Online Supplemental Material: "Fast, cheap, and imperfect? U.S. public opinion about solar geoengineering"

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In what follows, we provide a range of supplemental materials. The first part outlines our survey design, combined with descriptive statistics demonstrating its similarity to the general US population along a number of key demographic characteristics. We then present relevant text from the questionnaire, summarize correlations between primary factors driving respondents' opinions about the use and research of solar geoengineering, and presents robustness checks, suggesting that our key results hold under a number of alternative regression specifications. The final section 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. It does not.

Sampling design and descriptive statistics

Sampling design

The survey sample relied on two-stage matched random sampling wherein YouGov/Polimetrix (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. Active PollingPoint panelists were cross-classified and divided into strata based on race, income, and other demographic characteristics. Then YP sampled respondents from each stratum 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 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.

YP then combined the matched cases with the SSF and ran a case-control logistic regression for each PollingPoint observation's inclusion in the SSF. YP grouped SSF propensity scores into deciles and post-stratified calculated propensity scores for the PollingPoint sample observations so that their weighted proportions in each of the SSF deciles came to one-tenth. YP then drew a stratified national sample of adults from the opt-in panel based on (i) voter registration[1]; (ii) state size; and (iii) competitiveness of congressional districts.[2]

The resulting sample of 1,000 subjects used in this study was composed of 535 females and 465 males. After weighting individuals based on sampling weights, female responses composed approximately 52% of the sample.[3] 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.[4]

Descriptive statistics

This section offers descriptive statistics about the sample and provides further detail of primary factors of concern by party.

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 (Figure 5).

[1] Note that YP oversamples registered voters because it considers their preferences of particular interest.
[2] For additional information see Ansolabehere and Rivers (2013) and Vavreck and Rivers (2008).
[3] The remaining estimates incorporate sampling weights unless otherwise noted.
[4] Additional information, including response rate details, are available via the CCES.

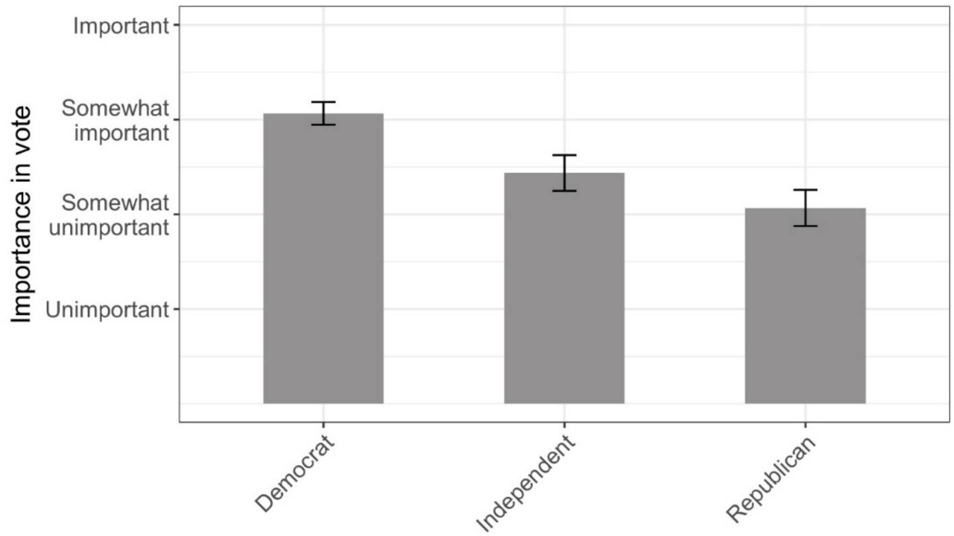
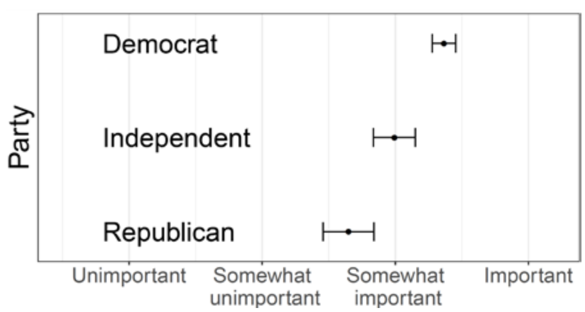
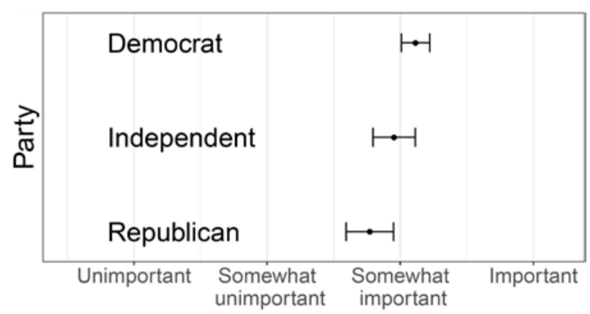


Figure 5: Importance of climate change in determining vote in 2016 presidential election.

