Fast, cheap, and imperfect? U.S. public opinion about solar geoengineering

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Solar geoengineering, which seeks to cool the planet by reflecting a small fraction of sunlight back into space, has drawn the attention of scientists and policymakers as climate change remains unabated. Unlike mitigation, solar geoengineering could quickly and cheaply lower global temperatures. It is also imperfect. Its environmental impacts remain unpredictable, and its low cost and immediate effects may result in "moral hazard," potentially crowding out costly mitigation efforts. There is little understanding about how the public will respond to such tradeoffs. To address this, a 1,000-subject nationally representative poll focused on solar geoengineering was conducted as part of the Cooperative Congressional Election Study (CCES) of the US electorate in October-November 2016. The importance that individuals place on solar geoengineering's speed and cost predicts their support for it, but there is little to no relationship between their concerns about its shortcomings and support for its research and use. Acquiescence bias appears to be an important factor for attitudes around solar geoengineering and moral hazard.

Keywords: solar geoengineering, solar radiation management, public opinion, CCES, climate change, moral hazard

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Introduction

Technological advances frequently offer alluring promises. Vexing problems can be addressed quickly and with minimal cost, two features that appeal to consumers and citizens. Of course, there are tradeoffs. Supposedly quick and cheap solutions may not only be suboptimal but, at worst, counterproductive. They may unintentionally distort the incentives of companies, constituents, and policymakers (Sovacool *et al.* 2015) and generate unforeseen risks (Barrett 2008; Jasanoff 2016). The very characteristics that make solutions quick and cheap may lead to unfavorable consequences. We focus here on solar geoengineering as one such new potential technology, and ask how individual views of implementation pace, cost, and imperfections influence public support for using and researching it. We unpack the role of each of these dimensions using a nationally representative survey in the US.

Geoengineering, also called 'climate engineering', is broadly defined as the deliberate and large-scale manipulation of the environment. More commonly it is used to describe efforts to reverse or moderate temperature changes associated with climate change in ways other than mitigating greenhouse gas emissions in the first place (Keith 2000). In particular, we focus on solar geoengineering, also known as 'solar radiation management' or SRM. While solar geoengineering encompasses many approaches, it commonly refers to methods that introduce sulfate aerosols or other light-scattering particles into the upper atmosphere by planes to reflect a small portion of solar radiation away from the earth and thereby lower global temperatures (NRC 2015b).[1] Investigation into this type of potential technology is relatively new, not least because of a long-standing taboo against researching it that was broken by Crutzen (2006) (Keith *et al.* 2010; Caldeira and Bala 2017). Two of its main features are that it could help reduce global temperatures more quickly and with lower direct costs than mitigation (NRC 2015b). Of course, geoengineering comes with imperfections and many unknowns. It is no substitute for cutting greenhouse-gas emissions in the first place and, despite its low direct costs, it may generate costly externalities. One major concern with deploying solar geoengineering is behavioral rather than technological: its use may reduce the incentive to mitigate greenhouse gases.

Here, adding to a growing public opinion literature on the topic (Burns *et al.* 2016), we present the results of one of the most detailed and comprehensive analyses to date of the

[1] The term "sulfate aerosol injection" most precisely describes this proposal, but we rely on the more common metonyms "solar geoengineering" and "solar radiation management," which appear more frequently in popular discourse.

determinants of support, in light of these tradeoffs, for the use and research of solar geoengineering among the US public. The next section provides background information on geoengineering, explaining its direct cost, speed, and drawbacks. It also reviews existing public opinion literature on the topic and discusses the potential role of demographic and political variables in explaining citizen preferences.

Explaining geoengineering preferences

Fast, cheap, and imperfect

Academic and policy debates over whether to use or research solar geoengineering often focus on individuals' willingness to accept its imperfections—risks of unpredictability and 'moral hazard', among many others—in exchange for its speed and low cost. These three core characteristics of solar geoengineering—fast, cheap, and imperfect—were first identified as such by Keith (2000) and recur in political, economic, legal, and theological discussions about solar geoengineering (e.g. Keith *et al.* 2010; Barrett and Moreno-Cruz 2015; Klepper and Rickels 2014; Parson and Ernst 2013, Moreno-Cruz *et al.* 2018). This characterization also informs academic and policy discussions about its impact on mitigation (Hale 2012; Preston 2013; Hamilton 2015; Moreno-Cruz 2015; Collins 2016; Gertner 2017), public reception (Pidgeon et al. 2012; Mercer, 2014), and governance (Bodansky 1996; Barrett 2008; Parson and Ernst 2013). We focus our analysis on these three core characteristics.[2]

We expect individuals who value speed or low cost to exhibit more support for the use and research of solar geoengineering than individuals who value predictability or creating incentives for mitigation efforts. While solar geoengineering's inexpensive and immediate effects may provide a necessary response to climate emergencies (Caldeira and Keith 2010) and may even increase mitigation efforts (Moreno-Cruz 2015), the same characteristics may tempt businesses and governments to use it as a substitute for more costly investments in mitigation (Hale 2012; Preston 2013). The fault lines in debates about solar geoengineering are even more apparent in mainstream writing on the topic, with proponents focusing on its speed and low cost, and opponents focusing on its unpredictability and the risk that it may crowd out further

[2] There are many others that deserve further careful study, including, for example, "controllability" (Bellamy *et al.* 2017), its effects on economic inequality, its impact on non-human species, or the timing of negative consequences. We conduct an experiment exploring whether beliefs about solar geoengineering as natural versus anthropogenic affect public opinion and find little to no effect (see methods).

mitigation (Hamilton 2015; Collins 2016; Gertner 2017). As such, we expect individual attitudes to diverge along similar lines.

