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

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This Draft: November 8, 2017

Abstract

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 continues largely 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," moving people away from wanting more costly mitigation efforts. In addition to the need for further research to quantify and compare these tradeoffs, there is also currently little understanding about how the public will respond to them. To address this question, we have conducted a 1,000-subject nationally representative poll focused on solar geoengineering as part of the Cooperative Congressional Election Study (CCES) of the US electorate in October-November 2016. We find that support for the use and research of solar geoengineering is indeed contingent on the importance that individuals place on solar geoengineering's speed and cost. Surprisingly, however, there is little to no relationship between concerns about solar geoengineering's shortcomings and support for its use. Subjects concerned about moral hazard and solar geoengineering's unpredictability also tend to support its research. We also examine demographic and political correlates of individual views of geoengineering.

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

*We would like to thank Lizzie Burns, David Keith, Johannes Urpelainen, and participants of the 2017 Gordon Research Conference on Climate Engineering for discussion and feedback. We would especially like to thank Josh Horton for early framing conversations and Jane Flegal for detailed feedback on an earlier draft. We thank the Weatherhead Initiative on Climate Engineering for support. Additional support comes from Harvard's Solar Geoengineering Research Program, which Wagner co-directs and on whose Advisory Committee Tingley and Wagner serve. All remaining errors are our own.

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1 Introduction

Technological advances often offer many 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. Quick and cheap solutions may not only be suboptimal but, at worst, counterproductive in the long run. 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 bad consequences.

We ask here how individual views of pace, cost, and imperfection influence public support for using and researching a new technology. We unpack the role of each of these dimensions using a nationally representative survey in the United States (US). The important role that public opinion plays in technological adoption is broadly understood (Katz and Shapiro, 1986; Freudenburg and Pastor, 1992; Stoneman and Diederen, 1994; Callon, 1999; Pidgeon et al., 2008; Kim et al., 2013), and so exercises like ours are useful insofar as they help us understand how future societal debates about this technology's use could unfold.

We focus on geoengineering, also called "climate engineering," a term broadly defined as the deliberate and large-scale manipulation of the environment but used more commonly 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, which proposes transporting light-scattering particles, such as sulfate aerosols, to the upper atmosphere, most likely by planes, to reflect sunlight away from the earth and thereby lower global temperatures (NRC, 2015b). This type of technology is relatively new, not least because of a long-standing taboo against researching it (Keith et al., 2010; Caldeira and Bala, 2017). However, estimates of its pace of action and cost suggest that it would reduce global temperatures more quickly and cheaply than mitigation (Crutzen, 2006; Wigley, 2006; Shepherd, 2009; Vaughan and Lenton, 2011; McClellan et al., 2012; NRC, 2015b; Harding and Moreno-Cruz, 2016). 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 in the first place. This paper presents the results of one of the most detailed, precise, and comprehensive analyses to date of the determinants of support for the use and research of solar geoengineering, in light of these tradeoffs, among the US public. It joins a growing public opinion literature on the topic (Burns et al., 2016).

The paper is structured as follows: Section 2 provides background information on geoengineering, explaining its 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. Section 3 introduces our survey instrument, and Section 4 presents our analysis. Section 5 concludes by explaining the implications of our findings for the introduction of other technologies and social policy tools.

2 Explaining geoengineering preferences

2.1 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 others — in exchange for its speed and low cost. These three core characteristics of solar geoengineering — fast, cheap, and imperfect — recur in political, economic, legal, and theological discussions about solar geoengineering (Keith, 2000; Keith et al., 2010; Barrett and Moreno-Cruz, 2015; Moreno-Cruz and Keith, 2013; Klepper and Rickels, 2014; Parson and Ernst, 2013; Shepherd, 2009). 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).[1]

As these three characteristics dominate current debates about solar geoengineering, we focus our analysis on them here as well.[2] To the extent that these three attributes matter, 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

[1] A number of other perceived characteristics of solar geoengineering may also affect public opinion toward it, such as beliefs about whether it occurs naturally or is artificial, the degree to which it will produce or exacerbate economic inequality, the time period over which its possibly negative consequences may materialize, and its impacts on non-human species. We conduct an experiment exploring the first possibility (see Appendix E) but leave studies of the remaining drivers of public opinion to future research.

[2] There are many others that deserve further careful study, including, for example, "controllability" (Bellamy et al., 2017) and other more specific risks of solar geoengineering.

for mitigation efforts. The relationship between support for solar geoengineering and concerns about speed and cost stem from properties of sulfate aerosols themselves. While humans have yet to use aerosols to cool the planet, scientists have studied volcanic eruptions—notably the 1991 eruption of Mount Pinatubo in the Philippines—to understand the atmospheric impacts of sulfate aerosols and other particulate matter. Mount Pinatubo's eruption had effects that were immediate and widely dispersed. Solar radiation decreased by up to 30% in remote locations (Dutton and Christy, 1992), resulting in global cooling of 0.5-1.0°C within a few months (Pitari and Rizi, 1993; Hansen et al., 1996). The timing and magnitude of the cooling from this single eruption suggest that anthropogenic deployment of aerosols could offset temperature increases over the next century at least 100 times more cheaply than traditional mitigation (Keith et al., 2010; Wagner and Weitzman, 2015). Cases for and against the use of solar geoengineering both rest on the premise that it is fast and cheap. While solar geoengineering's cheap 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 faultlines 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 disincentivize further mitigation (Hamilton, 2015; Collins, 2016; Gertner, 2017). We hence expect individual attitudes to diverge along the same 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). The term moral hazard, the recurring concern that solar geoengineering will disincentivize more costly greenhouse gas mitigation efforts by providing a cheap alternative, was first introduced into the solar geoengineering debate by Keith et al. (2010). It is technically a misnomer (Barrett, 2008). Its use in the solar geoengineering debate is more accurately described as a "lack of self-control" (Wagner and Weitzman, 2015).[3] Nonetheless, given the prevalence of the term "moral hazard" frequency in the solar geoengineering literature, we continue to use it here.

[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.

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 is less certain. On one hand, if using or researching solar geoengineering delays mitigation, younger generations would bear a disproportionate share of inter-generational costs, and so concerns about moral hazard would 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. Additionally, it is possible that moral hazard is less important in explaining variation in support among age groups than unpredictability. The relationship between age and risk perception remains unclear, but if, as early work suggested, risk tolerance decreases with age (Wallach and Kogan, 1961; McInish, 1982; Morin and Suarez, 1983; Harlow and Brown, 1990), then support for solar geoengineering may decrease in age. 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).[4] While understanding the relationship between age and concerns about moral hazard does not immediately adjudicate between these theories, we believe that it could contribute to ongoing debates.[5] We also believe that examining the current relationship between age and support for the use and research of solar geoengineering raises new questions about what explains inter-generational differences, if any, in support for using or research solar geoengineering in populations that tend to be unfamiliar with solar geoengineering.

[4]Gardiner (2011) fears that the sunk costs of researching solar geoengineering may provide future generations with an irrational justification for using it and Jamieson (1996) considers the role of organized groups with financial interests in the future use of solar geoengineering. With the assumption that support for solar geoengineering will increase over time, Keith et al. (2010) writes that the current generation would ban solar geoengineering to prevent further generations from using it, while Bunzl (2009) argues that they would rely on it as a backstop to justify less mitigation.

[5]It is also possible that current variation in public opinion across age brackets incorporates each generation's beliefs about reactions among other age groups.

2.2 Demographic and political characteristics

Demographic characteristics Research in the natural and social sciences observe that men are more risk-seeking than women (Arch, 1993; Bord and O'Connor, 1997; Byrnes et al., 1999; Niederle and Vesterlund, 2007; Croson and Gneezy, 2009; Charness and Gneezy, 2012). 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)[6]. That gender might be relevant to public opinion on this topic has been recognized in the literature: a growing body of work considers the underrepresentation of women in discussions about solar geoengineering while other research 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 (Buck et al., 2014). However, there is surprisingly limited empirical support that preferences for solar geoengineering vary by dender. (Corner and Pidgeon, 2015). Unlike previous studies, we directly ask respondents about the factors that drive their support for the use or research of solar geoengineering, so we can seek to replicate existing findings and then offer further insight into differences in support by genders and the extent to which such differences are driven by solar geoengineering's unpredictability. 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. An early body of work found risk tolerance to decrease with age (Wallach and Kogan, 1961; McInish, 1982; Morin and Suarez, 1983; Harlow and Brown, 1990), but it was later challenged by experimental studies that failed to detect an association between the two (Hariharan et al., 2000; Gollier, 2002). The tide has turned again as more recent work detects a relationship between risk and age (Hallahan et al., 2004), though most differences have been attributed to individual-level differences in risk profiles (Sahm, 2012). Corner and Pidgeon (2015) find no gender difference in support for geoengineering, but they do find that support for solar geoengineering decreases with age. There is conflicting evidence about the relationship between risk-tolerance and age, and so rather than relying on our own hypotheses, we seek evidence to help assess the importance of these competing effects.

[6]CDR, sometimes also referred to as 'CDR' for Direct Carbon Removal or also as 'air capture', is a class of technologies that aim to reduce atmospheric concentrations of carbon dioxide, is classified by some as a form of geoengineering (Keith, 2000; NRC, 2015a).

