environmental behavior has been operationalized as policy support and was not directly affected by reading about geoengineering. In the following studies, I explore another potential route for the prospect of geoengineering to jeopardize motivation for mitigation. Across 4 studies, I employ a behavior measure to examine the immediate effect of various geoengineering prompts on commitment to reduce carbon emissions.

Experiment 4

In experiment 4, I explore whether thinking about geoengineering diminishes pro-environmental behavior. I compared both primary types of geoengineering technologies (CDR and SRM) against each other and a climate-neutral control. Past research has found evidence for a moral hazard in response to reading about SRM (Raimi et al., 2019) but not following prompts about CDR (Campbell-Arvai et al., 2017). Additionally, the public has responded more negatively to SRM than CDR (Pidgeon et. al, 2012), suggesting that that CDR and SRM may pose different levels of threat.

Experiment 4 compares reading about CDR, SRM and non-climate science advancements on commitment to pro-environmental behavior. The procedure closely follows experiments 2 and 3. All participants read two brief science articles, then participants in the two geoengineering conditions read a third article. The geoengineering article described a group of scientists' work in developing either solar radiation management technology (SRM condition) or carbon dioxide reduction technology (CDR condition).

Then, all participants completed a Pro-Environmental Behavior Task (PEBT) to measure commitment to emissions reduction in a simulated transportation task (Lange, Steinke, & Dewitte, 2018). For a series of simulated trips, participants can travel by a quick but carbon-emitting car or a slow but emission-free bike. Thus, participants may choose to save time by taking the carbon-emitting car more often, or they may choose to be environmentally friendly by taking the bike more often. Evidence from Lange et al. (2018) as well as a pilot test of my own suggest that participants make deliberate choices informed by the CO_2 emissions and trip times of each choice in each trip. Accordingly, this task performs well as an in-lab measure of pro-environmental motivation.

I predicted that participants who read about either type of geoengineering would subsequently behave less pro-environmentally (i.e. make emission conserving transportation decisions less often) than those who didn't read about climate change at all, as measured by a pro-environmental behavior task immediately following the prompt.

Method

I recruited 401 participants on MTurk to complete a study on communication materials and randomly assigned them to one of three groups: control, geoengineering –

SRM, or geoengineering – CDR. All participants first viewed 2 filler articles about non-climate related science advancements, presented alongside 2 comprehension questions about the material to guide their comprehension. Participants in the two geoengineering conditions then continued on to view one more article about the topic corresponding to their condition, which was also presented alongside 2 comprehension questions. For each article, participants responded to questions about their interest in the topic of the article. Embedded in these questions were 2 attention checks (e.g. "Please select strongly agree for this statement.") Exclusions on the basis of failed attention checks ($N = 28$) and comprehension checks ($N = 10$) were equal across conditions ($\chi^2 < 0.1$). The final sample consisted of 122 participants in the control condition, 121 in SRM, and 120 in CDR for a total of N = 363.

After viewing the material, participants were introduced to the behavioral measure of climate-friendly behavior. They were informed that a corporate business was interested in determining how much carbon emissions could be saved by installing bike racks to encourage employees to commute by bike and were requested to participate in a simulated commuting task.

Pro-Environmental Behavior Task.

Behavior was measured using a modified Pro-Environmental Behavior Task (PEBT), wherein participants choose to travel by a time-costly bike or a carbon-costly car across a series of simulated trips. The PEBT has been tested for validity and determined to be highly reliable, consistent with self-reported pro-environmental motivation, and sensitive to variance (Lange, et al., 2018). For this and the following studies, the task was modified to be administered via Qualtrics and consisted of 2 example trips and 20 task trips. Trip-by-trip data verified that the modified PEBT performed similarly to the original task as a measure of pro-environmental motivation, with participants making deliberate and informed decisions throughout the task. As in the original PEBT, participants' travel choices throughout the modified task reflected the cost parameters of each trip, such that the car was taken more often when travel times were relatively longer and the bike was taken more often when emissions were relatively higher. Thus, I determined that the modified task was a satisfactory equivalent of the verified PEBT.

For each trip, participants viewed a screen that presents two travel options (bike and car) represented by a simple animated image alongside 2 details about each option: the CO_2 output (always 0 for the bike, but varying for the car) and the amount of time that the trip would take to complete. The bike always took longer than the car, but the time difference between the two options varied between trips. An example trip is depicted in Figure 2.1 in the Appendix. All trip parameter details are outlined in Table 2.3 in the Appendix.