We proxy for imperfection with 'moral hazard' and unpredictability. Extensive research in economics and psychology explains variation in risk profiles (Arrow 1982; Wärneryd 1996; Borghans *et al.* 2008), and associated findings have been extended to research about solar geoengineering (Ferraro *et al.* 2014; Aldy 2015). Keith (2000) introduces the economic term 'moral hazard' to solar geoengineering debates, using it to describe the recurring concern that solar geoengineering will crowd out more costly greenhouse gas mitigation efforts by providing a cheap alternative. Given the economic definition of 'moral hazard', this is technically a misnomer (Barrett 2008), and, in the context of solar geoengineering, it more accurately describes a "lack of self-control" (Wagner and Weitzman 2015) or simply 'crowding out'. Nonetheless, given the prevalence of the term 'moral hazard' in the solar geoengineering literature (Burns *et al.* 2016), we continue to use it here.[3]

Moral hazard and unpredictability, of course, do not span the universe of concerns about solar geoengineering. In fact, some fear *predictable* outcomes of solar geoengineering (e.g. Robock 2008), while others are more optimistic (e.g. Keith and Irvine 2016). Here we use moral hazard and unpredictability as limited proxies for broader concerns around solar geoengineering. Stronger wording around solar geoengineering's imperfections might have yielded stronger results, and vice versa.

Survey evidence from the UK suggests a negative relationship between climate skepticism and concerns about moral hazard (Corner and Pidgeon 2014). While we do not measure subjects' beliefs in climate science itself, we hypothesize that Democrats and climate issue voters will exhibit greater concern about moral hazard than Republicans and those who are not climate issue voters. The effects of age on subjects' support for solar geoengineering are less certain. On one hand, if researching or using solar geoengineering delays mitigation, younger generations would bear a disproportionate share of costs, so concerns about moral hazard should decrease with age. Alternatively, if respondents believe, as Goeschl *et al*. (2013) suggests, that researching solar geoengineering may motivate current generations to develop low-carbon technology while reducing emissions, they may exhibit less concern about moral hazard.

[3] See Rowell and Connelly (2012) and Dembe and Boden (2000) for a history of the term. See Wagner and Zeckhauser (2012) for a broader discussion of behavioral and psychological questions in the context of climate change policy.

Demographic characteristics

Research in the natural and social sciences observes that men are more risk-seeking than women (e.g. Arch 1993; Bord and O'Connor 1997; Croson and Gneezy 2009). This matters because the effects of solar geoengineering are frequently perceived as less predictable, and thus more risky, than those of mitigation or carbon dioxide removal (CDR) (Keith 2000; NRC 2015a). Buck *et al.* (2014) considers the possibility that gender might play a role in policy preferences for solar geoengineering versus CDR given the different risk profiles associated with each technology. However, there is surprisingly limited empirical support that preferences for solar geoengineering vary by gender. Corner and Pidgeon (2015), for example, find no variation by gender. We hypothesize that women will express greater concerns about solar geoengineering's unpredictability and that this concern will decrease support for its use and research when we control for other confounding variables.

The effects of age on risk perception are even less well understood, though Corner and Pidgeon (2015) find that support for solar geoengineering decreases with age. An early body of work found risk tolerance to decrease with age (Wallach and Kogan 1961; Harlow and Brown 1990), though more recent experimental evidence is mixed (e.g. Hariharan *et al.* 2000; Gollier 2002; Hallahan *et al.* 2004). So far, most research about the inter-generational dynamics of solar geoengineering focuses on the effect of moral hazard to predict future generations' optimal mitigation and geoengineering decisions (Gardiner 2011; Jamieson 1996; Keith *et al.* 2010; Bunzl 2009).

Political identification and issue voting

In the US, the sharp partisan divide over climate policy—Democrats are more receptive to climate mitigation than are Republicans (Leiserowitz 2006; Brulle *et al.* 2012)—is attributed in part to Republicans' lower willingness to pay for clean energy (Aldy *et al.* 2012; Ansolabehere and Konisky 2014) and greater skepticism about climate risks (Wiest *et al.* 2015; Albertson and Busby 2015).[4] Meanwhile, Republican politicians and think tanks were among some of the early advocates for solar geoengineering (Vidal 2011; Pethokoukis 2013), despite this greater

[4] Kam and Simas (2010) find that Republicans are generally less risk-accepting than Democrats, though risk-seeking behavior may differ across policy domains.

skepticism about climate risks. We test whether subjects identifying as Republican and 'non-issue-voters', for whom climate change was not an important factor in determining their presidential vote in the 2016 election, exhibit greater interest in solar geoengineering's low costs and less concern about its unpredictability or the risk of moral hazard than Democrats and issue-voters.

Relevant public opinion literature

With resurgent interest in solar geoengineering among natural scientists (Lawrence and Crutzen 2017), social scientists, too, have paid increased attention. Wright *et al.* (2014) finds generally negative attitudes toward solar geoengineering. Hiller and Renn (2012) review the literature and provide "normative guidance for public debate regarding geoengineering from a social science perspective." Reviewing over 30 empirical papers on the subject, Burns *et al.* (2016) finds that most studies are administered in Western countries and seek to gauge the public's familiarity with and acceptance of solar geoengineering.

