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LETTER

Does solar geoengineering crowd out climate change mitigation efforts? Evidence from a stated preference referendum on a carbon tax

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Abstract
Solar geoengineering is increasingly being considered a realistic approach to managing climate change. One crucial concern is whether geoengineering crowds out efforts to mitigate greenhouse gas emissions. Adding to a limited body of empirical evidence, we use a survey experiment to estimate how informing the U.S. public about solar geoengineering impacts support for a proposed national carbon tax. In contrast to the crowding-out hypothesis, we find that respondents who are provided with information about geoengineering are significantly more likely to support the tax. Further, we document systematic variation as people with egalitarian and communitarian worldviews are more responsive to the information relative to those with hierarchical and individualist worldviews. Our study suggests that the availability and awareness of solar geoengineering options may lead to an increase in greenhouse gas abatement efforts.

Keywords Climate change · Solar geoengineering · Moral hazard · Emissions · Experiment

1 Introduction

With the failure of the international community to sufficiently address climate change, researchers are increasingly contemplating the potential for geoengineering—the large-scale intentional intervention in the Earth's environment to offset the harmful effects of anthropogenic climate change (Peters et al. 2020). Geoengineering includes an array of options such as

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removing carbon dioxide from the atmosphere to diminish the greenhouse effect or increasing the albedo of the atmosphere by reflecting more solar radiation back into space (i.e., solar geoengineering). While carbon removal or negative emission technologies present longer-term potential, solar geoengineering offers quick and inexpensive—albeit imperfect—ways to lower global temperatures (Barrett 2008; Mahajan et al. 2019).

A long-standing behavioral concern surrounding geoengineering, and particularly solar geoengineering, is that it may decrease efforts to mitigate greenhouse gas emissions (Keith 2000; Lawrence and Crutzen 2016). Reynolds (2019 p. 32) contends this issue "has been the most widespread basis for resistance to solar engineering."[1] However, this view is not universal. A number of researchers have suggested solar geoengineering may serve as a clarion call to increase mitigation efforts (e.g., Moreno-Cruz 2015). There are several reasons for this response: It could result from the public viewing solar geoengineering as a threat, making climate change more salient (Kahan et al. 2015) and mitigation more attractive (Reynolds 2015; Burns et al. 2016). Also, Baron (2006) suggests there may be a preference that people should make sacrifice to address climate change (polluter-pays bias) and should not rely on a technological solution (naturalist bias).

A small but growing body of literature has explored empirically whether the availability of solar geoengineering crowds out or crowds in mitigation efforts. Thus far, the evidence is mixed. This research generally relies on focus groups, surveys, and survey experiments to measure how people respond to the prospects of solar geoengineering. Some studies find that individual support for mitigation efforts is unaffected by exposure to information about solar geoengineering (e.g., Fairbrother 2016), while others report that people respond to the potential of solar geoengineering with increased concern for climate change (Kahan et al. 2015) and increased willingness to purchase carbon offsets (Merk et al. 2016).[2] Recent work finds that a person's response to solar geoengineering depends on the role that geoengineering has in solving the climate crisis, with solar geoengineering crowding out emission abatement when it is presented as a major solution to climate change (Raimi et al. 2019).[3,4]

Our study contributes to this body of research by investigating whether providing the U.S. public with information about solar geoengineering significantly influences support for one specific mitigation instrument, a carbon tax. We expand on previous work by presenting participants with a detailed national carbon tax proposal that is based on Washington state's 2018 carbon tax referendum. Since support for general climate policy tends to be higher than support for specific climate policy instruments (e.g., Leiserowitz 2006), it is important to consider how the prospects for solar geoengineering may affect support for a specific climate policy. We also consider heterogeneous effects by considering investigating how individual cultural worldviews interact with the prospects of solar geoengineering.[5] That cultural

[1] David Keith, borrowing from the insurance literature, referred to the potential for solar engineering to diminish mitigation efforts as "moral hazard" (Keith 2000), and while this term has gained traction in the literature, many consider mitigation displacement (crowding-out) to be more appropriate (Morrow 2014).

[2] See Reynolds (2019) for a summary of the literature.

[3] Campbell-Arvai et al. (2017) consider carbon dioxide removal and find that learning about that technology can reduce support for mitigation policies.

[4] Game-theoretic studies (e.g., Millard-Ball 2012, and Urpelainen 2012) have also illustrated the possibility that a credible threat of future geoengineering can provide enough incentive for self-interested countries to increase their current abatement levels and to form meaningful climate agreements.