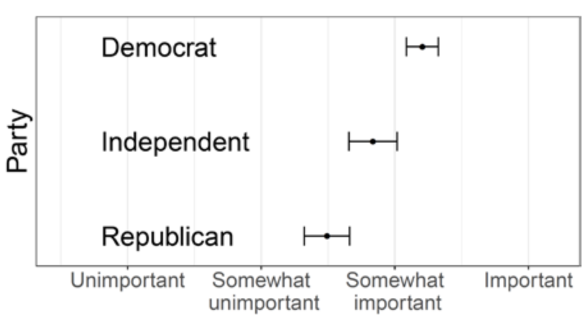
Figure 6, in turn, provides more corroborative evidence to data presented in the main text around how party affiliation intersects with the importance of primary factors tested in the survey.



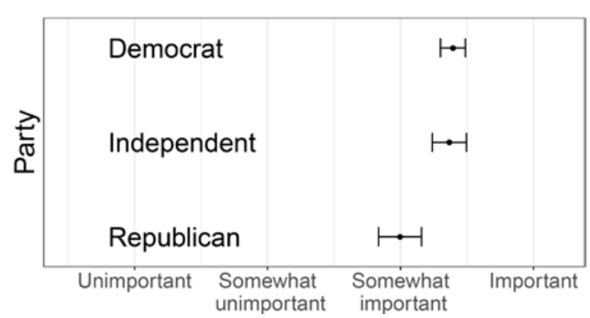
(a) Speed



(b) Cost



(c) Moral hazard



(d) Unpredictability

Figure 6: Importance of primary factors by party (excludes “Other” and “Unsure”).

Figure 7 describes the distribution of subjects' highest level of education. This aligns roughly with educational attainment among the US adult population.

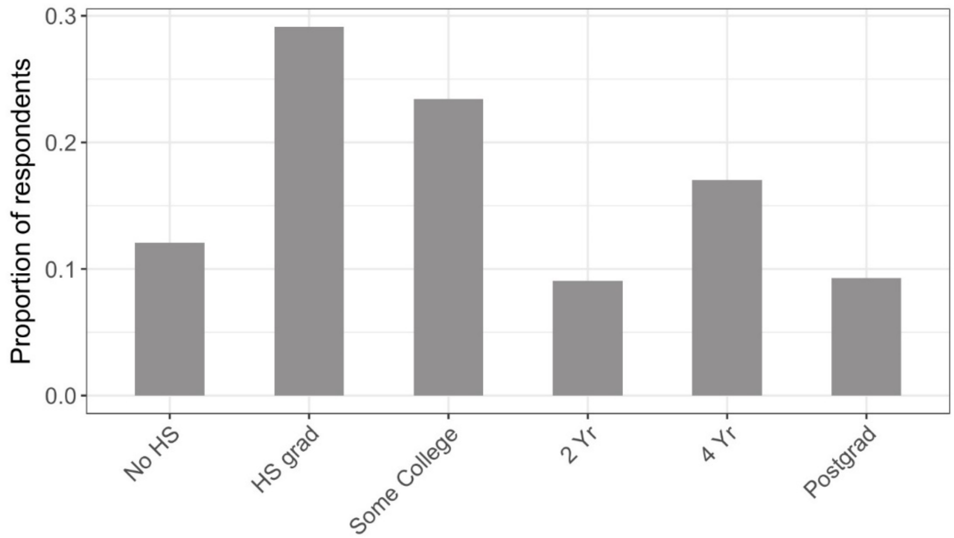


Figure 7: Distribution of education.

Figure 8 shows political leanings of survey respondents, roughly in line with polling results at the time.