Familiarity with solar geoengineering in Western Europe, Canada, and the US—the regions best studied to date—remains low. Estimates range from 2% to 20% of the population knowing about solar geoengineering (Mercer *et al.* 2011; McLaren *et al.* 2016; Merk *et al.* 2015) with few marked shifts over time (Corner *et al.* 2013). Fewer still can define it (Mercer *et al.* 2011; Burns *et al.* 2016). However, once offered information about solar geoengineering, subjects are able to distinguish between its use and research, and they hold divergent opinions about the two (Macnaghten and Szerszynski 2013). Terminology matters. Mercer *et al.* (2011) report that 8% of participants correctly define "solar geoengineering," while 45% correctly define "climate engineering." Sugiyama *et al.* (2016) reports that more than 50% of university students in non-OECD countries know "a lot or a little" about climate engineering.

Risk, uncertainty, and the possibility of moral hazard inform public opinion on many topics (Mercer *et al.* 2011; Winickoff *et al.* 2015), though there is little consensus as to their effects. Sütterlin and Siegrist (2017) find that the mere introduction of solar geoengineering reduces respondents' willingness to consider other mitigation technologies. Burns *et al.* (2016) summarizes the literature and reports that most surveys find respondents concerned about moral hazard. Meanwhile, Merk *et al.* (2016) focuses on revealed behavior finds that those hearing about solar geoengineering are more willing to offset their own emissions (Urpelainen 2012). Merk *et al.* (2016) hypothesizes, but finds no conclusive evidence, that the finding of 'inverse moral hazard' could be due to one or more of three possible reasons: the belief that solar geoengineering does not work; solar geoengineering acts as a clarion call; or solar geoengineering is viewed as a threat. Kahan *et al.* (2015), meanwhile, emphasizes the importance of the second explanation: 'inverse moral hazard' as the result of a greater concern about climate change upon learning more about solar geoengineering.

The salience of solar geoengineering's characteristics and their effects on public opinion may also vary across countries. Surveying mid-career environmental leaders from the global South, Winickoff *et al.* (2015) observes a belief that moral hazard should be reframed as "moral responsibility." Visschers *et al.* (2017) similarly finds differences in public opinion between respondents in Canada, the US, western Europe, and China. Chinese participants, particularly those who believe that solar geoengineering may reduce the need for costly mitigation efforts, exhibit greater support for the technology than western European and Canadian participants, who believe that solar geoengineering tampers with nature. These findings align with Sugiyama *et al.* (2016), who reports that subjects in non-OECD countries such as China, India, and the Philippines show greater concern about climate change than counterparts in Japan, Korea, and Australia, along with more openness to the possibility of using solar geoengineering.

Given these differences, it is possible that perceptions of solar geoengineering also vary across other dimensions, such as political identification, gender, age, and subjects' other beliefs about climate change. Corner and Pidgeon (2014) find that, within the UK, climate skeptics report less concern about the possibility that solar geoengineering will produce moral hazard than subjects who trust the scientific evidence on climate change. Similar variations have been observed based on subjects' beliefs about the relationship between solar geoengineering and nature (Corner and Pidgeon 2015). Pew Research Center (2018) finds a significant partisan split, with Liberal Democrats believing that solar geoengineering would help reduce the effects of climate change, and Conservative Republicans saying it would not. There is limited understanding of how theoretically motivated arguments for and against solar geoengineering — its low price, speed, unpredictable effects, and potential moral hazard — affect how subjects perceive it. We aim to fill this lacuna.

Survey

Our survey was part of the 2016 Cooperative Congressional Election Study (CCES) of the US electorate, which was administered online by YouGov/Polimetrix (YP).[5] The CCES survey gathered data from a nationally stratified sample of more than 50,000 respondents. In addition to a 36,500-person national survey of the electorate, the CCES included thirty-six 1,000-subject studies with questions customized for individual groups. Subjects were surveyed twice, in *pre-election* and *post-election* waves. Here we rely on data from the 1,000-subject pre-election wave administered in October and November of 2016. Half of the twenty-minute survey was composed of 'common content', which was identical across all customized surveys and gathers useful political and demographic information. The remaining 'group content' was composed of our questions, which were designed to understand public opinion about solar geoengineering.[6]