Participants selected a travel option, which advanced them to the next screen of a gif depicting the selected vehicle and a timer counting down the travel time of their selected option. If the car was selected, the screen also included a gif depicting CO_2 emissions releasing upwards. At all times, a box at the top of the screen displayed the cumulative amount of CO_2 emissions that had been released according to the participant's choices across the trips. Once all 20 of the trips are completed, the study completes. Pro-environmental behavior is measured as the number of times participants chose the bike option.

All participants were paid $1.50 regardless of the amount of time spent on the task. Thus, participants can be simultaneously motivated to complete the study quickly but also to demonstrate pro-environmental behavior by emitting less carbon.

Results

Means (± SE) are depicted in Figure 1.4. I tested the direct effect of geoengineering prompts on immediate motivation to behave pro-environmentally. An omnibus ANOVA revealed no differences between conditions in the amount of times the climate-friendly bike option was chosen ($F(2, 360) = 1.42$, $p = .24$). A planned-contrast ANOVA revealed no differences between geoengineering and control conditions ($p_{control\_v\_SRM} = 0.17$, $p_{control\_v\_CDR} = 0.12$). Additionally, a planned-contrast ANOVA yielded no significant difference in pro-environmental behavior following exposure to CDR versus SRM information ($M_{CDR} = 10.48$, $M_{SRM} = 10.64$, $F(1, 361) = 0.04$, $p = .84$).

The licensing hypothesis was not supported by results from experiment 4. Pro-environmental motivation, measured by commitment to emissions reduction in a behavioral task, was not weakened following prompts about CDR or SRM in comparison to not thinking about mitigation efforts at all.

Experiments 5 – 7

Following experiment 4, I continued the search for a potential manifestation of licensing effects due to geoengineering. In an effort to investigate additional contexts in which the public may be prompted to consider the prospect of geoengineering, I explored the business context as a potential opportunity to be introduced to geoengineering. I designed manipulations that simulate exposure to geoengineering information through the stock market performance of businesses involved in geoengineering efforts. As with experiments 2 – 4, I sought to isolate the influence of geoengineering prompts from thoughts about other mitigation efforts. Here, I reasoned that introducing geoengineering efforts in a business context can further remove the prospect of geoengineering from other thoughts about climate change or mitigation that may be influenced by preconceptions or political motivations.

I predicted that viewing stock market information about geoengineering advancements will diminish motivation for mitigation, measured by immediate pro-environmental behavior.

Method

In total, I recruited 826 MTurk workers to complete a study on communication materials ($N_{exp.5} = 243$, $N_{exp.6} = 285$, $N_{exp.7} = 298$) and randomly assigned participants to a control condition or a geoengineering condition. In experiments 5 and 6, participants first viewed filler stock market information about a business unrelated to climate change. There was no filler information in experiment 7. Then, participants in the geoengineering conditions viewed stock market information about a company that recently made advancements in CDR technology (experiments 5 and 7) or SRM technology (experiment 6). Participants in the control conditions viewed the same material, but the company was described as developing technology unrelated to climate change mitigation. In experiments 5 and 6, the information was presented with visual stock market information. In experiment 7, the material was presented as a business announcement. All participants responded to a comprehension check (e.g. "[the business in the announcement] mainly works on which of the following technologies?") to ensure they could correctly identify the type of business they viewed.

Exclusions on the basis of failed comprehension checks ($N_{exp.5}$= 10, $N_{exp.6}$= 6, $N_{exp.7}$= 45) were equal across conditions (all χ^2s < 0.5). The final samples consisted of 233 participants ($N_{geoengineering}$= 118) in experiment 5, 279 ($N_{geoengineering}$= 141) in experiment 6, and 253 ($N_{geoengineering}$= 132) in experiment 7.

Finally, all participants completed the modified 20-trip PEBT. The parameters of the PEBT were identical to those in experiment 4.

Results

Means (± SE) are depicted in Figure 1.4. I tested the direct effect of geoengineering prompts on immediate motivation to behave pro-environmentally on the within-study task. *T*-tests revealed no significant differences in the amount of times the climate-friendly bike option was chosen between geoengineering and control conditions (all p-values ≥ 0.35; all tests reported in Table 1.2)

In all three studies, I found little evidence that viewing the stock market information about geoengineering-involved businesses has an immediate effect on commitment to emissions reduction. Thus, experiments 5 – 7 provide no evidence for an immediate licensing effect in pro-environmental motivation due to geoengineering prompts.

Within-paper meta-analysis and equivalence testing

To consolidate these results, I conducted a mini meta-analysis on experiments 5 – 7. I consolidated the statistically equivalent ($F < 0.1$) CDR and SRM conditions in experiment 4 into one 'geoengineering' condition. The internal meta-analysis revealed no significant overall effect of geoengineering prompts (random-effects; $\beta = 0.01$, CI.95: [-0.14, 0.15], $p = .92$). Results are depicted in Figure 1.5.