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; McCright and Dunlap, 2011; Brulle et al., 2012) — is attributed in part to Republicans' lower willingness to pay for clean energy (Solomon and Johnson, 2009; Aldy et al., 2012; Ansolabehere and Konisky, 2014) and greater skepticism about climate risks (Wiest et al., 2015; Albertson and Busby, 2015). It is also possible that Republicans are more risk-accepting than Democrats on environmental issues.[7] Republicans' lower willingness to pay for clean energy, along with some early advocacy for solar geoengineering by Republican politicians and think tanks (Vidal, 2011; Pethokoukis, 2013), suggest that Republicans might favor this policy (Hamilton, 2015; Lukacs, 2017). Greater skepticism about climate risks, meanwhile, could counteract that support. We anticipate the same characteristics associated with Republicans to extend to groups that find climate change to be a low-salience issue. Consequently, we test whether subjects identifying as Republican and subjects for whom climate change was not an important factor in determining their presidential vote in the 2016 election (non-issue-voters) 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.[8]

2.3 Relevant public opinion literature

In line with resurgent interest in solar geoengineering among natural scientists (Lawrence and Crutzen, 2017), social scientists, too, have paid increased attention. Reviewing over thirty empirical papers on the subject, Burns et al. (2016) find that most studies are administered in Western countries and seek to gauge the public's familiarity with and acceptance of solar geoengineering. A subset of studies focuses on the effects of framing on the public's beliefs, with a number of studies testing the importance and effects of moral hazard.

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; Corner and Pidgeon, 2014; Merk et al., 2014) 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

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

[8] Subsequently, we abbreviate the first group as "R/NIV" and the second as "D/IV."

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) report 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. Burns et al. (2016) summarize the literature and report that most surveys find respondents concerned about moral hazard. A study by Merk et al. (2016) in which the researchers observe behavior directly finds that those hearing about solar geoengineering are more willing to offset their own emissions. Urpelainen (2012) and Millard-Ball (2012) provide some theoretical backing for those results. Merk et al. (2016) themselves hypothesize that their 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—though Merk et al. (2016) find no conclusive evidence for these explanations. Kahan et al. (2015), meanwhile, emphasize the importance of the second explanation: "inverse moral hazard" is 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 widely across countries. Surveying mid-career environmental leaders from the global South, Winickoff et al. (2015) observe a belief that moral hazard should be reframed as "moral responsibility." Visschers et al. (2017) similarly find 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 find that subjects in non-OECD countries such as China, India, and the Philippines report 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 likely 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). Despite the identification of these moderating variables, it remains unclear how most political and demographic factors affect US public opinion about solar geoengineering. More surprisingly, 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.

3 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).[9] 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 that was 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.[10]

Introduction to geoengineering and gauging familiarity The survey started with a short preamble to introduce the issue area (See Appendix **??** for exact wording).

We then asked 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 (Mercer, 2014; Burns et al., 2016;

[9]The exact text of relevant questions and additional details about the distribution of responses are provided in Appendices B and C.

[10]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. Appendix E presents details about the experiment.

McLaren et al., 2016), subjects' mean response was approximately 1.7—between "not at all familiar" and "a little familiar." Nearly 57% of the subjects indicated that they were "not at all familiar" with solar geoengineering (Figure 1).[11]

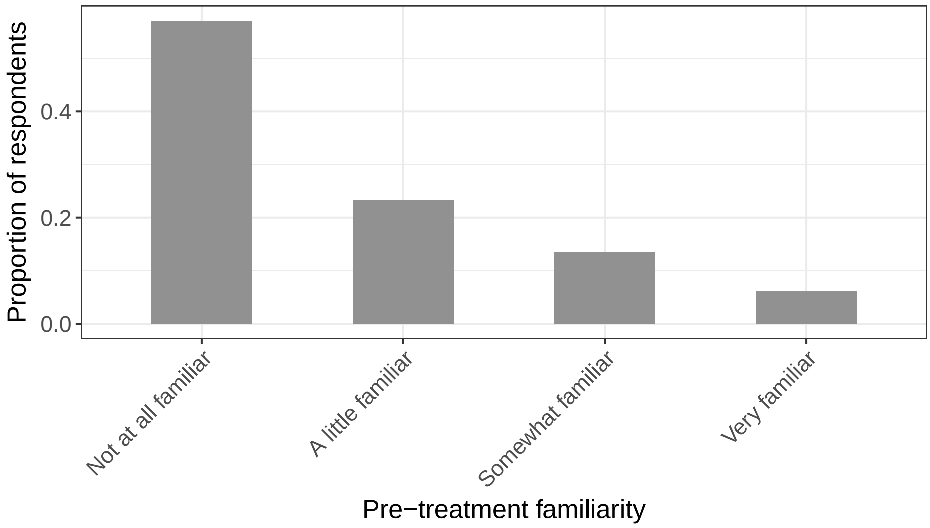


Figure 1: Pre-treatment familiarity with solar geoengineering[12]

Measuring geoengineering preferences We then ask whether subjects support both the use of solar geoenginering as well as whether more research should be done on it. We measured responses on a scale from 1 (*strongly disagree*) to 4 (*strongly agree*). Subjects were required to provide an answer to these questions before proceeding, and those who initially indicated that they were unsure about their opinion were asked to provide their best guess. 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 Appendix B for exact question wording.

Figure 2 shows the results. Approximately 67% of subjects support the use of solar geoengineering, whereas 81% support its research. Individuals appear to hold more moderate opinions about the use of solar geoengineering than about its research, with 63% of subjects indicating that they somewhat disagree or somewhat agree with researching solar geoengineering, as opposed to 72% who hold moderate opinions about its use. Most of this is driven by subjects' strong support for researching the technology. Likewise, subjects have greater 'strong'

[11]The distribution of our subjects' pre-treatment familiarity with solar geoengineering is somewhat greater than earlier studies. See Section 2.3.

[12]Unless otherwise noted, all of the following figures and tables incorporate sampling weights. See Appendix A for further details.

opposition to the use of solar geoengineering (15%) than to its research (7%).

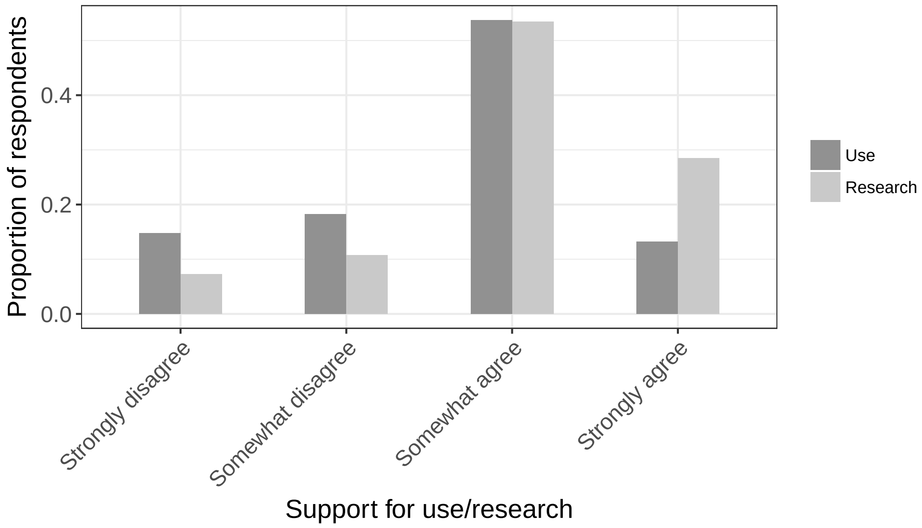


Figure 2: Distribution of support for use and research of solar geoengineering

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 compliment these measurements, we also consider the relationship between support for the use and research of solar geoengineering and various demographic and political variables.[13]

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 potential to decrease mitigation efforts—in their decision to support its use or research. Respondents were asked to rate each attribute on a scale from 1 (*unimportant*) to 4 (*important*). Although responses were not required for each risk/benefit before proceeding in the survey, the response rate for each attribute considered in this article was greater than 85%. There was a weak correlation between the importance placed by individuals on solar geoengineering's cost and speed, cost and the risk of solar geoengineering producing moral hazard, and the speed and the risk of solar geoengineering producing moral hazard (Figure 10a in Appendix C), however these relationships were not statistically significant (Figure 10b).

[13]See Appendices B and C for details.

4 Results

4.1 Fast, cheap, and imperfect

Table 1 summarizes the relationship between individuals' support for the use and research of solar geoengineering and the importance of various factors in the formation of their opinion. Unsurprisingly, individuals who considered, as a core characteristic of solar geoengineering, the fact that it was 'fast' were more likely to support both its use and research. Those who considered cost an important attribute were also likely to support its use. Additionally, concerns about solar geoengineering's unpredictability and the risk that it may generate moral hazard were weakly correlated with less support for its use. Concerns about unpredictability had a positive but insignificant impact on support for research while moral hazard concerns had a positive and statistically suggestive impact on support for research.[14][15].

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

	Use	**Research**
Importance: solar geoengineering speed	0.395^{***}	0.279^{***}
	(0.052)	(0.059)
Importance: cheaper than mitigation	0.232^{***}	0.071
	(0.051)	(0.055)
Importance: decrease society motivation	-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 in Section 2.1, the 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 because of these qualities (Keith et al., 2010; Caldeira and Keith, 2010). The observation that individuals concerned with the risk of moral

[14]Moreover, our 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.

[15]When other explanatory variables are disregarded we find both concerns to be strongly correlated with more support for both solar geoengineering's research. The concern about moral hazard (when considered as the only explanatory variable) is strongly correlated with support for both solar geoengineering's use and research. There is only a weak correlation between concerns about unpredictability (when considered as the only explanatory variable) and support for solar geoengineering's use. See Tables 7 and 9.

hazard are more supportive of research, especially when 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 (Keith et al., 2010; Blackstock, 2012; Preston, 2013; Macnaghten and Szerszynski, 2013). Our findings suggest that such opposition does not necessarily extend to research, and that the 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).

4.2 Demographic and political variables

Table 2 summarizes differences in support for the use and research of solar geoengineering by gender. Notably, support for using solar geoengineering is higher among women than men, a finding that holds up even after controlling for respondents' parties. This result differs from the findings of Corner and Pidgeon (2015), who observe no difference in the levels of support for solar geoengineering between men and women in their study conducted in the UK.