[5] In a closely related study, Kahan et al. (2015) examined how worldviews may explain any effect that geoengineering may have on people's concern for climate change. Raimi et al. (2019) considers political ideology and finds that conservatives and moderates are less affected by the prospects of solar geoengineering.

worldviews shape people's perception of risk and support for related policies originates from Douglas and Wildasky (1982) cultural theory of risk, and the literature provides considerable evidence that attitudes toward environmental risk and policies are indeed skewed along cultural lines (Kahan et al. 2011, 2015; Cherry et al. 2017).

The conjecture that worldviews matter follows from the finding that people with *individualistic* values, who are characterized by a strong belief in private freedom and free exchange, tend to downplay environmental or technological risks because they could be used to justify government interventions that restrict freedom. People with *hierarchical* values believe there is a clear and well-defined role for everyone in society and tend to downplay such risks because they can be seen as "indictments of social elites". By contrast, those with egalitarian and communitarian views tend to see the market as a source of inequality and unjustness, and thus tend to readily accept descriptions of risk that imply that the market should be regulated (see Kahan et al. 2011). Understanding how cultural perceptions of risk governs the public's response to solar geoengineering is increasingly important as the technology becomes more relevant, and as it pits one type of risk (risk from climate change) against another (risk from downsides of geoengineering).[6]

2 Experimental design

To investigate whether solar geoengineering crowds out or crowds in mitigation efforts, we design a survey experiment that introduces information about solar radiation management (SRM) prior to eliciting support for a proposed carbon tax. We focus on SRM because it is the leading candidate among the solar geoengineering technologies. The survey experiment was designed to address two primary research questions. First, how does the presence of SRM information affect a person's support for carbon taxes? And second, do behavioral responses to SRM information vary across people with different cultural worldviews?

The survey consisted of five sections. After an introduction that elicited informed consent, the survey started with a warm-up section with three questions on beliefs about the presence, cause, and severity of climate change. The survey concluded with a demographic section that collected general socio-economic characteristics, including education, gender, age, income, and political orientation. The middle three sections constitute the main elements of the experimental design.

In section two, respondents were randomly assigned to one of two SRM information treatments. This is the only section to vary across respondents. A *no-information baseline* did not provide any SRM information and constitutes a baseline or control group. An *SRM-information treatment* provided the treatment group a summary and illustration of SRM, which was drawn from Carlisle et al. (2020).[7]

The third section elicited preferences for mitigation policies. The primary policy of interest is a proposed hypothetical carbon tax. After a brief introduction of carbon taxes, the survey presented the following proposal:

[6] Public perception is just one factor in the decision-making process on the introduction of geoengineering technologies. Policymakers, scientists, lobby groups, and media play an important role in the development and deployment of technologies.

[7] We note that we cannot disentangle that the treatment introduces both additional content and additional text. Thus the treatment effect should be interpreted as the behavioral response to the *addition* of solar radiation information.

> *Suppose that the U.S. Congress decides to hold a national referendum on the 2020 ballot on the following carbon tax proposal:*
>
> *A national carbon tax will be implemented in 2021, with a starting rate of $15 per ton of carbon dioxide (CO_2). The proposed carbon tax is estimated to cost the average person $10 per month in higher prices. It's expected to generate $800 billion in revenues, which will be used to fund programs that develop clean energy, protect clean air and water, and develop local communities.*

Respondents were subsequently asked "*how would you most likely vote on this proposed carbon tax?*".[8] The referendum question was followed with three questions that may explain their support—how certain they were in their voting decision; how effective they believe the carbon tax will be at reducing greenhouse gases; and to what extent they believe the carbon tax will negatively impact their local economy. In order to capture a more general willingness to support reducing carbon emissions that is independent of a particular policy, we also asked respondents *to what extent should the U.S. prioritize reducing carbon dioxide (CO_2) emissions to address climate change*? Responses were elicited using a five-point Likert scale.

Section four employs the cultural worldview measure developed by Kahan et al. (2007) and used extensively in the literature (e.g., Kahan et al. 2011; Cherry et al. 2017). This approach measures cultural worldview along two dimensions. The first is hierarchy–egalitarianism, which reflects attitudes toward social stratifications that connect social roles and authority. The second is individualism–communitarianism, which indicates attitudes toward social orderings that expect individual self-sufficiency versus those with greater collective orientations. For each dimension, four statements were presented to respondents, who use a five-point Likert scale to indicate the degree to which they agree or disagree. Answers were assigned one to five points with higher (lower) numbers indicating stronger agreement (disagreement). Aggregating the points from the four questions in each dimension yields a cultural worldview measure ranging from four to 20. A higher (lower) score on the hierarchy–egalitarianism questions indicates a more hierarchical (more egalitarian) worldview, and a higher (lower) score on the individualism–communitarianism questions indicate a more individualistic (more communitarian) worldview.