With a lack of evidence to support either the licensing or commitment hypotheses, I again employed equivalence testing to further test the null hypothesis. With boundaries set at $\Delta_L = -0.2$ and $\Delta_U = 0.2$, an equivalence test on the effect size estimate produced by the meta-analysis indicated significant equivalence between geoengineering and control groups (Z = -2.57, $p = .005$; see Figure 1.6 for visualization of results). As the geoengineering and control groups are statistically equivalent and the meta-analytic effect size is not significantly distinguishable from zero, I can reject the possibility that licensing effects were detected in these experiments given a minimum absolute effect size of $d = 0.2$.

Discussion

The development of ‘geoengineering’ technologies has troubled some researchers and policymakers. Their concern is that the availability of such technologically advanced climate response options will jeopardize the public’s pro-environmental motivation and ultimately undermine mitigation efforts. With the advancement of geoengineering technology, this concern for a potential ‘moral hazard’ effect of geoengineering has become more pronounced. However, lab studies have not produced compelling evidence of a threat to mitigation efforts. Here, I continued the empirical exploration for a potential manifestation of a moral hazard afforded by the prospect of geoengineering.

To explore the potential for geoengineering technology to undermine individuals’ mitigation motivation, I tested new conditions to prompt thoughts about geoengineering and examined different climate-relevant outcomes. I observed the immediate effect of thinking about geoengineering on self-reported feelings of environmental urgency and behavioral commitment to climate-friendly efforts. In line with the moral hazard argument, I predicted that considering the prospect of geoengineering would weaken resolve for mitigation, both in self-reported attitudes and behavior. Across 7 studies, I found little evidence that increased momentary awareness of geoengineering technology had an observable immediate influence on self-reported or behaviorally measured environmental concern. Internal meta-analyses yielded no significant effects in either direction. However, the presence of a small effect ($d \leq 0.2$) could not be ruled out for self-reported environmental concern immediately following a geoengineering prompt.

While these studies did not yield evidence of a situation in which geoengineering awareness undermines motivation for mitigation, these results provide only a narrow representation of potential moral hazard effects of geoengineering. I found that an immediate change in feelings of environmental urgency or behavioral commitment to emissions reduction is unlikely to occur following exposure to neutral geoengineering information. If geoengineering has the potential to threaten mitigation motivation, it may be realized in any other form of mitigation that was not tested here. While self-reported feelings of environmental urgency did not seem to change, threat perceptions are not always directly reported and can instead manifest in heightened arousal or attentional demand. Future research may examine whether the availability of geoengineering options diminishes the attentional demand of climate change issues. For example, whether spontaneous climate-relevant thoughts occur less often or attention to climate prompts is sustained for shorter periods of time after learning about geoengineering advancements. If climate-relevant thoughts occur less often, then concern for climate change consequences and attention to mitigation opportunities can diminish, resulting in a gradual neglect of costly mitigation behaviors.

Additionally, I did not test the potential for continued geoengineering exposure to generate effects as it compounds over time. These studies only observed immediate changes in urgency and simulated pro-environmental behavior following exposure to neutral information about geoengineering. As geoengineering technologies continue to become part of the climate conversation, the public will increasingly encounter prompts to consider the prospect of geoengineering. It is possible that repeated exposure to thoughts about geoengineering will produce different reactions than I observed in immediate reactions, potentially because repeated exposure tends to make options seem more favorable (Zajonc, 1968). If repeated exposure to these prompts ultimately translates into more favorable views of geoengineering, then the public may shift toward favoring geoengineering options over other climate response options, culminating in a threat to crucial mitigation efforts.

Further, while this research did not reveal evidence of a relationship between geoengineering awareness and commitment to mitigation, I limited my search to direct, overall effects. However, in goal pursuit, competing goals and processes can co-occur, making them more difficult to detect. For example, while progress on a goal can yield licensing effects, an alternative outcome is a commitment effect wherein progress on a goal stimulates continued efforts to complete the goal. Consequently, when a workout is framed as a sign of commitment to health, as opposed to making progress toward a goal weight, people sustain their healthy eating for longer instead of indulging in a reward for their efforts (Zhang, Fishbach, & Dhar, 2007). However, if the workout is considered a past action instead of a future action, then licensing is more likely to co-occur with commitment, and dieters become slightly more likely to indulge in a sugary reward.