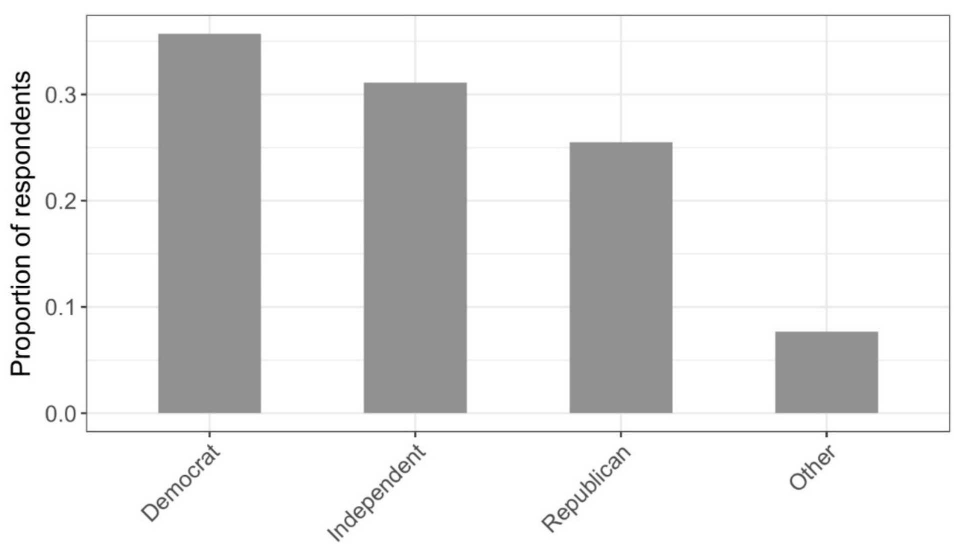


Figure 8: Distribution of political identification.

Figure 9 presents the distribution of subjects' age brackets, which were again similar to that in the overall US population. 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[5].

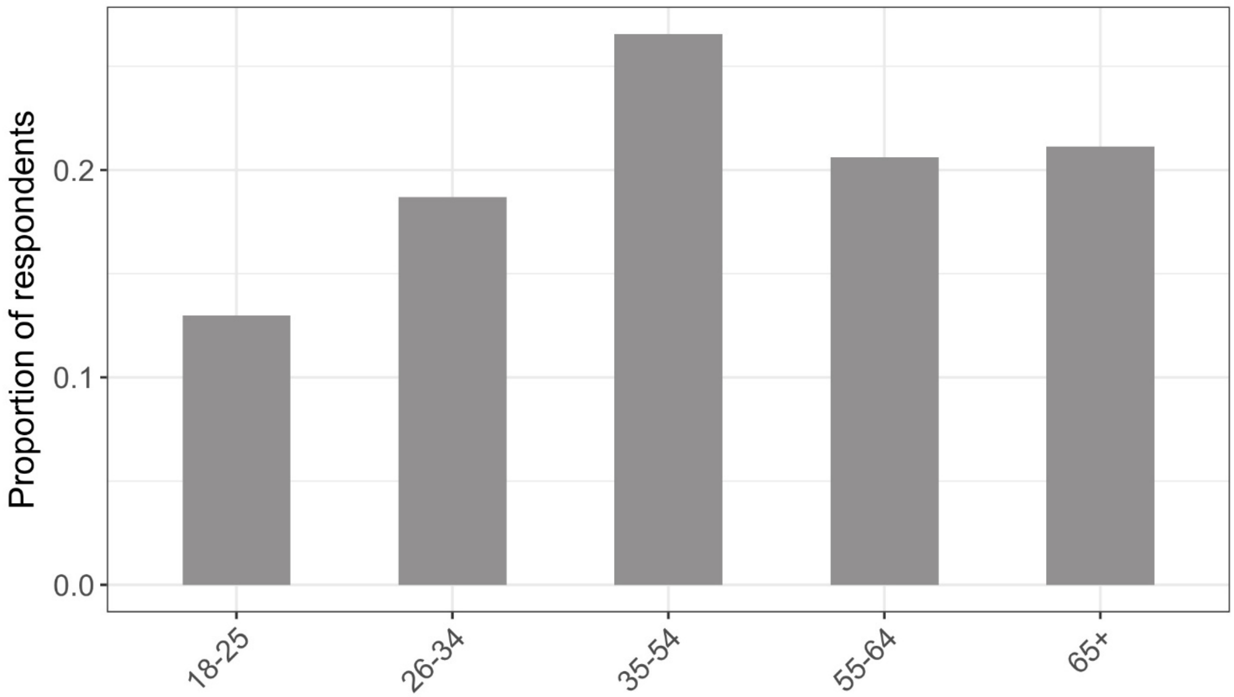


Figure 9: Distribution of age by decile

Relevant text from questionnaire

Our 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,

[5] 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

> 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.