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)

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

The higher level of support for solar geoengineering among women stems from the fact that 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 several ways. First, 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 at higher rates than women (Kirby and Maraković, 1996; Coller and Williams, 1999). Second, the similarity in male and female respondents' concerns about unpredictability also diverge from the finding that women are, on average, less accepting of risk than men (Arch, 1993; Bord and O'Connor, 1997; Byrnes et al., 1999; Niederle and Vesterlund, 2007; Charness and Gneezy, 2012; Croson and Gneezy, 2009). These findings suggest that further research is needed to determine whether traditional economic assumptions about differences in gender are actually rather nuanced and do not hold up 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)

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

Another important finding that emerges is that there is a negative relationship between age and support for the use and research of solar geoengineering, even after controlling for respondents' political alignment (Table 3). Age is not measurably associated with concerns about the unpredictability of solar geoengineering, and so it seems unlikely that these results are driven by a general relationship between risk-tolerance and age, for which there is conflicting evidence (Wallach and Kogan, 1961; McInish, 1982; Morin and Suarez, 1983; Harlow and Brown, 1990; Gollier, 2002; Hallahan et al., 2004; Sahm, 2012). Rather, it is more likely that these preferences reflect a rational response to the inter-generational distribution of climate risks: younger generations, who will be more affected by climate change down the line, are more interested in addressing its effects (Schelling, 1996; Gosseries and Meyer, 2009), whether that means cutting carbon dioxide emissions or solar geoengineering (Bunzl, 2009; Moreno-Cruz and Keith, 2013; Goeschl et al., 2013). 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. Subjects rated their political leanings on a scale from 1 (*Strong Democrat*) to 7 (*Strong Republican*).[16] Increases in subjects' self-identification as Republi-

[16] Subjects could also rate their political leanings as *Unsure*. Approximately 4% of subjects self-identified as

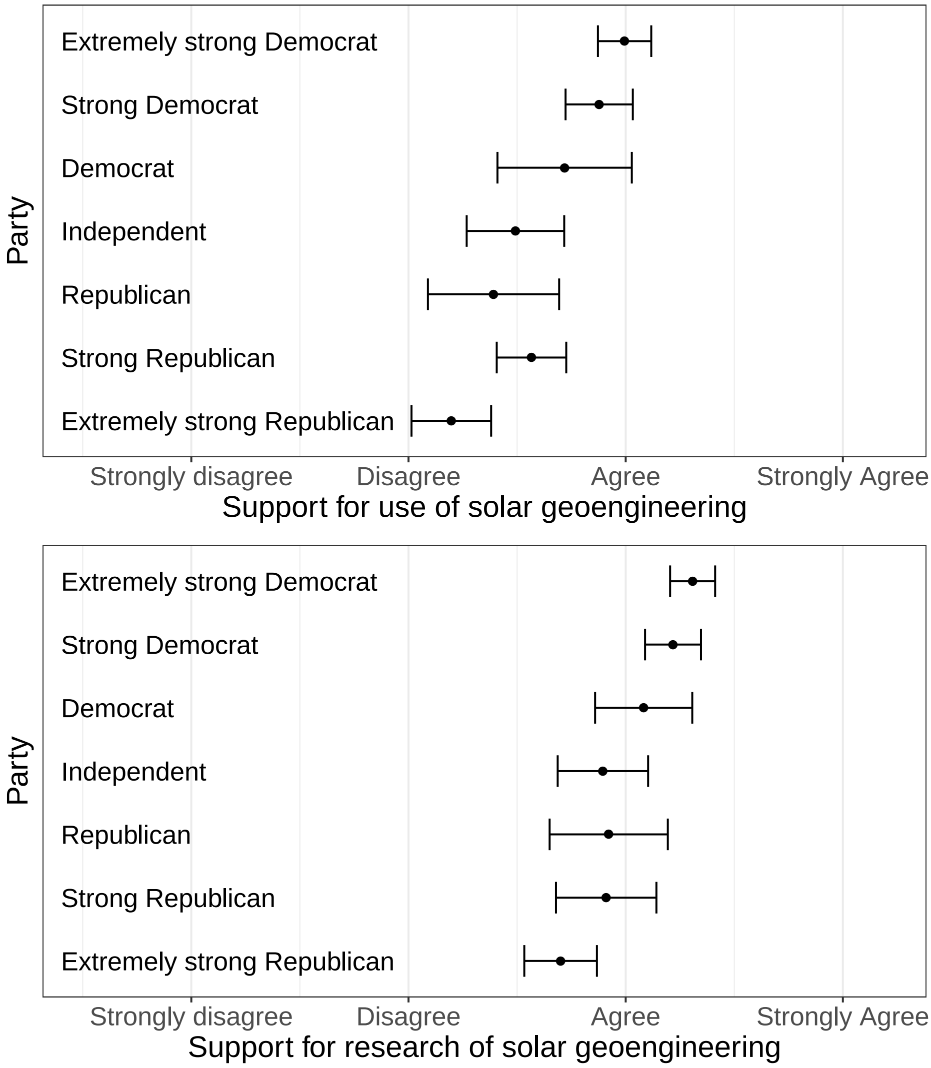


Figure 3: Support for use/research of solar geoengineering by party

cans 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. Republicans find the risks and benefits associated with solar geoengineering to be less important than Democrats (Figure 5). When asked about the importance of climate change in determining their vote in the 2016 election, Democrats on average rated the issue as "somewhat important." Republicans, meanwhile, rated it as "somewhat unimportant" (Figure 4).

unsure. We excluded those responses from Table 4.

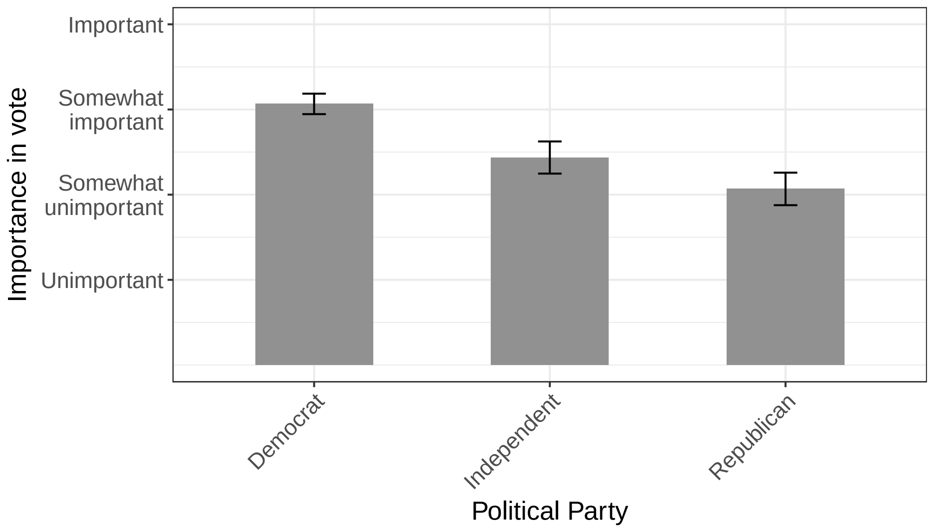


Figure 4: Importance of climate change in determining vote in 2016 presidential election

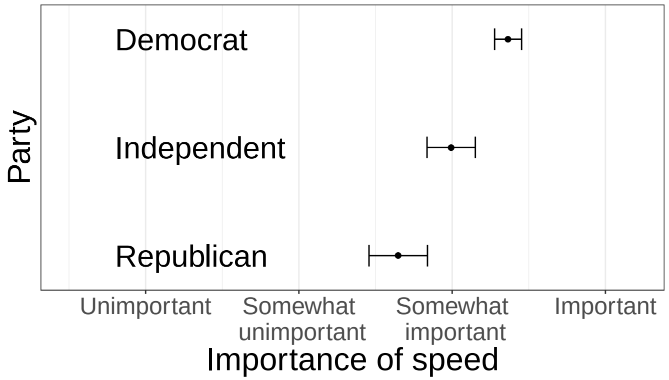
Table 5 further illustrates a positive association between support for the use and research of solar geoengineering and subjects' perceptions about the importance of climate change. Compared to Democrats and independents, Republicans indicated that climate change was a less important factor in determining their 2016 presidential vote, and they profess less concern about the costs and risks of solar geoengineering. Together these results suggest that their low support for its use and research may be due to the low saliency of the broader issue of climate change within the party.[17]

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

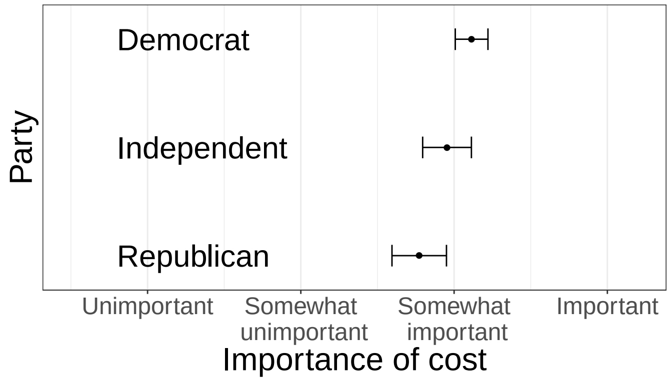
	Use	**Research**	**Speed**	**Cost**	**Motivation**	**Unpredictable**
Importance in election	0.192***	0.223***	0.342***	0.234***	0.328***	0.130***
	(0.037)	(0.034)	(0.038)	(0.039)	(0.043)	(0.034)
Constant	2.167***	2.464***	2.158***	2.374***	2.056***	2.948***
	(0.101)	(0.096)	(0.114)	(0.117)	(0.122)	(0.102)

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

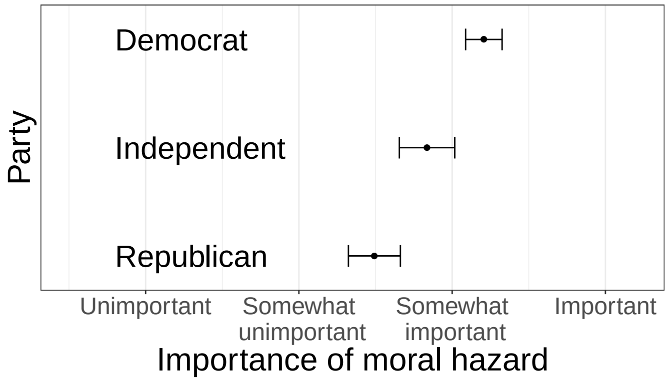
[17]We also tested the link between support for nuclear energy and solar geoengineering and found no link. We do find a link with pessimism toward technology, which decreases support for both solar geoengineering's use and research.