Similarly, perhaps a climate-conscious voter feels slightly less concerned about climate change after reading about geoengineering advancements (licensing effect), which simultaneously bring to mind memories of past pro-environmentalism and invoke feelings of commitment to mitigation efforts (commitment effect). Consequently, the prospect of geoengineering affords a licensing effect, but depending on the circumstances, one that competes with a commitment effect. The current research did not pursue this possibility or attempt to explore the circumstances in which these effects might compete and result in different outcomes. Future work can examine the potential for geoengineering to afford more potent licensing or commitment effects and describe the cases in which each occurs.

Finally, while I did not find that commitment to mitigation was influenced by exposure to geoengineering, I limited this research to examine the effect of neutral geoengineering prompts. As geoengineering advancements become more prominent in the media and in public knowledge, the increasing amounts of media pieces that the public is exposed to will not always be neutral. These findings do not encompass the range of the potential routes of exposure as it might manifest in the real world, such as: media pieces that depict geoengineering efforts positively (or negatively), politicians or public figures endorsing (or condemning) the development of geoengineering technology, or scientists advocating for (or negating) the potential of geoengineering developments. Further research is needed to determine the magnitude of the potential moral hazard effect across the wide range of possible geoengineering exposure.

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Tables and Figures

Table 1.1
Supplemental study 1 & experiments 1 – 3: Experimental designs and main effects
Negative effect sizes indicate licensing effects (decrease in environmental urgency, compared to control) and positive effect sizes indicate an increase in feelings of urgency.

Exp.	Treatment	Control	*t* *control v treatment*	*p* value	Cohen's *d*
Supp. 1 *N* = 283	CDR	Traditional mitigation	*t*(186) = 0.56	.57	0.08 [-0.21, 0.37]
	SRM		*t*(191) = -0.08	.94	-0.01 [-0.29, 0.27]
1 *N* = 328	SRM	Traditional mitigation	*t*(326) = -0.98	.33	-0.11 [-0.32, 0.11]
2 *N* = 265	SRM	Neutral (no climate change)	*t*(263) = -2.06	.04	-0.25 [-0.49, -0.01]
3 *N* = 264	SRM	Neutral (no climate change)	*t*(262) = 0.83	.41	0.1 [-0.14, 0.34]

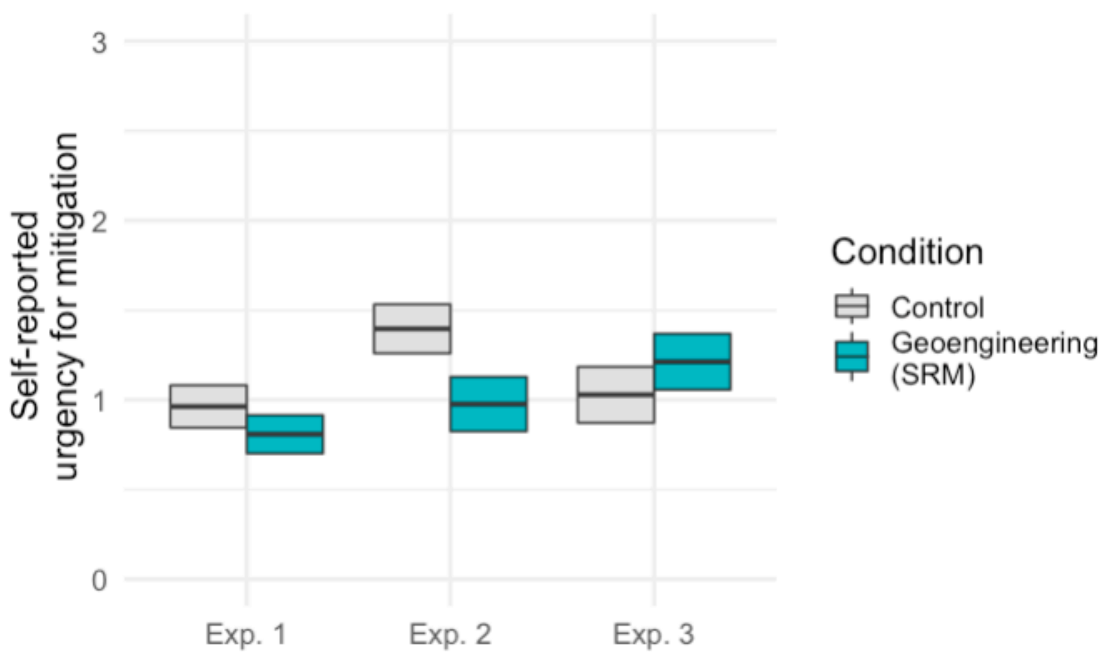

Figure 1.1. Experiments 1 – 3: Standard errors (boxes) around means (black horizontal lines) of self-reported feelings of urgency for mitigation after reading about SRM (blue

boxes) or not (grey boxes). Full scale range is -3 to 3.

