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Climate cooperation in the shadow of solar geoengineering: an experimental investigation of the moral hazard conjecture

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ABSTRACT
As international efforts to mitigate greenhouse gases continue to fall short of global targets, the scientific community increasingly debates the role of solar geoengineering in climate policy. Given the infancy of these technologies, the debate is not yet whether to deploy solar geoengineering but whether solar geoengineering deserves consideration and research funding. Looming large over this discussion is the moral hazard conjecture – normalizing solar geoengineering will decrease mitigation efforts. Using a controlled experiment of a collective-risk social dilemma that simulates the strategic decisions of heterogeneous groups to mitigate emissions and deploy solar geoengineering, we find no evidence for the moral hazard conjecture. On the contrary, when people in the experiment are given the option to deploy solar geoengineering, average investment in mitigation increases.

KEYWORDS Climate change; solar geoengineering; moral hazard; mitigation deterrence; crowding out; experimental economics

1. Introduction

A recent National Academies of Science, Engineering and Medicine report recommends the U.S. invest in a 5-year $100–200 million solar geoengineering research program (National Academies of Sciences 2021). Solar geoengineering – a large-scale intervention to cool the planet by managing the amount of solar radiation that reaches the Earth – appeared as a climate policy option in the 1960s (United States President's Science Advisory Committee-Environmental Pollution Panel 1965). In the subsequent

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decades, the scientific community has followed a 'long-standing, self-imposed, unspoken near-moratorium on solar geoengineering research' (Wagner 2021). However, as international efforts to reduce global greenhouse gases (GHG) continue to fall short, the potential for solar geoengineering becomes more difficult to ignore (Aldy *et al.* 2021, National Academies of Sciences 2021). The National Academies report (National Academies of Sciences 2021) and prominent social and natural scientists argue that research is needed to enhance policymakers' understanding of climate policy options and inform decisions of *if, when* and *how* to deploy solar geoengineering technology (Parker 2014, Chavez 2016, MacMartin *et al.* 2019, Parson 2021).

The report has sparked a lively debate on the role of solar geoengineering in climate policy, with many scientists and commentators quickly expressing opposition to the report's recommendations (Biermann 2021, Stephens *et al.* 2021a, 2021b). A leading concern among critics is that solar geoengineering opportunities will deter mitigation efforts. This effect is often referred to as 'moral hazard' (Keith 2000), but many experts have clarified that this term is a misnomer (Reynolds 2019b). Others have termed the effect as 'mitigation deterrence' (McLaren 2016), 'risk compensation' (Reynolds 2015), or 'crowding out' (Cherry *et al.* 2021). Regardless of the adopted term, a small but emerging literature has set out to test the moral hazard conjecture and largely finds that informing individuals about solar geoengineering options tends to *increase* mitigation efforts, rather than decrease them (Fairbrother 2016, Merk *et al.* 2016, Austin and Converse 2021, Cherry *et al.* 2021). This is sometimes referred to as 'reverse moral hazard' (Reynolds 2019a).

Existing studies, however, rely on survey responses by isolated individuals to hypothetical scenarios (Fairbrother 2016, Cherry *et al.* 2021) or consumer responses to information provision (Merk *et al.* 2016, Austin and Converse 2021). This work is limited to the analyses of stated preferences outside potentially important strategic interactions among group members. The findings in those studies, therefore, offer evidence on how people acting alone respond to hypothetical scenarios that introduce solar geoengineering. Such individual responses to solar geoengineering may stem from perceived risks, moral concerns, or the novelty of the technology.

Considering that international climate policy is a collective action for a collective problem, the moral hazard conjecture must consider important strategic interactions (Moreno-Cruz 2015). Our study provides one of the first attempt to move beyond individual-level moral hazard to examine collective moral hazard. To illustrate, if one group member expects another member to unilaterally deploy solar geoengineering, a best response may be to increase or decrease mitigation. We conduct a collective-risk social dilemma experiment based on a game-theoretic model to investigate strategic mitigation and solar geoengineering decisions in order to avoid climate damages. Therefore, we consider both *individual* and *collective* channels through which mitigation decisions are affected by the introduction of solar geoengineering. Furthermore, by employing controlled experiments, we also move beyond stated behavior in hypothetical scenarios to examine actual behavior with consequential outcomes. While our experiment is the first to investigate mitigation responses to solar geoengineering (i.e. 'moral hazard'), it follows an extensive literature that has used induced-value, incentivized experiments to better understand strategic behavior in the social sciences (Falk and Heckman 2009) and specifically in the context of climate change policy (Barrett and Dannenberg 2012, Abatayo *et al.* 2020).