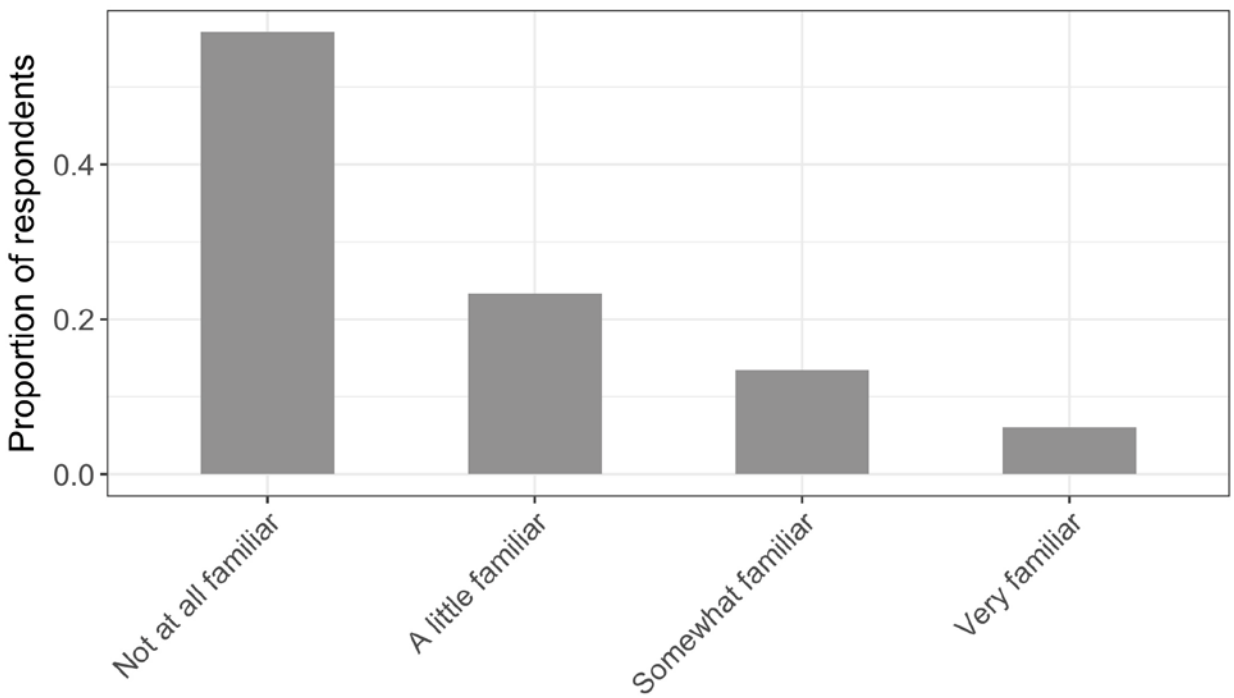


Figure 1. Pre-treatment familiarity with solar geoengineering.

Note: Unless otherwise noted, all figures and tables incorporate sampling weights. (See online supplemental material for further details.)

[5] We provide the exact text of relevant questions and additional details about the distribution of responses in online supplemental material.

[6] In administering the survey, we embedded an experiment at the beginning to explore whether public perceptions toward solar geoengineering would vary based on whether subjects perceived it as 'natural' or 'unnatural'. Surprisingly, subjects to whom we presented solar geoengineering as a naturally occurring process were no more supportive of its use or research than subjects to whom we presented it as an artificial process. In all results below we collapse the two treatment conditions together. Online supplemental material presents details about the experiment.

Introduction to geoengineering and gauging familiarity

The survey starts with a short preamble to introduce the issue area. We then ask respondents to rate their familiarity with solar geoengineering on a scale from 1 (*not at all familiar*) to 4 (*very familiar*). In line with previous research demonstrating the public's limited knowledge about solar geoengineering, subjects' mean response is approximately 1.7—between *not at all familiar* and *a little familiar*. While the distribution of our subjects' pre-treatment familiarity with solar geoengineering appears greater than earlier studies, nearly 57% of the subjects indicated that they were *not at all familiar* with solar geoengineering (Figure 1).

Measuring geoengineering preferences

After gauging subject's pre-treatment familiarity with solar geoengineering (Figure 1), we randomly provide them with one of three frames, which vary in their characterization of solar geoengineering as natural or unnatural. (See note 6 and online supplemental material.) We then ask whether subjects support the use of solar geoengineering and whether more research should be done on it, measured on a scale from 1 (*strongly disagree*) to 4 (*strongly agree*). Subjects who initially indicated that they were unsure about their opinion were asked to provide their best guess before proceeding. As a result, we collected responses from all 1,000 participants, though our substantive results do not change if we use only those who gave an opinion when first asked. (See online supplemental material for exact question wording.)

Figure 2 shows the results. Approximately 67% of subjects support the use of solar geoengineering, whereas 81% support research into it. Individuals appear to hold more moderate opinions about the use of solar geoengineering than about researching it, with 72% indicating that they *somewhat disagree* or *somewhat agree* with researching solar geoengineering, compared to 63% who hold moderate opinions about its use. Most of this is driven by subjects' *strong* support for researching the technology. Likewise, subjects more often *strongly* oppose the use of solar geoengineering (15%) than its research (7%).