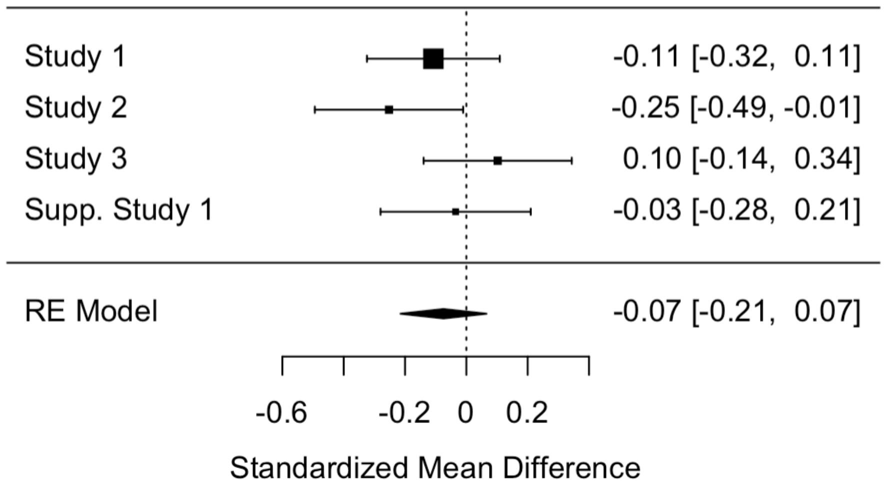

Figure 1.2. Within-paper meta-analysis of experiments 1-3 and supplemental study 1.
Mean differences (black squares), 95% confidence intervals (horizontal lines) and estimated effect size of the meta-analysis (black diamond).

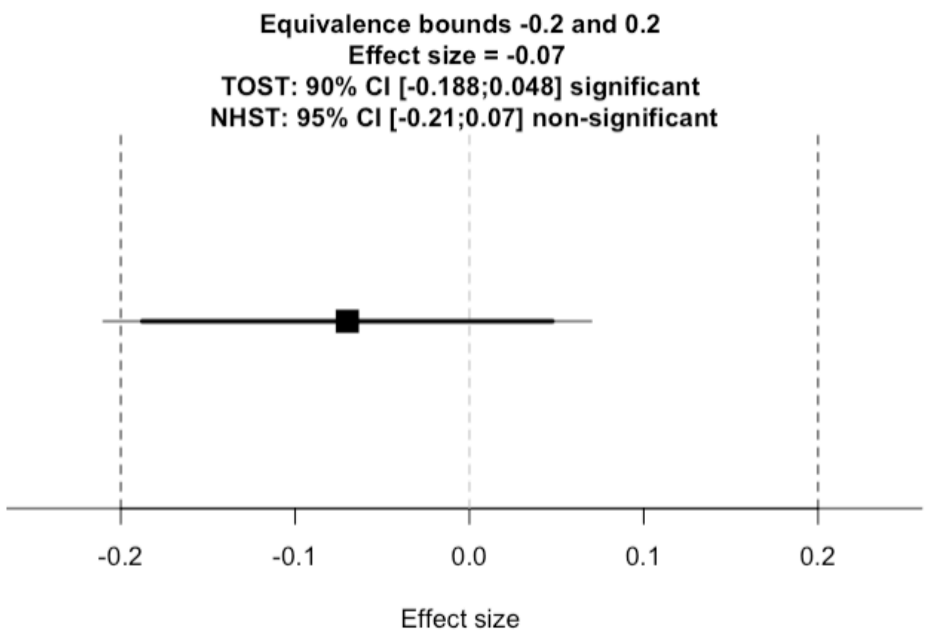

Figure 1.3. Equivalence test on meta-analysis estimate for experiments 1-3 and supplemental study 1.
Mean differences (black square), 90% confidence intervals (thick horizontal line) and 95% CIs (thin horizontal line) with equivalence bounds Δ_L = -0.2 and Δ_U = 0.2.