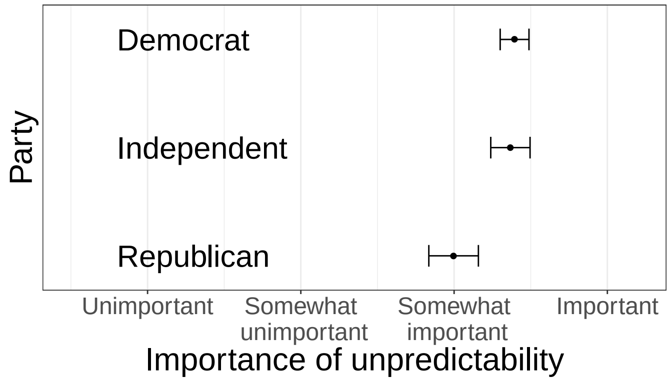
(a) Speed



(b) Cost



(c) Moral hazard



(d) Unpredictability

Figure 5: Importance of primary factors by party (excudes “Other” and “Unsure”)

4.3 Multivariate analysis

Thus far we have largely confined our results to a set of bivariate analyses. Here we consider 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 (Table 6).[18] We continue to find similar results as above. Women are more supportive of its use than are men, although the gap is smaller and there is no longer a statistically significant difference between men 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. Those that are more concerned about the environment as an issue supported use and research more, but also assigned greater importance to considerations of speed, cost, motivation, and unpredictability. Those 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.[19] Robustness checks are presented in Appendix D.

[18]We use the same variables as above, though we code party as a binary variable with a "1" indicating the person self-identified as Republican.

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

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)

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

4.4 'Moral hazard' and acquiescence bias

There are competing theories about how solar geoengineering will affect society's motivation to mitigate (e.g., Corner et al., 2013; Preston, 2013; McLaren, 2016). Burns et al. (2016) summarize the literature. Most prior studies using surveys find that geoengineering would effect society's motivation to mitigate ('moral hazard'). In contrast, Merk et al. (2016), who observe behavior directly rather than through a survey instrument, find weak support for 'inverse moral hazard'; i.e., that knowledge of solar geoengineering increases subjects' desire to mitigate.[20] Our results in Table 1 above did not indicate a strong relationship between moral hazard concerns and support for the use of geoengineering, but this does not speak to the question of whether 'moral hazard' would ensue if the technology were available. Given the importance of moral hazard considerations in previous work, we further scrutinize the moral hazard hypothesis and consider a potential role for 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; Swain et al., 2008; Lance et al., 2010).

Most prior studies phrase the moral hazard questions as asking questions equivalent to whether solar geoengineering "will motivate society to cut emissions *less*."[21] This may lead to biased results, as subjects 'acquiesce' to the valence of the survey item (i.e., the direction in which way society could move). Earlier work on moral hazard and geoengineering does not test acquiescence bias. Meanwhile, varying the use of negatively worded questions to avoid systematic response tendencies is a standard practice and can help to avoid acquiescence bias.

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*." We find that respondents who were asked whether solar geoengineering would cause society to cut

[20]Merk et al. (2016) ask their respondents to buy carbon offsets with money given to them in the experimental setup. Those who are told about solar geoengineering spend more of their own money on offsets.

[21]Visschers et al. (2017), for example, ask 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.

emissions *more* were more likely to believe that this would be the case than those asked whether solar geoengineering would cause society to cut emissions *less* (Figure 6), and vice versa.[22]

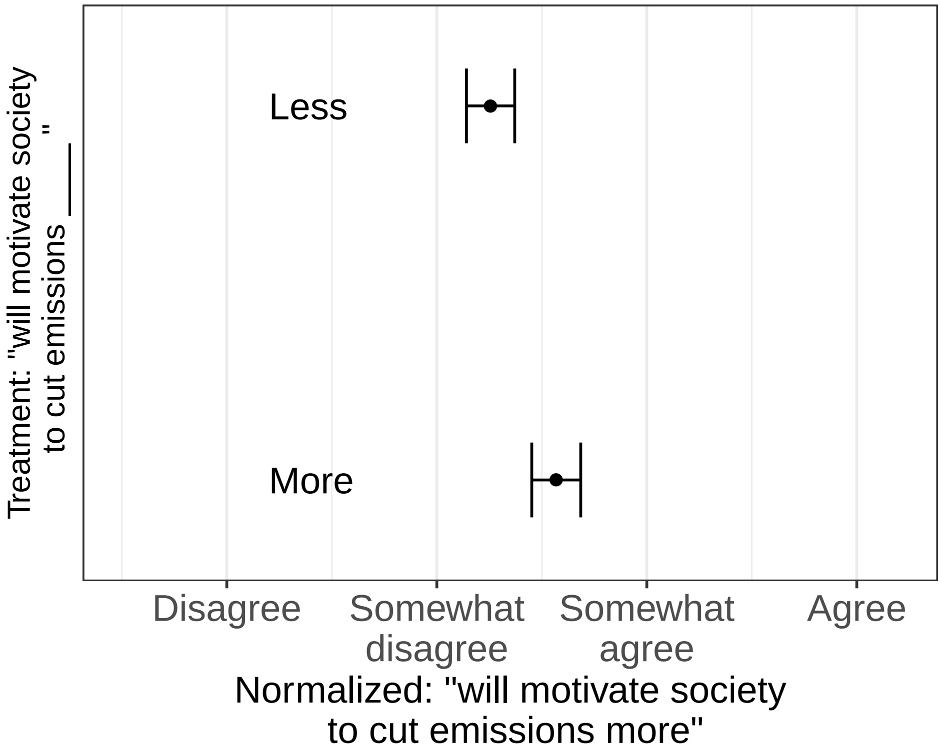


Figure 6: Effect of treatments on belief that knowing about solar geoengineering would cause societies to cut emissions more/less (standardized to "more")

Given our finding in Figure 6, prior findings of moral hazard perhaps are due at least in part to acquiescence bias. A potentially fruitful avenue for further research might be to test acquiescence bias more broadly, especially in light of low 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 might well affect some of the weaker results found in our and prior studies beyond moral hazard.

5 Conclusion

Solar geoengineering is not a replacement for cutting emissions to address global warming. It is, at best, an imperfect supplement. Despite these imperfections, risks, and uncertainties,

[22]Figure 6 standardizes all responses to the same scale, reflecting the belief that knowing about solar geoengineering would cause society to cut emissions more. When we break out individuals with some degree of prior familiarity versus no familiarity, we find both groups with the pattern presented in Figure 6, though the gap is larger for individuals with some familiarity.

some scientists increasingly consider solar geoengineering to have a potential role in a rational climate policy portfolio. Our survey finds that a majority of US respondents agree. They overwhelmingly (81%) support research into solar geoengineering, and, perhaps surprisingly, even support its use (67%).

To better understand the motivation for this level of support, we examine the relevance of 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 imperfection by the technology's unpredictability and by the possibility for moral hazard, the interaction of mere talk of solar geoengineering with the desire to mitigate. Unpredictability, perhaps surprisingly, has no significant effect in our survey, while moral hazard concerns increase desire for research. Probing deeper, we find that concern about moral hazard is correlated with party, age, and issue in predictable ways. In particular, 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 and even use of the technology. Moreover, we find bias in wording around moral hazard questions. When asked whether solar geoengineering would lead to "less" desire to mitigate, subjects agree somewhat, a finding that supports the moral hazard hypothesis. When asked whether solar geoengineering would lead to "more" desire to mitigate, subjects also tend to agree. Prior surveys aimed at identifying moral hazard-like attitudes have tended to focused on the former, revealing a potential bias in those results and a potentially productive avenue for further research.

We further find that support for both research and use matches previously seen party identification, age, and risk patterns. Our survey differs from hypothesized gender patterns, with women showing greater support than men. 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, and the key results hold when we control for it.

Solar geoengineering, of course, is not the only technology to offer the promise of being fast acting, cheap, but imperfect. Debates about antibiotic growth promoters in livestock production squarely fit this description. The routine administration of antibiotics helps livestock grow faster and avoid disease. But it causes antibiotic resistance, which can compromise life-saving antibiotics. As another example, the widespread use of plastic enables easy and cheap consumption but has led to billions of tons of plastic waste globally. Beyond technology, social policy tools also show similar patterns. Central banks may quickly print cheap money, but the injection of this capital into an economy can have disastrous consequences. Hence, while our study focuses on a single technology, solar geoengineering, our results may apply more broadly to understand how considerations about pace, cost, and risky consequences influence support for technologies and policies.

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Online Appendix

In what follows, we provide a range of supplemental materials. Appendix A outlines our survey design along with descriptive statistics demonstrating its similarity to the general US population along a number of key demographic characteristics. Appendix E describes the design and results of an embedded survey experiment exploring the extent to which framing solar geoengineering as natural or unnatural changes respondents' attitudes toward it. Appendix B presents relevant text from our questionnaire, and Appendix C summarizes correlations between primary factors driving respondents' opinions about the use and research of solar geoengineering. Finally, Appendix D presents robustness checks, suggesting that our key results hold under a number of alternative regression specifications.