The survey experiment was conducted online on June 4, 2020 among a national sample of adults 18 years and older. Respondents were drawn from SurveyMonkey Audience, a professionally maintained panel. The survey took less than five minutes to complete and had a 98% completion rate. We received 1739 completed surveys. To identify suspicious data, the survey included an attention question (what is 3 + 2). After eliminating 168 observations that failed this reliability test, we have 1571 observations for the analysis. We note the sample is diverse in age, income, and geographical location, but overrepresents women (59%) and people with at least a bachelor's degree (46%).[9] Though not entirely representative of the U.S. population, the sample effectively serves our interests of estimating treatment effects rather than point estimates. The usual caveat about the reliability of inconsequential responses to hypothetical survey questions applies.

[8] Respondents could choose between "Yes—support the proposal" and "No—oppose the proposal".
[9] A chi-square test for covariate balance failed to reject the null that the covariates are balanced ($p = 0.999$).

3 Results

We begin by reviewing aggregate behavior in the baseline and information treatments and continue by investigating the potential for heterogeneous treatment effects among individual cultural worldviews. Table 1 summarizes the support for a carbon tax. From the first column, 67.2% of all respondents indicated support for the proposed carbon tax. The observed level of support is similar to a recent report from the Energy Policy Institute at the University of Chicago that found two-thirds of respondents supported a carbon tax when the proceeds were directed for environmental restoration (EPIC-APNORC 2019).

We consider the first hypothesis by comparing the level of support for the proposed carbon tax across the baseline and SRM information treatments. The aggregate numbers indicate that information about SRM increased support for the carbon tax proposal. The first column of Table 1 shows that 68.7% of respondents indicated support for the carbon tax in the information treatment, which is 3.2 percentage points higher than in the baseline treatment ($p = 0.172$; two-sided test). This preliminary unconditional comparison suggests that SRM may crowd in rather than crowd out mitigation efforts.

To consider a more nuanced understanding, we explore how the treatment effects vary across worldviews. To facilitate comparisons, we assign subjects to worldview categories based on their scores. The hierarchy measure has a mean of 9.93 (on a range from 4 to 20) and standard deviation of 3.50, while the individualism measure has a mean and standard deviation of 12.42 and 3.32, respectively. Participants that scored above the mean of the hierarchy and individualism measures are defined as hierarchists and individualists, respectively, while those that scored below the mean of each measure are defined as egalitarians and communitarians.

The numbers in Table 1 reveal two main findings. First, consistent with the literature, we find that individual cultural worldviews have substantial influence on how people view public policy (e.g., Cherry et al. 2017). Independent of treatment, support for the tax varied considerably across worldviews. Second, we find the SRM information treatment effect varies across worldview types. The SRM information appears to increase support for the carbon tax among egalitarian and communitarian types but not among hierarchical and individualistic types.

We follow the aggregate numbers with a formal conditional analysis by estimating the likelihood of supporting the proposed carbon tax with the following linear probability model:

$$y_{\mathrm{i}} = \alpha + \beta SRMInfo_{\mathrm{i}} + \omega' Worldviews_i + \theta' X_i + \varepsilon_{\mathrm{I}},$$

where y_{i} is a binary variable that indicates whether the i$^{\mathrm{th}}$ respondent indicated support for the proposed carbon (=1 if yes; =0 otherwise); $SRMInfo_i$ is an indicator variable that signifies whether the i$^{\mathrm{th}}$ respondent was in the SRM information treatment (=1 if yes; =0 otherwise);

Table 1 Support for carbon tax by treatment and worldviews

		Hierarchy		Individualism	
	Pooled	Hierarchical	Egalitarian	Individualistic	Communitarian
All treatments	67.2	45.7	83.0	46.8	82.5
By treatment					
Baseline no information	65.5	45.6	79.8	47.0	79.4
SRM information	68.7	45.7	86.1	46.7	85.6