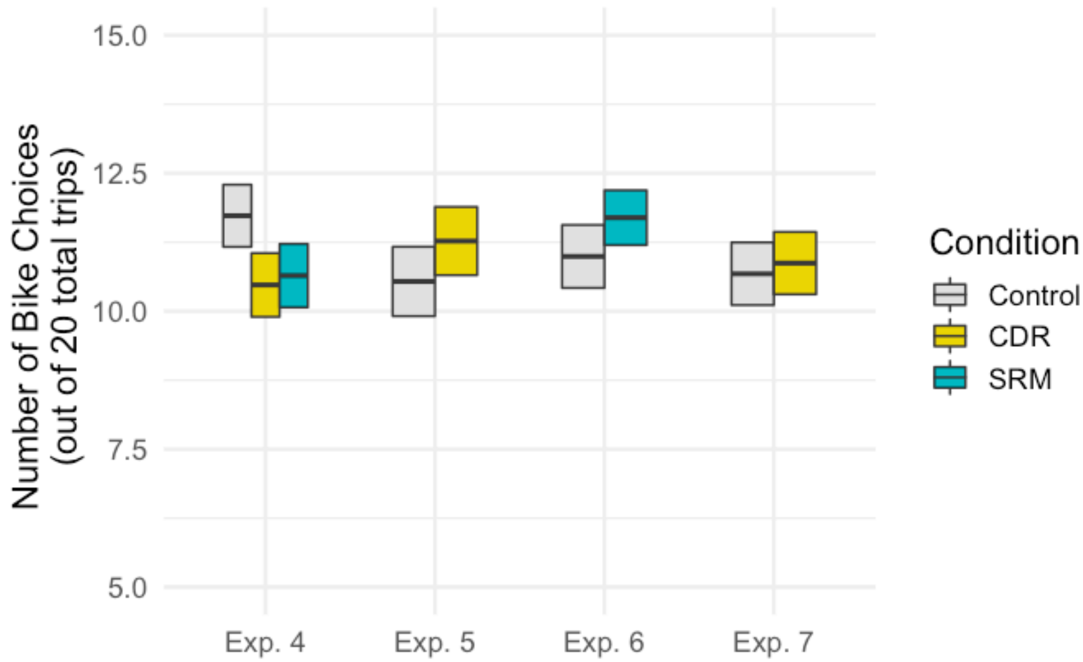

Figure 1.4. Standard errors (boxes) around means (black horizontal lines) of number of bike choices in the PEBT after reading about geoengineering (blue and yellow boxes) or not (grey boxes) in experiments 4 – 7.

Table 1.2
Experiments 4 - 7: Experimental designs and main effects

Exp.	Treatment	Control	*t* *control v treatment*	*p* value	Cohen's *d*
4 *N* = 363	CDR	Neutral (no climate change)	*t*(240) = -1.55	.12	-0.20 [-0.45, 0.05]
	SRM		*t*(241) = -1.35	.18	-0.17 [-0.42, 0.08]
5 *N* = 233	CDR	Neutral (no climate change)	*t*(231) = 0.83	.41	0.11 [-0.15, 0.37]
6 *N* = 279	SRM	Neutral (no climate change)	*t*(277) = -0.93	.35	0.11 [-0.12, 0.34]
7 *N* = 253	CDR	Neutral (no climate change)	*t*(251) = -0.24	.81	0.03 [-0.22, 0.28]

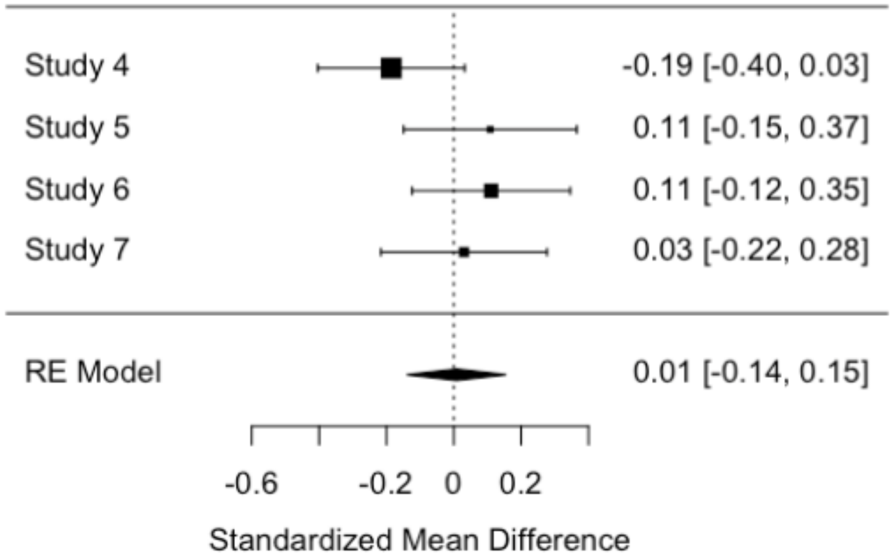

Figure 1.5. Within-paper meta-analysis of experiments 4 – 7.
Mean differences (black squares), 95% confidence intervals (horizontal lines) and estimated effect size of the meta-analysis (black diamond).