A Sampling design and descriptive statistics

The survey sample relied on two-stage matched random sampling wherein YP sought to randomly select individuals from its PollingPoint opt-in panel of respondents who had agreed to participate in surveys in a manner that was representative of the general population and provided sufficient coverage along relevant strata, described below. Active PollingPoint panelists were cross-classified based and divided into strata based on race, income, and other demographic characteristics. Then YP sampled respondents from each strata to gather a sample proportional to their corresponding size in the US population. For each of the thirty-six group surveys, the sample of active panelists was then matched to a synthetic sampling frame (SSF) that was representative of the broader population. The SSF was constructed from consumer lists that cover approximately 95% of the US adult population. A stratified sample was then drawn from the SSF and then observations from the target PollingPoint sample were matched to the realized SSF sample according to its weighted Euclidean distance. This procedure strengthened the assumption that selection was ignorable.

The matched cases were then combined with the SSF and a case-control logistic regression was estimated for each PollingPoint observation's inclusion in the SSF. SSF propensity scores were then grouped into deciles and the calculated propensity scores for the PollingPoint sample observations were post-stratified so that their weighted proportions in each of the SSF deciles came to one-tenth. From the opt-in panel, a stratified national sample of adults was then drawn based on (i) voter registration[23]; (ii) state size; and (iii) competitiveness of congressional districts.[24] The sample of 1,000 used in this study was composed of 535 females and 465 males, and after weighting individuals based on sampling weights, female responses composed approximately 52% of the sample.[25] Democrats, Republicans, and Independents made up approximately 36%, 25%, and 31% respectively. On average, participants held some college education but had not earned a two- or four-year degree. Distributions of participant political identification, education level, ages, and familiarity with solar geoengineering are provided in the following section along with corresponding figures from the US adult population, which the sample closely resembles.[26]

[23] YP oversamples registered voters because their preferences are of particular interest to voters.

[24] For additional information see Ansolabehere and Rivers (2013) and Vavreck and Rivers (2008)

[25] The remaining estimates incorporate sampling weights unless otherwise noted.

[26] Additional information, including response rate details, are available via the CCES.

A.1 Descriptive statistics

This section offers descriptive statistics about the sample. Figure 7 describes the distribution of subjects' highest level of education. Twelve percent of the weighted sample had not completed high school, and 29% had completed high school but not attended college. Twenty-three percent had received some college education but not completed it, 9% had completed a two-year college degree, 17% had completed a four-year college degree, and approximately 9% had earned a post-graduate degree.[27] This aligns with educational attainment among the US adult population. Maximum educational attainment in the US is as follows: 12% had less than a complete high school education, 29% had completed high school, 17% had completed some college but not graduated, 10% had completed a two-year Associates degree, 21% had completed a four-year Bachelor's degree, and 12% had completed an advanced degree.[28]

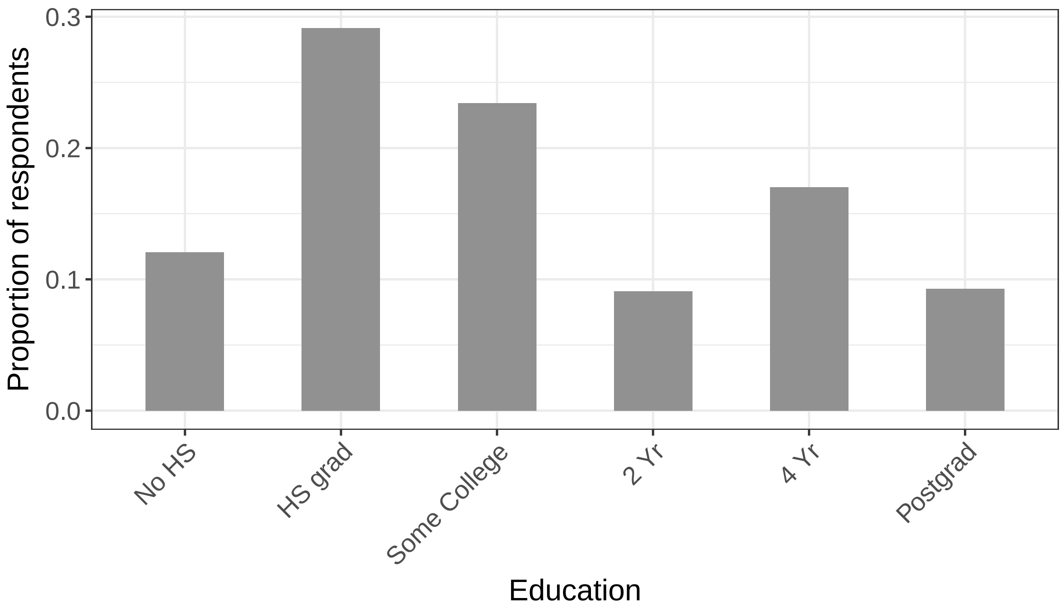


Figure 7: Distribution of education

Figure 8 describes subjects' political self-identification. Thirty-five percent of the subjects self-identified as Democrats, 31% as Independents, 26% as Republicans, and 8% as "Other." This, too, aligns with the political self-identification of the US adult population. According to the Gallup Poll, over the period October 5-9, when the pre-election CCES survey was administered, 27% of US voters identified as Republicans, 30% as Democrats, and 40% as Independents.

[27] Any difference between the sum of the proportions presented in the paper and 1 is due to rounding.
[28] Source: 2015 United States Census

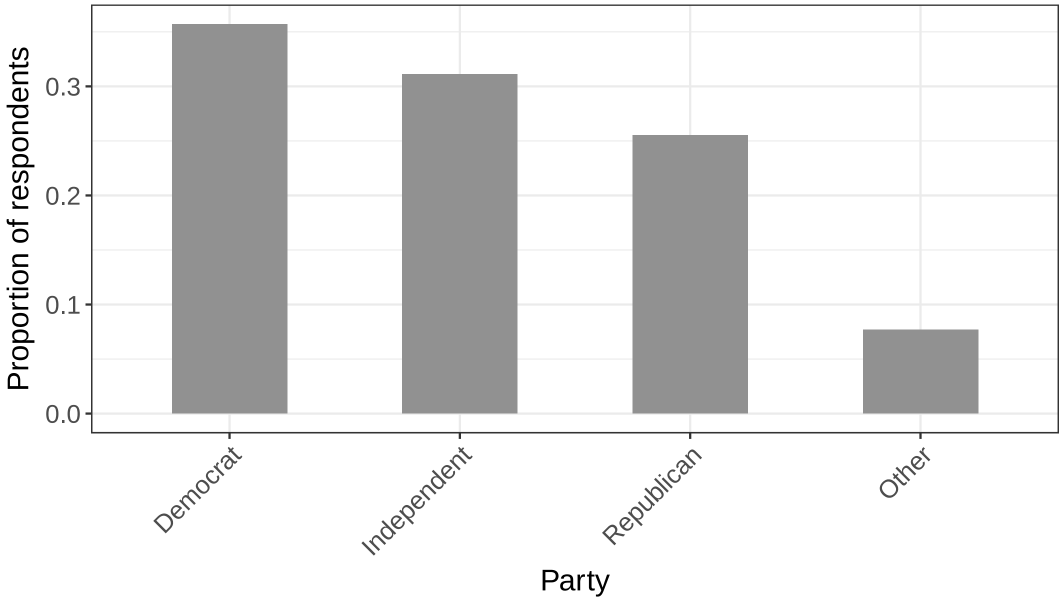


Figure 8: Distribution of political identification

Figure 9 presents the distribution of subject age brackets. Among participants, 13% fell between ages 18 and 25, 19% between ages 26 and 34, 27% between ages 35 and 54, 21% between ages 55 and 65, and 21% over age 65. Among US adults, 13% fall between the ages of 19 and 25, 16% between ages 26 and 34, 35% between ages 35 and 54, 17% between ages 55 and 64, and 20% over age 65.[29] The distribution of ages in the sample is similar to that in the US population.

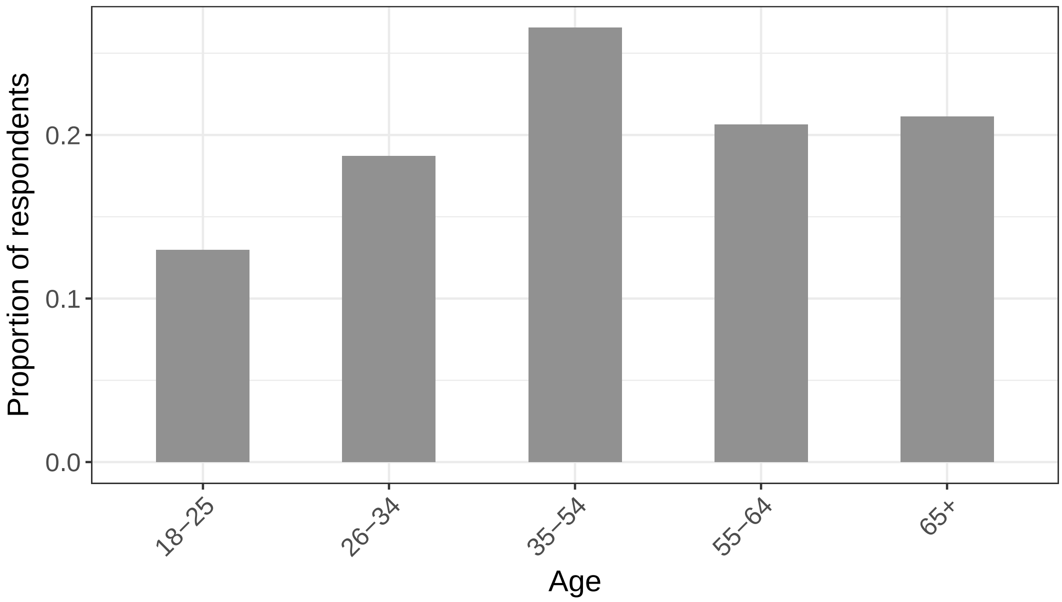


Figure 9: Classified by decile

[29]The data are based on the Census Bureau's March 2016 Current Population Survey, as presented by the Kaiser Family Foundation (KFF). Percentages provided by the KFF included children, which composed 25% of the sample, so each bracket was normalized by dividing KFF figures by 0.75.