2. Experimental design

Our experiment consists of groups of players that can invest in solutions to reduce damages from an impending disaster – akin to avoiding catastrophic climate change. The *baseline mitigation treatment* is a variant of a public-good game, in which members of a group have an experimental currency (XC) that can be invested in group protection (i.e. mitigation), which benefits all group members. Higher group investment in mitigation results in lower XC losses for each group member. The socially optimal behavior is to invest fully in mitigation (i.e. cooperation) though standard game theory predicts no mitigation. Decades of research using public-good experiments consistently report behavior in line with field observations – more cooperation than game-theoretic equilibrium predictions but less than socially optimal outcomes (Chaudhuri 2011).

The *solar geoengineering* (*SGE) treatment* extends the baseline treatment by adding a second stage that allows players the option to deploy a technology (e.g. stratospheric aerosol injection) to lessen the impact from too little mitigation in the first stage.[1] After observing mitigation decisions and outcomes, players in the SGE treatment have a second, albeit imperfect, chance to partially avoid suffering losses. The second-chance option has four important properties that correspond to solar geoengineering (Moreno-Cruz and Keith 2013, Heyen *et al.* 2015). First, it is free to implement (capturing that real-world SGE is relatively inexpensive). Second, more mitigation in stage 1 reduces the need for SGE in stage 2. Third, SGE cannot fully protect against losses (capturing that it is an imperfect substitute for mitigation). Fourth, players have different preferred levels of SGE (both too much and too little SGE is costly).

SGE is modelled as a 'best-shot' technology – the highest level chosen is the level realized for all group members (Barrett 2007, Weitzman 2015). Theory predicts a free-driver result – the party that prefers the highest level of SGE will deploy the technology to a point that exceeds the social optimum (Weitzman 2015). Players can reduce the consequences of free-driver behavior by increasing investment in mitigation (Moreno-Cruz 2015). To focus on this strategic behavior, we assume that the outcomes of the SGE option are certain. Given that people are generally risk averse, certainty in SGE outcomes makes the technology more attractive, resulting in more substitution away from mitigation and towards SGE, thus tilting the decision in favor of the moral hazard conjecture.

See the Supplementary Materials for the theoretical framework and predictions, the experimental parameters and instructions, and supporting results from the data analyses. Supplemental materials can be accessed at doi.org/10.17605/osf.io/e6acp.

All experimental sessions were conducted online using a program specifically developed for this study. Participants with no prior experience with the decision setting were recruited from a large subject database of students at Appalachian State University in Boone, NC. All standard protocols for induced-value controlled experiments were followed. The study was approved by the Institutional Review Board committee (#20200514TC02753), and data and code have been deposited at Open Science Framework (see Supplementary Materials). After obtaining informed consent, the participants completed instructions, answered ex ante comprehension questions (88% correct), and then, they began the experiment. During the session, participants did not communicate and were only allowed to submit questions via chat to the experimenter.

All the experimental sessions consisted of 15 independent periods. To correspond with the static nature of the theoretical framework, members were unable to communicate (coordinate), and groups were reshuffled after every period to minimize reputation effects and strategic behavior over periods. Furthermore, to reinforce independence across periods, subjects were informed their earnings would be determined by two randomly drawn periods. After the experiment, participants answered five ex post comprehension questions with 94% of responses indicating they understood the experiment. On average, the experimental sessions lasted about 60–70 min and subjects earned approximately 21 USD, paid immediately after the session.

In the baseline treatment, there were 15 periods of the mitigation game without a solar geoengineering option. In the SGE treatment, the first five periods mirrored the baseline treatment (no SGE option), and the last 10 periods were the SGE treatment (mitigation w/ SGE option). We conducted four sessions for each of the two treatments, and in total 120 unique subjects participated in our experiments, resulting in 1800 individual-level observations. Participants were assigned to groups of three, and the group assignments changed each period, resulting in 600 unique groups. In the baseline treatment, 63 subjects participated and generated 945 individual observations and 315 group-level observations. In the SGE treatment, 57 subjects participated and generated 855 individual observations and 285 group-level observations.

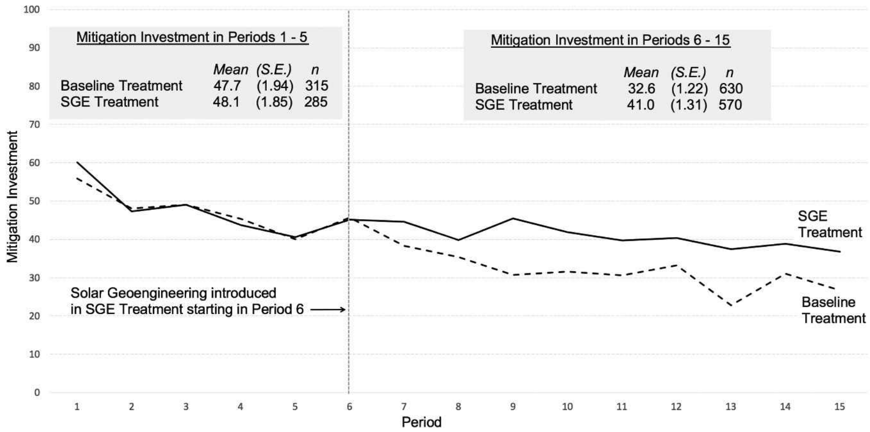

Figure 1. Average individual investment in mitigation over periods by treatment.