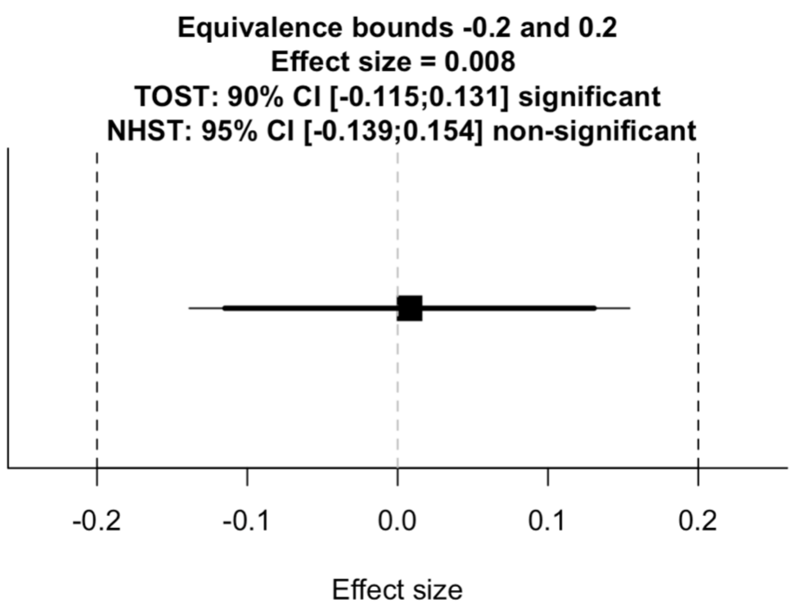

Figure 1.6. Equivalence test on meta-analysis of experiments 4 – 7.
Mean differences (black square), 90% confidence intervals (thick horizontal line) and 95% CIs (thin horizontal line) with equivalence bounds Δ_L = -0.2 and Δ_U = 0.2.

Appendix

Table 2.1

Supplemental Study 1: Policy support scale (Campbell-Arvai et al., 2017)

Scale items "How much do you support or oppose each of these policies?" *7-point response scale from strongly oppose to strongly support.*
Sign an international treaty to reduce emissions from the U.S and other countries.
Require car manufacturers to increase the fuel efficiency of their vehicles.
Increase subsidies for renewable energy such as wind and solar power.
A per-gallon tax on gasoline and diesel, based on the amount of greenhouse gases emitted.
Require appliance manufacturers to increase the efficiency of energy-using appliances.
Encourage individuals to use less energy in their home and vehicles.
Reduce greenhouse gas emissions from coal-fired power plants.
Set national targets to limit greenhouse gas emissions.

Table 2.2

Experiments 1 – 3: Urgency for mitigation scale

Scale prompt	
Experiment 1	Experiments 2 – 3
Climatologists have documented quickly escalating global average temperatures in recent decades. In climate change initiatives, scientists have determined that we should maintain the global temperature	Scientists have suggested that global temperatures should not reach 2°C above previous levels in order to avoid negative global consequences. In order to avoid a 2°C increase in global temperatures, policymakers have set

within 2°C of pre-industrialization rates. Scientists have outlined various goals to maintain ideal global temperatures to mitigate climate change. One main goal is to lower our global CO_2 production. Specifically, that we should lower our CO_2 production to 1.5 tons per person by 2030. For these questions, the 'goal' refers to the goal of lowering our CO_2 production to 1.5 tons per person by 2030.	a goal for countries to cut per-person CO_2 production in half by 2030.

Scale items

7-point response scale from strongly disagree (-3) to strongly agree (3).

Experiment 1	Experiments 2 – 3
I wish I was contributing to completing this goal right now.	I wish my country was doing more right now to cut CO_2 production.
This goal feels urgent to me.	Cutting our CO_2 production feels like an urgent priority to me.
I would not be upset if this goal does not get completed.	If we do not cut our CO_2 production in half by 2030, I would not be too worried.
I am unconcerned with whether this goal gets done soon.	I am not so concerned with whether we begin decreasing our CO_2 production anytime soon.
I am concerned with our progress on this goal.	Our progress toward cutting CO_2 production needs to speed up.
I am comfortable with the amount of time we have to complete this goal.	I am comfortable with the amount of time we have to cut our CO_2 production in half
I feel frustrated that this goal is not being completed right now.	It is critical that we begin cutting our CO_2 production immediately.
This goal is important to me.	