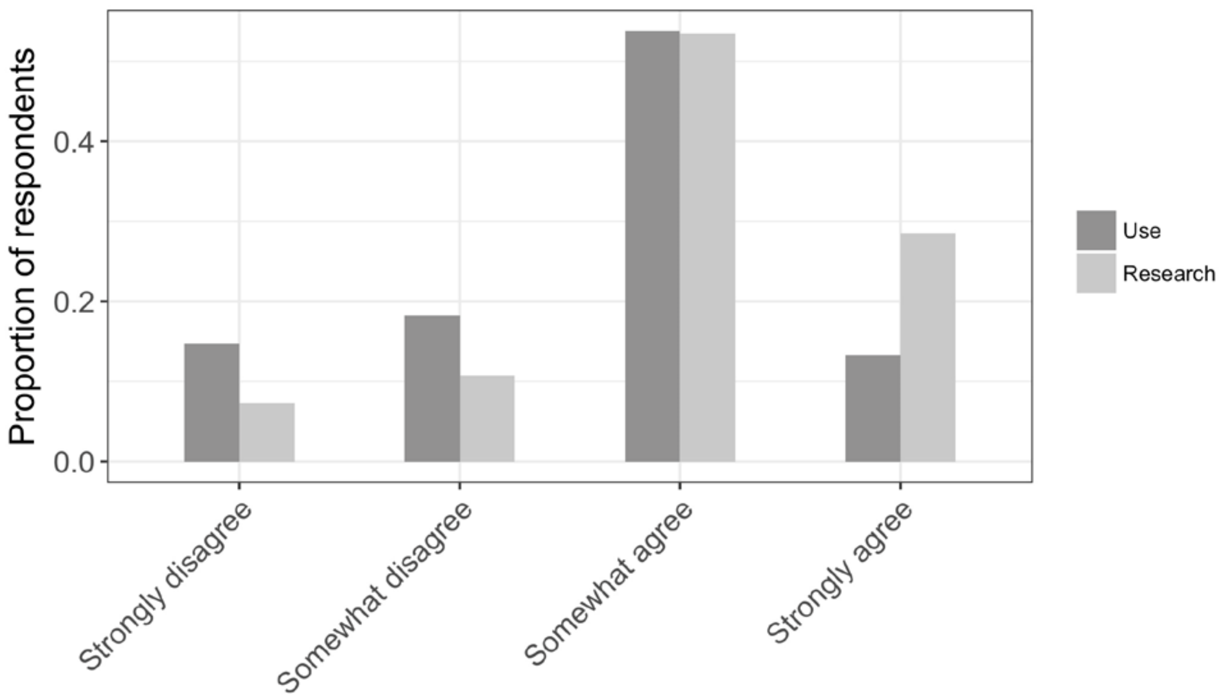


Figure 2. Distribution of support for use of and research into solar geoengineering.

Explanatory variables

The main independent variables of interest are subjects' self-reported ratings of the importance of various costs and benefits in forming their opinion about solar geoengineering. To complement these measurements, we also consider the relationship between support for the use and research of solar geoengineering and various demographic and political variables.

To directly measure attributes that subjects value, we ask them to rate the importance of these risks and benefits—that is, solar geoengineering's speed, cost, unpredictability, and moral hazard—in their decision to support its use or research. We ask respondents to rate each attribute on a scale from 1 (*unimportant*) to 4 (*important*).[7] Although responses are not required for each risk/benefit before proceeding in the survey, the response rate for each attribute considered in this article is greater than 85%. There is a weak though non-significant correlation between the importance placed by individuals on solar geoengineering's cost and speed, cost and moral

[7] Note that importance does not necessarily imply that a particular feature is desirable. The results in Table 1 and our own intuition conform with our understanding that high speed and low cost are indeed good, while decreased motivation to mitigate and unpredictability are bad. However, someone who considers solar geoengineering highly undesirable may well believe that high speed and low cost, while important, are also bad. This is particularly important for the moral hazard argument, which rests in part on the desirability of solar geoengineering's low cost. We thank Christine Merk for pointing this out.

hazard, and speed and moral hazard (Figure 10 in online supplemental material).

Results

"Fast, cheap, and imperfect"

Table 1 summarizes the relationship between individuals' support for the use of and research into solar geoengineering and the importance of various factors in the formation of their opinion, based on ordinary least squares regressions. Unsurprisingly, individuals who consider that, as a core characteristic, solar geoengineering is 'fast' were more likely to support both its use and research. Those who consider cost an important attribute are also likely to support its use. Additionally, concerns about solar geoengineering's unpredictability and the risk that it may generate moral hazard are weakly correlated with less support for its use. Concerns about unpredictability have a positive but insignificant impact on support for research while moral hazard concerns had a positive and statistically suggestive impact on support for research. Results do not change with prior familiarity with solar geoengineering as tested in a pre-treatment question (see Figure 1). That provides supportive evidence that our information given is sufficient to educate subjects about the topic.

Table 1: Effect of drivers on support for use and research of solar geoengineering

	Use	**Research**
Importance: speed	0.395^{***}	0.279^{***}
	(0.052)	(0.059)
Importance: cheaper than mitigation	0.232^{***}	0.071
	(0.051)	(0.055)
Importance: decrease society's motivation to mitigate	-0.044	0.103^{*}
	(0.051)	(0.056)
Importance: unpredictable effects	-0.082	0.063
	(0.051)	(0.054)
Constant	1.144^{***}	1.466^{***}
	(0.173)	(0.186)

$^{***}p < .01$; $^{**}p < .05$; $^{*}p < .1$

As hypothesized above, findings that subjects who care about solar geoengineering's speed and low cost are more supportive of its use align with the conventional belief that solar geoengineering is attractive precisely for these reasons. The observation that individuals concerned with the risk of moral hazard are more supportive of research, especially when disregarding other explanatory variables, is more surprising. Concerns about the possibility that solar geoengineering will reduce incentives to mitigate are typically attributed to opponents of the technology. Our findings suggest that such opposition does not necessarily extend to research, and that members of the public who exhibit concern about moral hazard may also be receptive to more nuanced ethical arguments that such concerns should not preclude research (Hale 2012; Preston 2013).

Demographic and political variables

Table 2 summarizes differences in support for the use and research of solar geoengineering by gender. Notably, and in contrast to of Corner and Pidgeon's (2015) results for the UK, support for using solar geoengineering is higher among women than men. (Table 6 shows that findings for use hold after controlling for respondents' age, parties, and importance of climate change in the election. For research, the finding is similar in magnitude but no longer significant.)