Our experiment allows us to test the moral hazard conjecture by comparing investments in mitigation with and without an option to deploy solar geoengineering. The moral hazard conjecture predicts a decrease in mitigation levels when solar geoengineering is an option. The experimental design also allows a test of the 'free-driver' hypothesis (Weitzman 2015).

3. Results

Figure 1 shows the average investment in mitigation with and without the solar geoengineering option. In both treatments, over the first five periods, we observe the well-documented behavior in social dilemma experiments – partial cooperation that decays over time (Chaudhuri 2011). Moreover, the average investment in mitigation over the first five periods closely overlaps, which is expected given that the treatments are identical in those periods. Subjects had an endowment of 100 XC that could be invested in mitigation each period. From Figure 1, we observe that the average investment in mitigation is 47.7 and 48.1 in the baseline and SGE treatments, respectively.

Once players are introduced to solar geoengineering as a second-chance option (period 6), however, we observe a gap in mitigation investment across the two treatments but not in the direction the moral hazard conjecture predicts – mitigation is higher in the SGE treatment (baseline: 32.6 vs. SGE: 40.99). This finding is observed across different SGE preferences and is robust to conditional estimates using generalized least squares that take advantage of the panel nature of the data to control for participant-, period-, and session-specific-effects, as well as observational dependence within sessions with robust standard errors (see Supplemental Material). Results therefore do not support the moral hazard conjecture.

Contrary to what is predicted by the moral hazard conjecture, results are more consistent with the suggestion that solar geoengineering may serve as a clarion call to increase mitigation efforts (Moreno-Cruz 2015). Conditional estimates indicate that the SGE treatment leads to increases in mitigation relative to the baseline ($p = 0.029$), which is consistent with the findings from recent survey-based studies (Austin and Converse 2021, Cherry *et al.* 2021).

We also find evidence of free-driving behavior that leads to excessive levels of solar geoengineering, which is consistent with Weitzman (2015). On average, the chosen level of SGE is about 25% higher than the optimal level (77.97 vs. 62.39, $p = 0.019$), and as predicted, these inefficiencies are largely driven by the party that prefers the highest level of SGE (80.5% of cases). This finding is in line with Abatayo *et al.* (2020) who report free-driving behavior and excessive solar geoengineering in a one-stage game, but unlike in our framework, they do not consider investment in mitigation.

The threat of free-driving behavior may underlie the finding that players respond to solar geoengineering with greater investment in mitigation. Rather than an easy coordinating solution, solar geoengineering introduces complex strategic behavior across policy instruments. By increasing mitigation, one party can reduce the need for and potential harm from other party's deployment of solar geoengineering.

4. Summary

Reynolds (2019a) explains that the concern over moral hazard 'has been the most widespread basis for resistance to solar geoengineering (p.32).' This study is the first to test the moral hazard conjecture in a controlled experiment that mimics the strategic decisions of heterogeneous groups to mitigate GHG emissions with and without the option of deploying solar geoengineering. Managing climate change is clearly more complex than the decisions made in this study. Yet, induced-value laboratory experiments isolate behavioral responses to consequential tradeoffs that generally extend beyond the controlled setting (Alm *et al.* 2015, Snowberg and Leeat 2021). The method is particularly useful when the proposed policies have no counterpart in reality, such as climate change (Barrett and Dannenberg 2012, Abatayo *et al.* 2020).

Fundamentally, our experimental results provide insights into how people respond when presented with a cheap but imperfect substitute (i.e. a quick technology fix) to cooperation behavior (i.e. mitigation) aimed at resolving a collective-risk social dilemma. Designed to capture incentives and tensions presented by solar geoengineering, the experiment offers evidence that is contrary to the "moral-hazard" conjecture. Rather, the results suggest that solar geoengineering may lead to greater mitigation efforts. Given response to solar geoengineering likely depends on the nature of the technology, future research should explore how mitigation efforts respond to changes in the technology (e.g., risk, efficacy). Our findings emerge from a collective decision setting that incorporates important strategic influences in the absence of coordination. The lack of support for the moral hazard conjecture in our strategic incentivized setting is qualitatively similar to previous survey-based studies that elicit responses from people that act alone (Austin and Converse 2021, Cherry *et al.* 2021) and more broadly consistent with the experimental literature on social dilemmas (Chaudhuri 2011).

Note

1. Stratospheric aerosol injection is also referred to solar radiation modification, solar radiation management or climate engineering.

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