B Relevant text from questionnaire

The survey began with an introduction to the issue area.

> Adding carbon dioxide into the atmosphere traps heat. This is commonly called the "greenhouse gas effect". Too much carbon dioxide in the atmosphere leads to anthropogenic climate change, raising temperatures above pre-industrial levels, which harms societies and ecosystems by causing droughts, heat waves, rising seas, and powerful storms.
>
> People have emitted carbon dioxide as a byproduct of producing energy since the industrial revolution. Carbon dioxide stays in the atmosphere for many years, so even if humans stop emitting carbon dioxide today, the effects of the accumulated gas will persist for many years. Climate change is already felt today, but will get worse if carbon dioxide continues to build up in this manner.
>
> Today, one solution to reduce carbon dioxide emissions is mitigation, the development of new energy sources and promotion of energy efficiency. Reducing emissions directly addresses the problem of climate change, but it is also expensive.
>
> Another potential solution is Solar Radiation Management, also known as solar geoengineering. How would you describe your familiarity with the term "Solar Radiation Management" (SRM) or solar geoengineering?

This was followed by a question on familiarity described in the body text.

After administering the experimental treatment described in Appendix E, subjects were asked numerous questions about geoengineering. The questions used to gather data to identify drivers of solar geoengineering support, outlined in Section 2.1.

Subjects were first asked about their support for the use or research of solar geoengineering and could respond with either *strongly disagree*, *somewhat disagree*, *somewhat agree*, and *strongly agree*, or *I am unsure*. Subjects who indicated that they were unsure were then asked to provide their best guess of their support. Unlike the questions used to operationalize the independent variables (below), subjects were required to indicate their support for using or researching solar geoengineering before proceeding. The exact text of the question used to measure support for the use of solar geoengineering was

> Do you think that solar geoengineering should be used to help address global warming?

and if subjects responded that they were unsure, they were asked

> You indicated that you were not sure whether solar geoengineering should be used. What is your best guess to the question of whether solar geoengineering should be used to help address global warming?

The analogous question used to measure support for researching solar geoengineering was

> What do you think about researching solar geoengineering to learn more about the technology?

and the follow-up, posed to respondents who indicated that they were unsure, was

> You indicated that you were unsure about whether we should research solar geoengineering to learn more about the technology. What is your best guess to the question about whether additional research should be conducted on solar geoengineering to learn more about the technology?

As summarized in Section 2.1, to measure the attributes that determined attitudes toward solar geoengineering, subjects were asked to rate the importance of various risks and benefits in determining their opinion about solar geoengineering. Subjects could rate each attribute as either *unimportant*, *somewhat unimportant*, *somewhat important*, or *important*. Throughout the survey, whenever subjects were asked to rate or rank options on a scale, the order of options was randomly either ascending or descending. Likewise, whenever subjects were asked about a number of related attributes or options, the questions were randomly assigned. The exact text is replicated below.[30]

> Earlier, you read a description about solar geoengineering. Please rate the importance of each of the following risks and benefits to you in forming your opinion about solar geoengineering. Note: Some of these risks and benefits may not have been covered in the informational passage.
>
> 1. It will quickly slow global warming and reduce global warming's dangerous impacts, giving us more time to cut greenhouse gas emissions.
> 2. It is the only way to manage the risk of rising temperatures (caused by long lasting greenhouse gases) during this century.
> 3. It will stop a climate emergency before too much damage is done.
> 4. It will be much cheaper than stopping our use of fuels that release greenhouse gases.
> 5. It will take away society's motivation to cut its use of coal, oil and natural gas.
> 6. It will allow coal, oil and natural gas companies to keep releasing greenhouse gases into the atmosphere.
> 7. It will potentially cause something to happen that we can't predict.

In addition to their political identification, age, and gender, which were part of the CCES Common Content (see Appendix A for more details), subjects were asked whether the importance of climate change in determining their vote in the 2016 presidential election was *unimportant*, *somewhat unimportant*, *somewhat important*, or *important*. The exact text of the question was

> How important is climate change in determining who you will vote for in the upcoming presidential election?

Subjects were also asked about the extent to which they agreed with the following statement regarding technological advancements and could choose from the responses *definitely agree*, *somewhat agree*, *somewhat disagree*, and *definitely disagree*:

[30] In the paper we only focus on four of these questions, but our results do not change substantively if we include all of them. Of the excluded items, the most influential was the positive impact of concerns about a climate emergency on support for research.

> Do you agree or disagree with the following statement?: "Technological advancements will lead to a future in which people's lives are mostly better."

They were also asked about their support for nuclear power and could choose from the responses *yes, definitely*, *yes, but with reservations*, *probably not*, and *definitely not*:

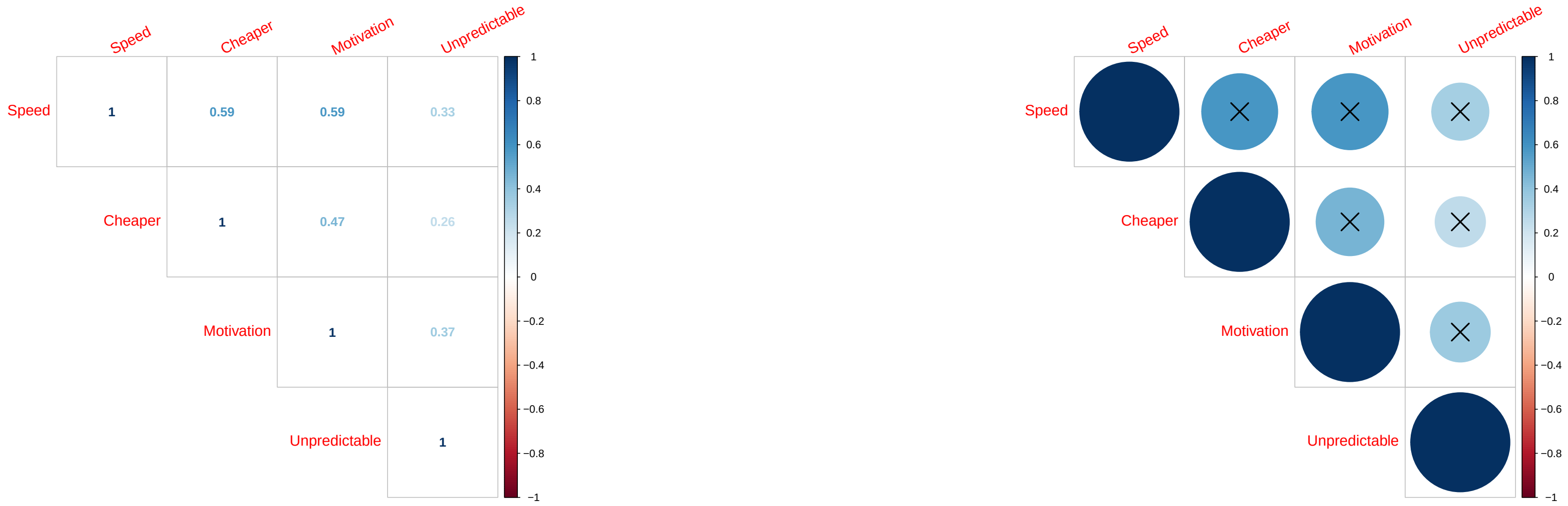
> If there were a safe effective way to deal with nuclear waste, would you support a significant expansion of nuclear power to meet your energy needs?

Finally, subjects were asked about whether they believed in chemtrail conspiracy theories, and in response to the question below, they could choose from the responses *completely false*, *somewhat false*, *somewhat true*, and *completely true*:

> Do you believe it is true that the government has a secret program that uses airplanes to put harmful chemicals into the air (often called "chemtrails")?

C Correlations between primary factors and distribution of responses

This appendix summarizes the distribution of the primary factors that respondents found important in forming an opinion about the use and research of solar geoengineering and correlations between their responses. Figure 10 summarizes the correlation between the primary factors, with Figure 10a summarizing the correlation coefficient sand Figure 10b summarizing their statistical significance at 5%. Correlation coefficients were calculated using sampling weights. Missing observations accounted for approximately 6% of the sample for “speed”, 11% for “cheaper”, 13% for “motivation”, and 13% for “unpredictable.” Figure 10 relies on pairwise deletion of missing observations, though no relying on listwise deletion produces no meaningful differences.



(a) Correlation between primary factors

(b) Statistical significance of correlation between primary factors

Figure 10: Summary of correlation between primary factors

D Robustness checks

D.1 Robustness checks: importance of risks/benefits and support for use of solar geoengineering

Table 7: Effect of importance of risks on support for use of solar geoengineering (1/2)

	Use of solar geoengineering							
Speed	0.469^{***}				0.366^{***}	0.467^{***}	0.507^{***}	
	(0.039)				(0.044)	(0.043)	(0.044)	
Cheaper		0.418^{***}			0.201^{***}			0.387^{***}
		(0.041)			(0.045)			(0.044)
Motivation			0.253^{***}			-0.006		0.079^{*}
			(0.046)			(0.043)		(0.046)
Unpredictable				0.080			-0.123^{***}	
				(0.052)			(0.046)	
Constant	1.240^{***}	1.405^{***}	1.922^{***}	2.388^{***}	0.938^{***}	1.264^{***}	1.528^{***}	1.256^{***}
	(0.115)	(0.125)	(0.136)	(0.180)	(0.124)	(0.139)	(0.167)	(0.159)

Note: *p<0.1; **p<0.05; ***p<0.01

Table 8: Effect of importance of risks on support for use of solar geoengineering (2/2)