Table 2: Gender and support for use/research of solar geoengineering and drivers of support

	Use	Research	Speed	Cost	Motivation	Unpredictable
Female	0.204^{***}	0.136^{*}	0.192^{**}	0.228^{***}	0.078	0.082
	(0.078)	(0.070)	(0.082)	(0.084)	(0.093)	(0.072)
Constant	2.346^{***}	2.824^{***}	2.740^{***}	2.632^{***}	2.773^{***}	3.154^{***}
	(0.136)	(0.121)	(0.133)	(0.136)	(0.152)	(0.115)

$^{***}p < .01$; $^{**}p < .05$; $^{*}p < .1$

Women place more importance on the high speed and low cost of solar geoengineering than men do, whereas the importance of the risk of moral hazard and unpredictability does not differ across genders. This result runs counter to conventional wisdom in two ways. First, the similarity in male and female respondents' concerns about unpredictability diverges from the finding that women are, on average, less accepting of risk than men, as hypothesized above. Second, the finding that women place greater importance on speed runs counter to experimental research in psychology and economics that suggests that men tend to discount risk at higher rates than women (Kirby and Maraković 1996; Coller and Williams 1999). If confirmed, these findings suggest broader open questions around traditional economic assumptions about differences in gender, especially when other concerns, such as climate change, are present.

Table 3: Age and support for use/research of solar geoengineering and drivers of support

	Use	**Research**	**Speed**	**Cost**	**Motivation**	**Unpredictable**
Age (increase in year)	-0.012***	-0.006***	-0.007***	-0.007***	-0.007***	-0.003
	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)	(0.002)
Constant	3.211***	3.319***	3.369***	3.333***	3.245***	3.408***
	(0.100)	(0.095)	(0.117)	(0.129)	(0.138)	(0.108)

***p < .01; **p < .05; *p < .1

Table 3 shows that age is inversely linked to support for the use and research of solar geoengineering. (Table 6 confirms these findings after controlling for respondents' political alignment and other factors.) Meanwhile, age is not measurably associated with concerns about the unpredictability of solar geoengineering, so it appears unlikely that these results are driven by a general relationship between risk-tolerance and age. Rather, it seems more likely that these preferences reflect a general response to the inter-generational distribution of climate risks: younger generations, who will be more affected by climate change, are more interested in addressing its effects (Schelling 1996; Gosseries and Meyer 2009), whether that means cutting carbon dioxide emissions or solar geoengineering. While our finding does not adjudicate between diverging theories, it does lend support to the overarching premise.

Table 4: Partisanship and support for use/research of solar geoengineering and drivers of support

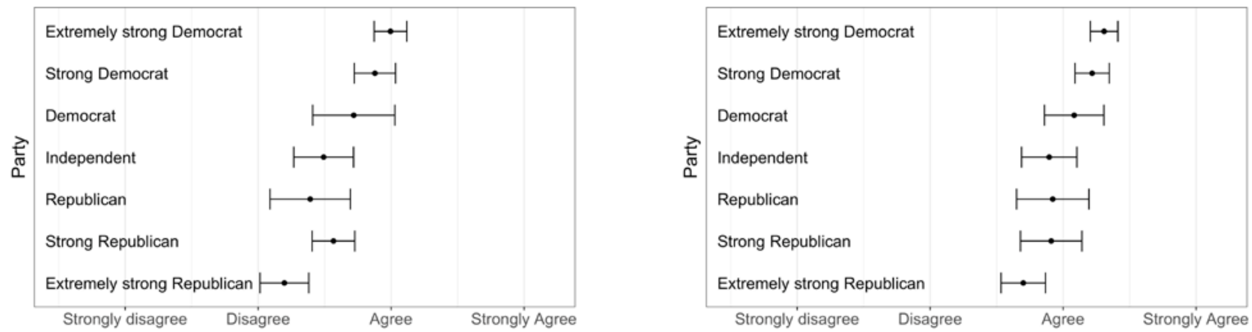
	Use	**Research**	**Speed**	**Cost**	**Motivation**	**Unpredictable**
Identification as Republican	-0.123***	-0.096***	-0.151***	-0.074***	-0.142***	-0.073***
	(0.016)	(0.015)	(0.019)	(0.019)	(0.020)	(0.018)
Constant	3.097***	3.386***	3.575***	3.220***	3.401***	3.554***
	(0.066)	(0.056)	(0.065)	(0.071)	(0.078)	(0.063)

***p < .01; **p < .05; *p < .1

Table 4 and Figure 3 show some partisan differences between support for the use and research of solar geoengineering. Republicans find the risks and benefits associated with solar geoengineering to be less important than do Democrats. Subjects rate their political leanings on a scale from 1 (*Extremely Strong Democrat*) to 7 (*Extremely Strong Republican*).[8] Increases in

[8] Subjects could also rate their political leanings as Unsure. Approximately 4% of subjects self-identified as unsure. We excluded those responses from Table 4 and Figure 3.

subjects' self-identification as Republicans were associated with decreases in their support for the use and research of solar geoengineering, in line with partisan explanations around the desire to mitigate the effects of climate change.[9]



(a) Use (b) Research

Figure 3: Support for (a) use and (b) research of solar geoengineering by party

Table 5 further illustrates a positive association between support for the use and research of solar geoengineering and subjects' perceptions about the importance of climate change. Together with Republicans considering climate change less of a concern than do Democrats, this suggest that Republicans' lower support for solar geoengineering's use and research, illustrated in Figure 3, may be due to the low saliency of the broader issue of climate change among Republicans.