This was followed by a question on familiarity (Figure 1):

> How would you describe your familiarity with the term “Solar Radiation Management” (SRM) or solar geoengineering?

After administering the experimental treatment described below, we asked subjects numerous questions about (solar) geoengineering, outlined in the main text

We first asked subjects about their support for the use of solar geoengineering:

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

Subjects 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:

> 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?

Unlike the questions used to operationalize the independent variables (below), subjects were required to indicate their support for using solar geoengineering before proceeding. The same applied to subjects' opinions on researching solar geoengineering.

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?

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 the main text, we then asked subjects 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 randomized to be 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:

> 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 the paper we only focus on four of these questions. Our results do not change substantively if we include all seven. Of the excluded items, the most influential was the positive impact of concerns about a climate emergency on support for research.

In addition to their political identification, age, and gender, which were part of the CCES Common Content, 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* (Figure 5):

> 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*:

> 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?

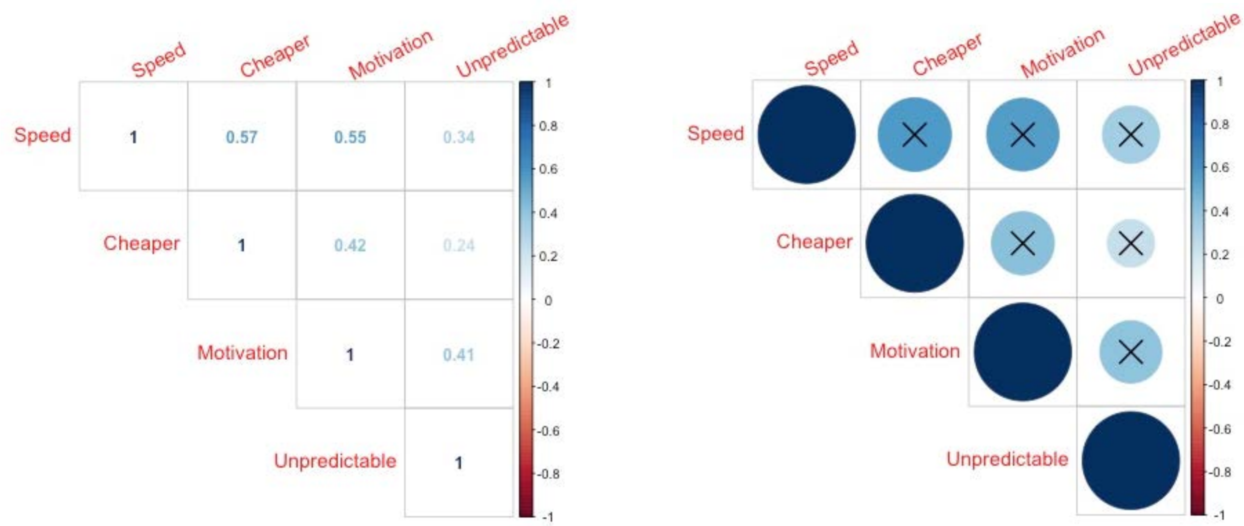
Finally, subjects were asked about whether they believed in chemtrail conspiracy theories, and in response to the question below, they could choose from the responses *completely false*, *somewhat false*, *somewhat true*, and *completely true*:

> 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")?

See Tingley and Wagner (2017) for results to that survey question.

Correlations between primary factors affecting respondents' attitudes

Figure 10 shows the correlations between primary factors affecting respondents' attitudes toward use and research of solar geoengineering. Figure 10a shows the correlation coefficients using sampling weights, and Figure 10b shows their statistical significance at 95%. 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; a listwise deletion produces no meaningful differences.



(a) Correlation between primary factors (b) Statistical significance

Figure 10: Summary of correlation between primary factors.

Robustness checks

Multivariate analysis

Table 6 in the main text presents the multivariate analysis with identification as conservative on a seven-point scale and, thus, summarized in one variable: "Identification as Republican." Table 7 here shows the analysis with political identification coded as a factor variable.