	Use of solar geoengineering							
Speed			0.376^{***}	0.399^{***}	0.489^{***}		0.395^{***}	0.280^{***}
			(0.047)	(0.049)	(0.048)		(0.052)	(0.060)
Cheaper	0.424^{***}		0.230^{***}	0.208^{***}		0.390^{***}	0.232^{***}	0.202^{***}
	(0.047)		(0.048)	(0.049)		(0.048)	(0.051)	(0.051)
Motivation		0.276^{***}	−0.062		0.016	0.104^{*}	−0.044	−0.087
		(0.053)	(0.044)		(0.051)	(0.053)	(0.051)	(0.053)
Unpredictable	−0.017	−0.033		-0.113^{**}	-0.107^{**}	−0.038	−0.082	-0.108^{**}
	(0.048)	(0.054)		(0.045)	(0.051)	(0.054)	(0.051)	(0.045)
Research								0.413^{***}
								(0.076)
Constant	1.437^{***}	1.942^{***}	0.994^{***}	1.189^{***}	1.470^{***}	1.290^{***}	1.144^{***}	0.538^{***}
	(0.171)	(0.193)	(0.147)	(0.162)	(0.178)	(0.182)	(0.173)	(0.170)

Note: *p<0.1; **p<0.05; ***p<0.01

D.2 Robustness checks: importance of risks/benefits and support for research of solar geoengineering

Table 9: Effect of importance of risks on support for research of solar geoengineering (1/2)

	Research of solar geoengineering							
Speed	0.430***				0.380***	0.338***	0.392***	
	(0.038)				(0.046)	(0.046)	(0.043)	
Cheaper		0.313***			0.090*			0.210***
		(0.047)			(0.055)			(0.047)
Motivation			0.308***			0.120**		0.213***
			(0.043)			(0.048)		(0.042)
Unpredictable				0.238***			0.082*	
				(0.049)			(0.048)	
Constant	1.739***	2.101***	2.139***	2.247***	1.619***	1.670***	1.589***	1.782***
	(0.123)	(0.151)	(0.137)	(0.169)	(0.149)	(0.145)	(0.164)	(0.172)

Note: *p<0.1; **p<0.05; ***p<0.01

Table 10: Effect of importance of risks on support for research of solar geoengineering (2/2)

	Research of solar geoengineering							
Speed			0.299***	0.355***	0.307***		0.279***	0.127**
			(0.054)	(0.050)	(0.050)		(0.059)	(0.058)
Cheaper	0.262***		0.082	0.073		0.188***	0.071	−0.018
	(0.053)		(0.053)	(0.059)		(0.050)	(0.055)	(0.057)
Motivation		0.288***	0.104**		0.123**	0.204***	0.103*	0.120**
		(0.051)	(0.046)		(0.058)	(0.048)	(0.056)	(0.056)
Unpredictable	0.167***	0.106**		0.079	0.064	0.093*	0.063	0.095*
	(0.048)	(0.053)		(0.048)	(0.054)	(0.053)	(0.054)	(0.049)
Use								0.385***
								(0.054)
Constant	1.697***	1.835***	1.582***	1.489***	1.535***	1.561***	1.466***	1.026***
	(0.182)	(0.175)	(0.172)	(0.176)	(0.172)	(0.188)	(0.186)	(0.167)

Note: *p<0.1; **p<0.05; ***p<0.01

E Solar geoengineering as natural versus anthropogenic

Research suggests that public perceptions toward technologies, and solar geoengineering in particular, increase in their belief that the technologies are natural (Slovic and Weber, 2002; Pidgeon et al., 2012; Corner et al., 2013). In the course of providing subjects with background about solar geoengineering[31], we tested this relationship by randomly assigning subjects across three groups ("control", "nature", and "anthropogenic"), which determined the initial description of solar geoengineering provided to them:

1. **Control**: Some experts have proposed a new approach to limit climate change called solar radiation management or solar geoengineering. This approach would involve spreading particles such as sulfate aerosols in the atmosphere to reflect some incoming sunlight into space. By reducing the sunlight reaching the Earth, solar geoengineering would cool the planet.
2. **Nature**: Some experts have proposed a new approach to limit climate change called solar radiation management or solar geoengineering. This approach would involve spreading particles such as sulfate aerosols in the atmosphere to reflect some incoming sunlight into space. During the volcanic eruption of Mount Pinatubo in the Philippines, the sulfate aerosol particles that were naturally lofted into space led to global cooling of 0.9 degrees Fahrenheit (0.5 degrees Celsius). By reducing the sunlight reaching the Earth, solar geoengineering would cool the planet.
3. **Anthropogenic**: Some experts have proposed a new approach to limit climate change called solar radiation management or SRM. This approach would involve spreading particles such as sulfate aerosols in the atmosphere to reflect some incoming sunlight into space. Some factories have already emitted these particles as a byproduct of industrial processes (not for the purposes of cooling the atmosphere). By reducing the sunlight reaching the Earth, SRM would cool the planet.

Subjects exposed to one of three descriptions about solar geoengineering (control, nature, and anthropogenic) and then again asked to rate their familiarity with it. Consequently, the average score increased to 1.8 among the subjects, though as shown in Figure 11, there was no variation by treatment.

[31] Overwhelmingly, the public tends to be unfamiliar with solar geoengineering (Mercer, 2014; Burns et al., 2016; McLaren et al., 2016).

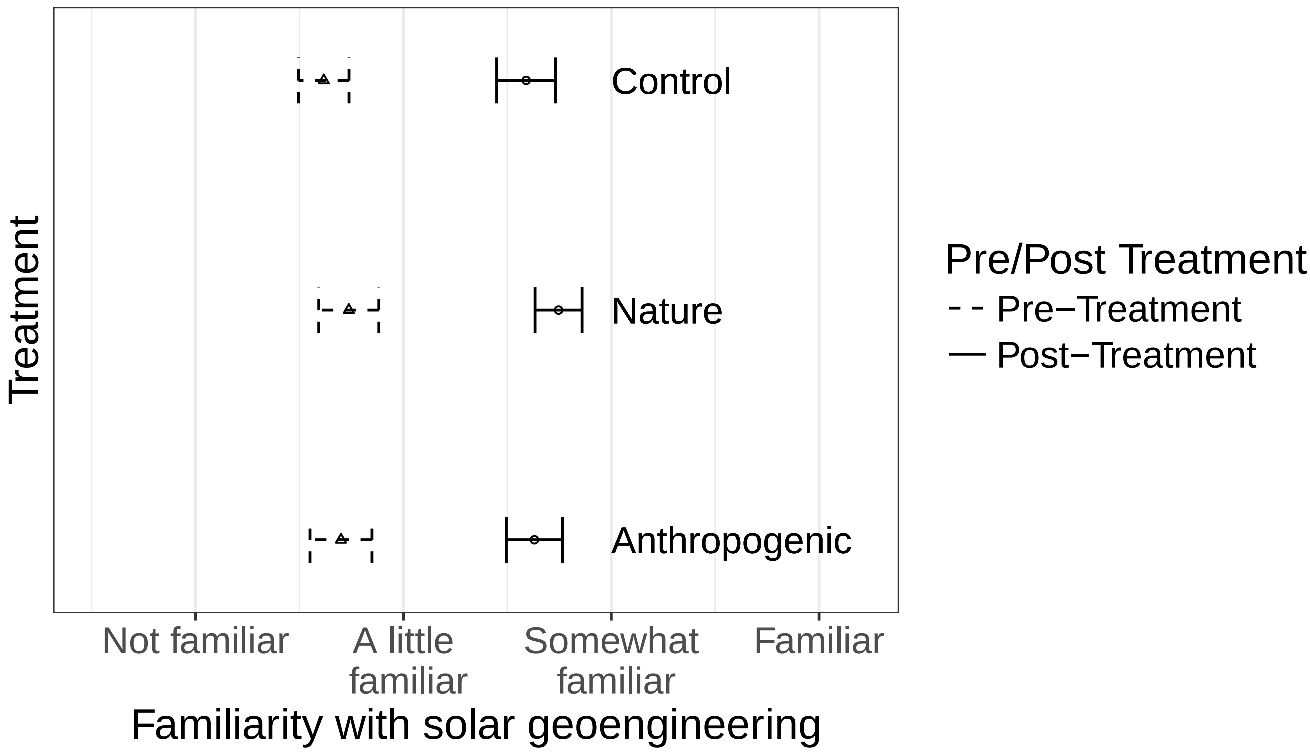
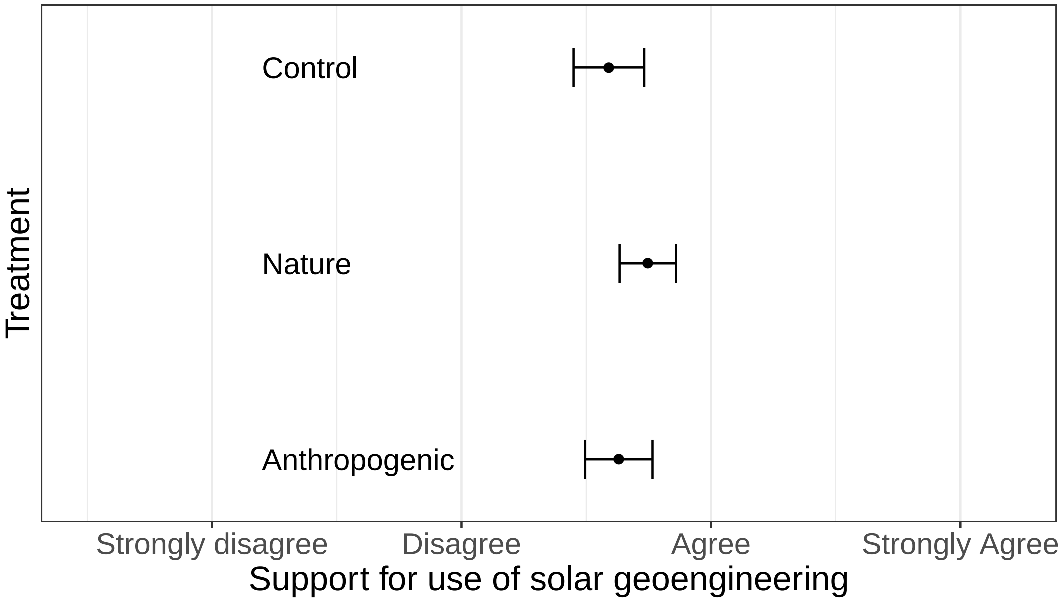