Table 2 Estimates of carbon tax vote models

	Pooled	Hierarchical	Egalitarian	Individualist	Communitarian
SRM information	0.035 (0.040)	−0.014 (0.622)	0.069 (0.001)	0.004 (0.892)	0.061 (0.006)
Tax effectiveness	0.125 (0.000)	0.152 (0.000)	0.123 (0.000)	0.142 (0.000)	0.115 (0.000)
Tax negative impact	−0.041 (0.000)	−0.040 (0.000)	−0.070 (0.000)	−0.074 (0.000)	−0.043 (0.000)
Climate change concern	0.070 (0.000)	0.095 (0.000)	0.072 (0.000)	0.105 (0.000)	0.089 (0.000)
Education	−0.004 (0.532)	0.002 (0.861)	0.002 (0.775)	−0.014 (0.189)	0.012 (0.116)
Age	−0.034 (0.000)	−0.077 (0.000)	−0.020 (0.037)	−0.048 (0.000)	−0.027 (0.008)
Gender	0.027 (0.129)	0.041 (0.166)	0.007 (0.743)	0.008 (0.795)	0.029 (0.199)
Individualism	−0.020 (0.000)	–	–	–	–
Hierarchy	−0.019 (0.000)	–	–	–	–
Constant	0.683 (0.000)	0.103 (0.191)	0.310 (0.000)	0.201 (0.012)	0.165 (0.008)
R^2	0.479	0.438	0.294	0.465	0.265
F (p value)	159.58 (0.000)	73.42 (0.000)	53.26 (0.000)	83.21 (0.000)	45.57 (0.000)
N	1571	668	903	677	894

The dependent variable is support for the proposed carbon tax (=1 if support; =0 if opposed)

p values are reported in parentheses

and $Worldviews_i$ is a vector containing the i^{th} respondent's two continuous worldview measures for the hierarchy and individualism dimensions; α is the estimated intercept; ε_{it} is the well-behaved error term; and X_i is a vector of controls that includes education, age, gender, concern for climate change, and views of the tax's efficacy at reducing emissions and negative impact on the economy.[10] We estimate five models—a pooled model that uses the full sample of data and four worldview-specific models that use data from one of the four worldview types. The pooled model provides average treatment effects while the worldview models allow for possible heterogeneous treatment effects.[11]

Table 2 presents the estimates of the carbon tax support model. The estimated coefficients for the treatment (SRM Info) inform the primary research question—does introducing information about SRM affect support for the proposed carbon tax? Results in the pooled model indicate the answer is yes. The estimated coefficient indicates that support for the carbon tax was 3.5 percentage points higher in the SRM information treatment than in the no-information baseline ($p = 0.040$). However, the worldview models reveal that this average treatment effect varies across people with different worldviews. Estimates indicate a significant SRM information treatment effect for egalitarian and communitarian types, but not for hierarchical and individualistic types. We note that, across all models, support for a carbon tax was significantly influenced by the tax's perceived efficacy at reducing emissions and negative impact on the economy. Estimates for these and other control variables correspond to a priori expectations and therefore offer some confidence in the internal consistency of the data.[12]

In addition to the main findings regarding support for the tax, we consider how the prospect of SRM affects people's general views on how to prioritize emission abatement. For this analysis, the dependent variable is the respondent's opinion on how the US should prioritize reducing carbon emissions. We estimate five models that mirror the carbon tax models in

[10] Concern for climate change, tax efficacy in reducing emissions and tax negative impact on local economy are measured using a 5-point Likert scale with higher numbers indicating more concern, greater efficacy and more negative impact.

[11] Results are robust to probit and logit specifications.

[12] Following the literature, we elicited the level of certainty that respondents had in their referendum vote. A test of proportions indicates no significant difference between the baseline and treatment groups ($p = 0.179$).

Table 2 but without the tax effectiveness and tax impact questions. The results are qualitatively similar to the carbon tax regressions. In particular, the SRM information treatment has a significant positive effect on how people prioritize carbon emission abatement in the pooled model ($p = 0.060$), and the effect is only significant for egalitarian ($p = 0.003$) and communitarian worldviews ($p = 0.058$).

4 Conclusion

Our study contributes to the small, but growing, literature on whether the availability of solar geoengineering crowds out the public's willingness to support climate policies. Using a survey experiment, we provide half of respondents in a sample of the U.S. population with moderately framed information about SRM before asking them about their level of support for a carbon tax proposal. The other half of the sample receive no information about SRM. We find that providing information about SRM significantly increases support for a carbon tax, a result that contradicts the crowding-out (or moral hazard) hypothesis. The crowding-in response to SRM information varied systematically with cultural worldviews, as the treatment only impacts those with egalitarian and communitarian views. People that hold more hierarchical and individualistic views did not significantly respond to the SRM information. We augment the analysis of a specific carbon tax by looking at how SRM information may affect the public's view prioritizing reducing carbon emissions, independent of any particular policy. Similar to the tax, we find that information on SRM increases the priority level that respondents place on reducing carbon emissions to address global warming. The literature shows that preferences for solar geoengineering vary across individuals, as well as the framing of the risk and the context of the deployment. However, in contrast to the crowding-out (or moral hazard) hypothesis, we contribute to the emerging body of evidence that the prospects of solar geoengineering can often lead to an increase in support for efforts to mitigate GHG emissions. Future research should examine whether the "crowding-in" response is due to the looming (real or perceived) threats from geoengineering, the increased salience of the climate change problem, or an aversion to using technology to address climate change.

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