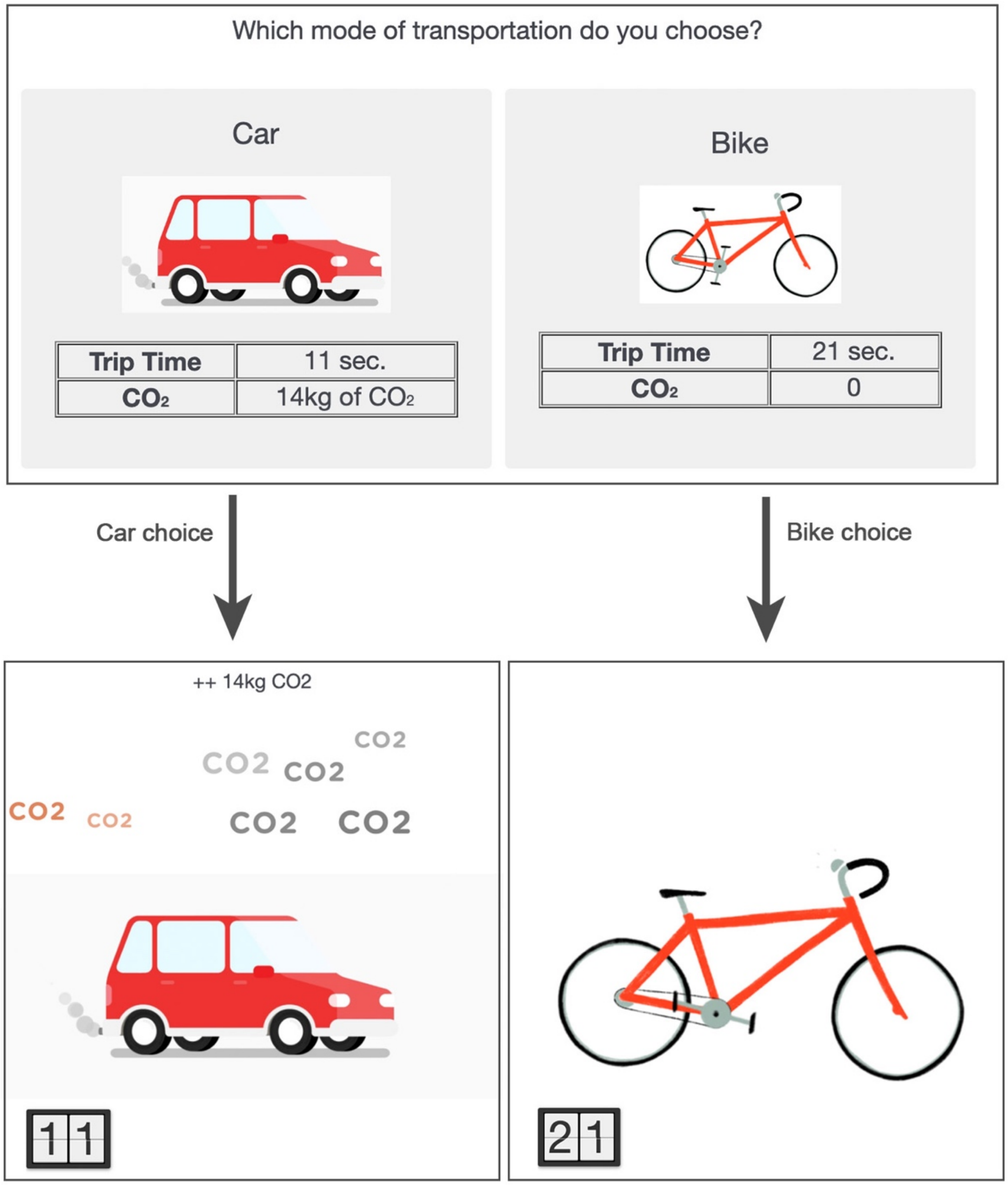

Figure 2.1. Example of PEBT stimuli used in studies 4 – 7 (modified from Lange et. al, 2018).

Table 2.3

Experiments 4 – 7: Trip parameters for PEBT

Trip	Car time *sec.*	Car CO² *kg*	Bike time *sec.*	Travel time difference *Bike - car*
1	6	12	21	15
2	8	9	23	15
3	9	15	10	1
4	7	11	17	10
5	11	15	31	20
6	5	18	6	1
7	12	16	27	15
8	9	15	19	10
9	10	7	25	15
10	13	8	33	20
11	3	17	28	25
12	15	12	20	5
13	11	14	21	10
14	12	10	22	10
15	8	14	13	5
16	17	11	22	5
17	10	19	35	25
18	4	9	24	20
19	7	11	27	20
20	3	13	8	5