Table 5: Importance of climate change in presidential vote and support for use/research of solar geoengineering and drivers of support

	Use	**Research**	**Speed**	**Cost**	**Motivation**	**Unpredictable**
Importance in election	0.192^{***}	0.223^{***}	0.342^{***}	0.234^{***}	0.328^{***}	0.130^{***}
	(0.037)	(0.034)	(0.038)	(0.039)	(0.043)	(0.034)
Constant	2.167^{***}	2.464^{***}	2.158^{***}	2.374^{***}	2.056^{***}	2.948^{***}
	(0.101)	(0.096)	(0.114)	(0.117)	(0.122)	(0.102)

$^{***}p < .01$; $^{**}p < .05$; $^{*}p < .1$

[9] Figure 5 in the online supplemental material shows differences across party in how important climate change was in determining votes: Democrats on average rated the issue as *somewhat important*, Republicans as *somewhat unimportant*. Figure 6 shows the importance of primary factors by party, with Democrats considering each factor more important than Republicans.

Multivariate analysis

Thus far we have largely confined our results to a set of bivariate analyses. Table 6 shows the core demographic and political variables in a single model to estimate their combined impact on support for the use and research of solar geoengineering as well as the level of importance assigned to its speed, cost, moral hazard, and unpredictability. Results here largely confirm prior interpretations. Women are more supportive of solar geoengineering's use than are men, although the gap is smaller and there is no longer a statistically significant difference between men's and women's support for research. Age has a consistently negative impact on support for both use and research. So, too, does identifying as a Republican. Respondents who are more concerned about the environment as an issue supported use and research more, but they also assigned greater importance to considerations of speed, cost, motivation, and unpredictability. (See online supplemental material for further robustness checks.)

Table 6: Multivariable analysis

	Use	**Research**	**Speed**	**Cost**	**Motivation**	**Unpredictable**
Female	0.186^{**}	0.098	0.148^{*}	0.198^{**}	0.028	0.054
	(0.075)	(0.068)	(0.078)	(0.079)	(0.087)	(0.072)
Age	-0.010^{***}	-0.005^{**}	-0.004^{*}	-0.005^{**}	-0.005^{**}	-0.002
	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.002)
Identification as Republican	-0.094^{***}	-0.058^{***}	-0.088^{***}	-0.026	-0.082^{***}	-0.052^{***}
	(0.018)	(0.017)	(0.021)	(0.019)	(0.023)	(0.019)
Importance in election	0.093^{**}	0.161^{***}	0.263^{***}	0.207^{***}	0.253^{***}	0.085^{**}
	(0.041)	(0.040)	(0.046)	(0.042)	(0.052)	(0.040)
Constant	3.131^{***}	3.004^{***}	2.804^{***}	2.663^{***}	2.772^{***}	3.339^{***}
	(0.198)	(0.192)	(0.209)	(0.205)	(0.239)	(0.195)

$^{***}p < .01$; $^{**}p < .05$; $^{*}p < .1$

Note: Table 6 presents the incremental effect of identifying as more conservative on a seven-point scale rather than presenting less readable contrast-coded variables. Conducting the analysis with political identification coded as a factor variable, the negative relationship between age and speed is less strong, and the negative relationship between unpredictability and identification as Republican is largest among strong Republicans. Other coefficients remain unchanged.

Respondents who considered climate change an important factor in determining their vote in the 2016 election also exhibited greater concern about the risks of moral hazard, an effect that remained robust even after controlling for party.[10]

'Moral hazard' and acquiescence bias

Most prior surveys find that geoengineering would affect society's motivation to mitigate (Burns *et al.* 2016). Given the importance of moral hazard in previous work, we further scrutinize the moral hazard hypothesis and consider the potential role of acquiescence bias, the observation that survey respondents tend to agree with the way the question is phrased (Cohen *et al.* 1996; Podsakoff *et al.* 2003).

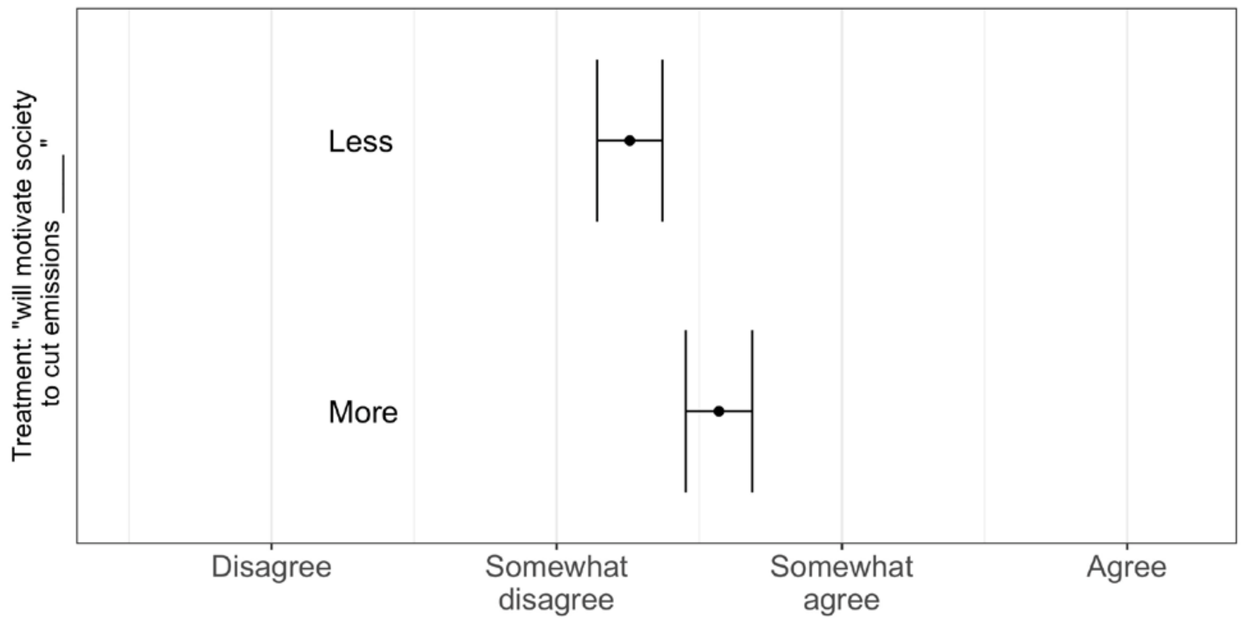
Past studies have phrased the moral hazard questions in terms of whether solar geoengineering "will motivate society to cut emissions *less*."[11] This may bias results, as subjects 'acquiesce' to the valence of the survey item—i.e., the direction in which way society could move.