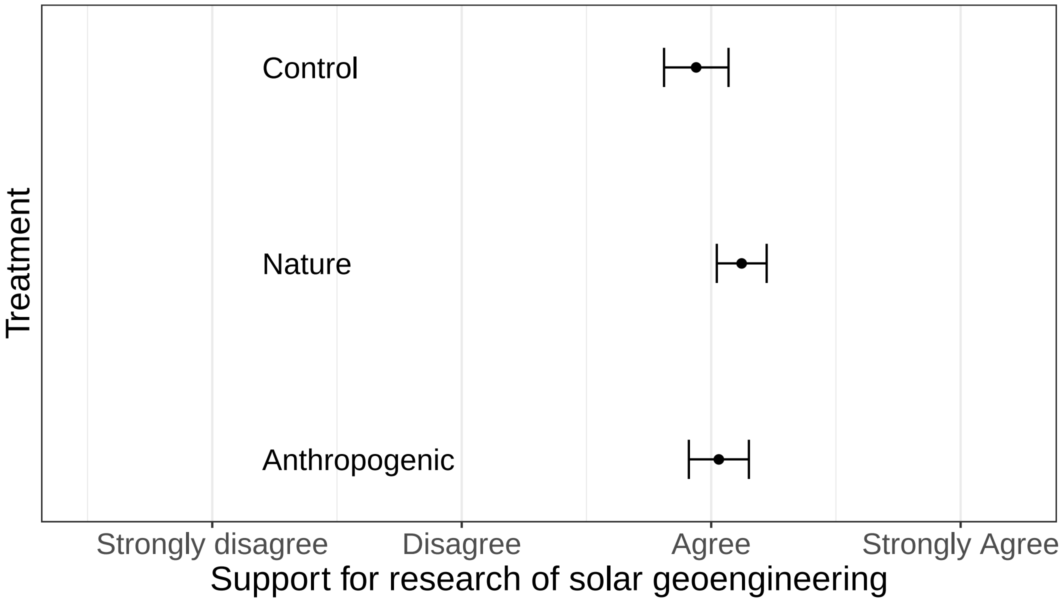
Figure 11: Effect of treatments on familiarity with solar geoengineering

More surprisingly, as illustrated in Figures 12a and 12b, the presentation of solar geoengineering as a natural or anthropogenic process has no effect on support for its use or research. These results differ from Corner and Pidgeon (2015), who find greater support for solar geoengineering among subjects to whom geoengineering was described as a natural process. The limited effect extended to the drivers of support for use and research, as shown in Figure 13.

Randomization of the treatment precludes confounding, and as demonstrated in Figure 14, the treated and controlled samples have similar distributions of characteristics affecting attitudes toward the use and research of solar geoengineering. Additionally, because we rely on a within-subjects design, the risks of fatigue or carryover effects are slim (Krosnick, 2011), though participants may have found the wording of the vignette unclear or suspicious.

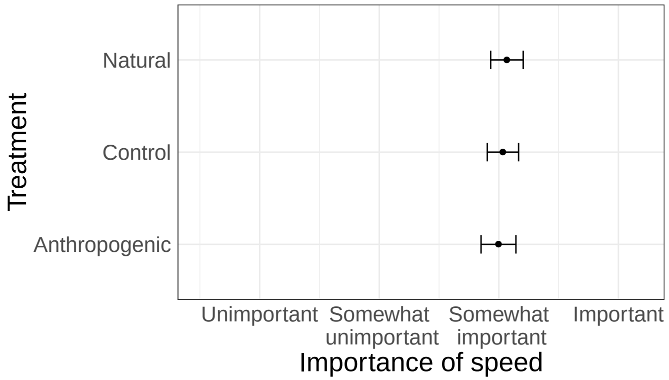


(a) Effect of treatments on support for use of solar geoengineering

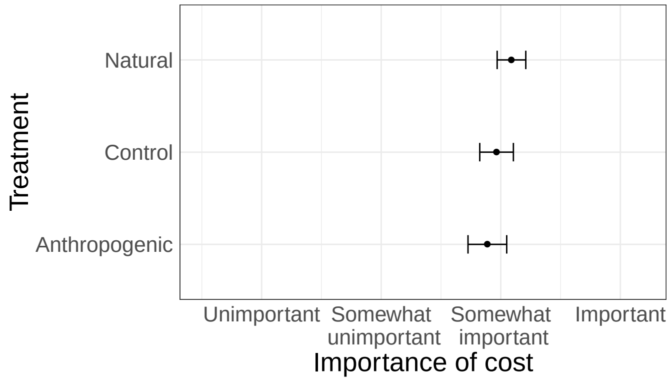


(b) Effect of treatments on support for research of solar geoengineering

Figure 12: Effect of treatments on support for use and research of solar geoengineering

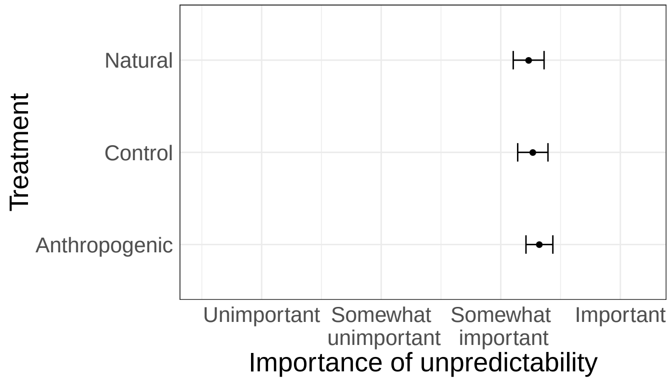


(a) Speed



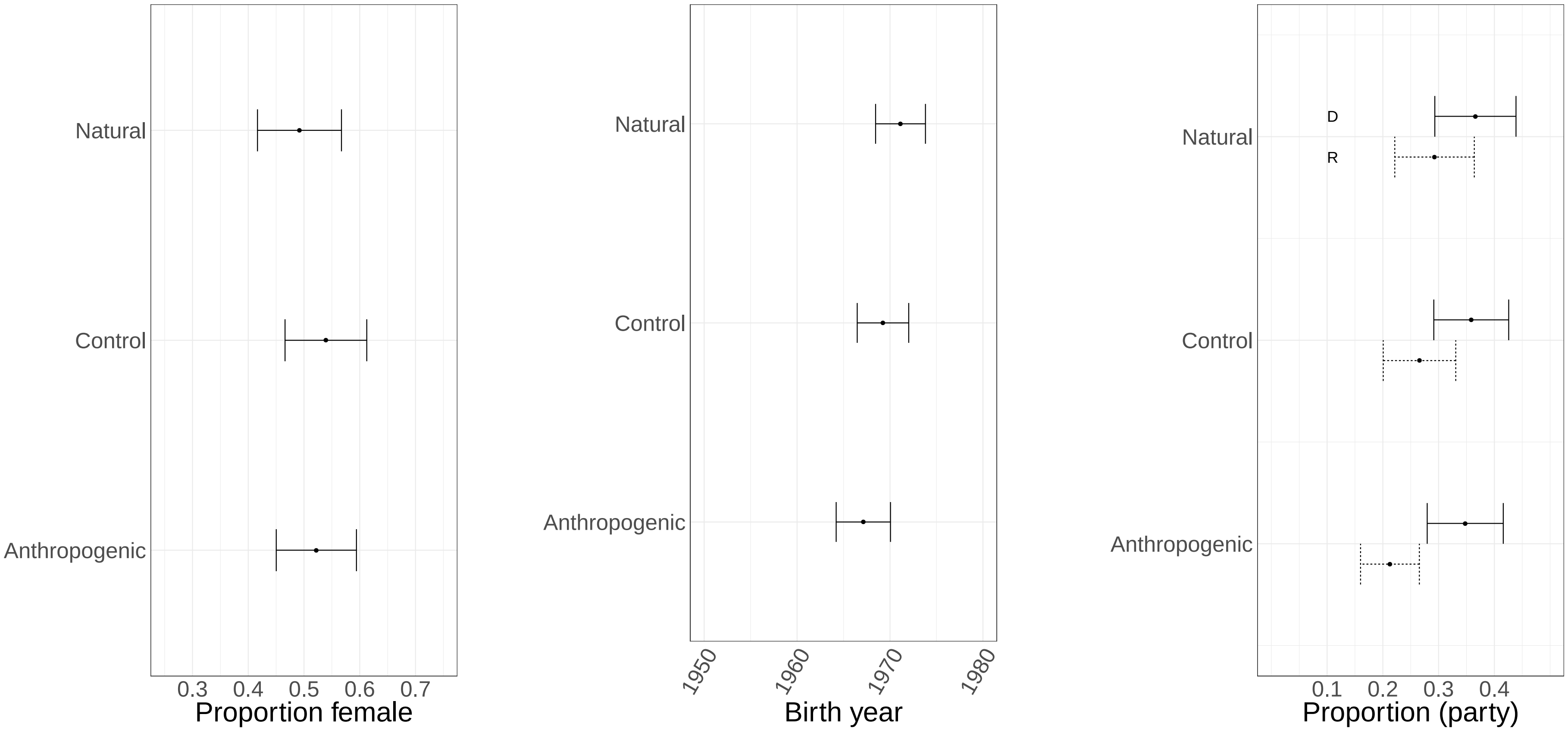
(b) Cost

(c) Moral hazard



(d) Unpredictability

Figure 13: Importance of primary factors by treatment



(a) Gender distributions by treatment

(b) Distribution of birth year by treatment

(c) Party distributions by treatment

Figure 14: Distribution of treatment group characteristics