To understand whether negated items would generate acquiescence bias in beliefs about how solar geoengineering will affect society's motivation to cut emissions, we embedded a simple experiment in our survey. Subjects were randomly assigned to one of two groups: the first was asked about the extent to which they agreed with the statement that "knowing about solar geoengineering will motivate society to cut emissions *more*"; the second was asked whether "knowing about solar geoengineering will motivate society to cut emissions *less*." Figure 4 shows that respondents who are asked whether solar geoengineering would cause society to cut emissions *more* are more likely to believe that this would be the case than those asked whether solar geoengineering would cause society to cut emissions *less*, and vice versa.

[10] These findings are consistent with work by Corner and Pidgeon (2014), who assessed how subjects in the UK responded to moral hazard arguments against solar geoengineering and found that climate skeptics were less likely to find moral hazard arguments convincing than those who trust the science on climate change.

[11] Visschers et al. (2017), for example, asks two types of moral hazard questions in their cross-country survey: whether solar geoengineering "would remove the motivation to use energy more efficiently," and whether it "would decrease the motivation to reduce CO2 emissions." They find sufficiently weak support of each question—a mean of 3.75 and standard deviation of 1.45 on a 6-point Likert scale in the first case, and a mean of 3.84 and standard deviation of 1.44 in the second (Table A-2) that acquiescence bias may well have played a role. Note that both Mercer et al. (2011) and Merk et al. (2015) test for acquiescence bias in overall attitudes on use. Mercer et al. (2011) asks both whether solar geoengineering "should" and "should never" be used and find that 29% of their sample are "supporters": they *strongly* or *somewhat agree* with the first, while *strongly* or *somewhat disagreeing* with the second question. For 20%, whom Mercer et al. (2011) calls "detractors," the responses are reversed. That leaves around 50% who fall in neither category, potentially pointing to large acquiescence bias.

Figure 4: Effect of treatments on belief that knowing about solar geoengineering would cause societies to cut emissions more/less (standardized to "more")



Note: Figure 4 standardizes all responses to the same scale, reflecting the belief that knowing about solar geoengineering would cause society to cut emissions more. When broken out by prior familiarity, both groups exhibit the pattern presented here, though the gap is larger for individuals with some familiarity.

Figure 4 suggests that prior measurements of respondents' concerns about moral hazard may suffer from acquiescence bias. One fruitful avenue for further research would be to test for acquiescence bias among respondents with greater pre-treatment familiarity with solar geoengineering. While acquiescence bias is unlikely to have sufficiently high effects to reverse the overall findings (e.g. 81% support for research or 67% for its use), it may affect some weaker results found in our and prior studies, beyond moral hazard.

Conclusion

Our survey finds that a majority of US respondents (81%) support research into solar geoengineering, and, perhaps surprisingly, even support its use (67%).

To better understand these high levels of support, we examine the salience of three key characteristics of solar geoengineering: that it is 'fast', 'cheap', but also 'imperfect'. We find that speed matters for support of both research and use. Low cost matters for use, but not for research. We proxy for imperfection with the technology's unpredictability and the possibility for moral hazard. Surprisingly, unpredictability has only a limited effect, while concerns about moral hazard increase support for research. Concern about moral hazard is correlated with party, age, and issue in predictable ways. Those most concerned about climate change—and, thus, most supportive of mitigation efforts—are also most concerned about moral hazard. That said, the concern does not seem to diminish public support for research or even for use of the technology.

In addition, we observe acquiescence bias in responses to questions about moral hazard. Subjects asked whether solar geoengineering would lead to *less* desire to mitigate, *and* those asked whether it would lead to *more* desire to mitigate, both agreed. Prior surveys aimed at identifying moral hazard-like attitudes have tended to rely on the former phrasing, revealing susceptibility to acquiescence bias. Further exploration of this phenomenon may offer a productive avenue for further research.

Finally, we find that support for both research and use matches previously seen party identification, age, and risk patterns. Our findings differ from hypothesized gender patterns, with women showing greater support than men. Perhaps surprisingly, and despite generally low pre-treatment familiarity, subjects' beliefs about the risks and benefits of solar geoengineering and their support for its use and research do not differ significantly on the basis of their pre-treatment familiarity with the technology.

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