Table 7: Multivariable analysis with party identification as a factor variable

	Use	**Research**	**Speed**	**Cost**	**Motivation**	**Unpredictable**
Female	0.181**	0.095	0.142*	0.195**	0.032	0.050
	(0.074)	(0.068)	(0.077)	(0.079)	(0.086)	(0.072)
Age	-0.010***	-0.005**	-0.004	-0.006**	-0.005**	-0.001
	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.002)
Not Very Strong Democrat	-0.171	-0.076	0.062	-0.190	-0.055	0.097
	(0.107)	(0.088)	(0.087)	(0.122)	(0.118)	(0.100)
Low Democrat	-0.325**	-0.202*	-0.043	-0.095	-0.099	0.131
	(0.143)	(0.117)	(0.138)	(0.133)	(0.179)	(0.112)
Independent	-0.435***	-0.280**	-0.123	-0.152	-0.154	0.065
	(0.132)	(0.123)	(0.122)	(0.133)	(0.134)	(0.101)
Low Republican	-0.505***	-0.202	-0.596***	-0.136	-0.537***	0.073
	(0.178)	(0.160)	(0.165)	(0.188)	(0.186)	(0.168)
Not Very Strong Republican	-0.325***	-0.221*	-0.293*	-0.068	-0.552***	-0.141
	(0.112)	(0.123)	(0.160)	(0.139)	(0.167)	(0.131)
Strong Republican	-0.646***	-0.402***	-0.488***	-0.243*	-0.352**	-0.348**
	(0.119)	(0.111)	(0.149)	(0.130)	(0.150)	(0.135)
Importance in election	0.089**	0.161***	0.260***	0.207***	0.249***	0.097**
	(0.041)	(0.040)	(0.046)	(0.042)	(0.051)	(0.040)
Constant	3.128***	2.980***	2.652***	2.703***	2.697***	3.104***
	(0.204)	(0.198)	(0.203)	(0.214)	(0.223)	(0.187)

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

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

Table 8a: 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)

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

Table 8b: 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)

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

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

Table 9a: 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)

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

Table 9b: 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)

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

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, 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:

> *[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.
>
> *[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.
>
> *[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.

We first assess subjects' familiarity with solar geoengineering (Figure 1), expose them to one of the three descriptions about solar geoengineering, and then ask again to rate their familiarity (Figure 11). The average score increased to 1.8 after treatment, though there was no statistically significant variation by treatment.

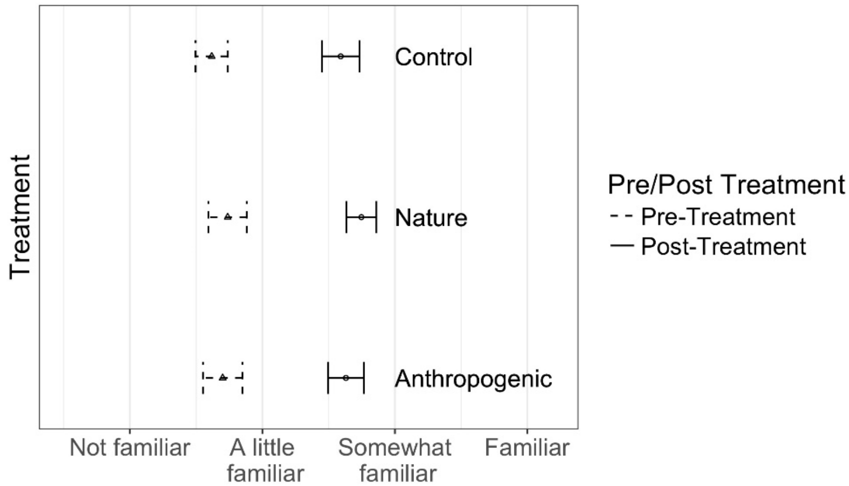
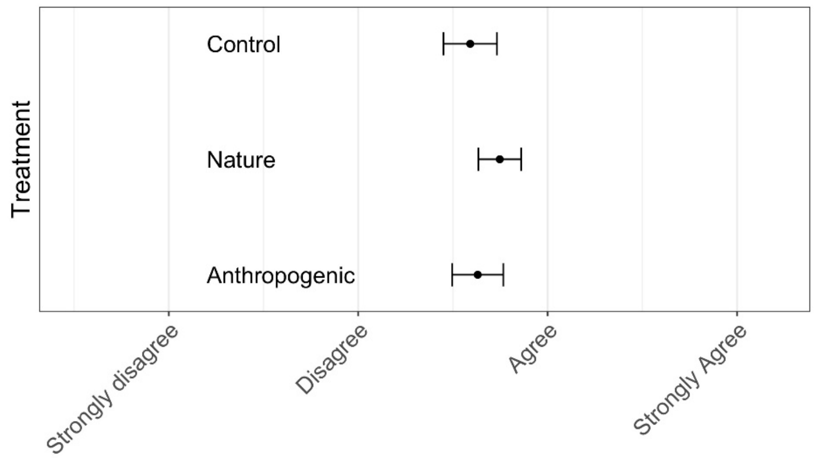
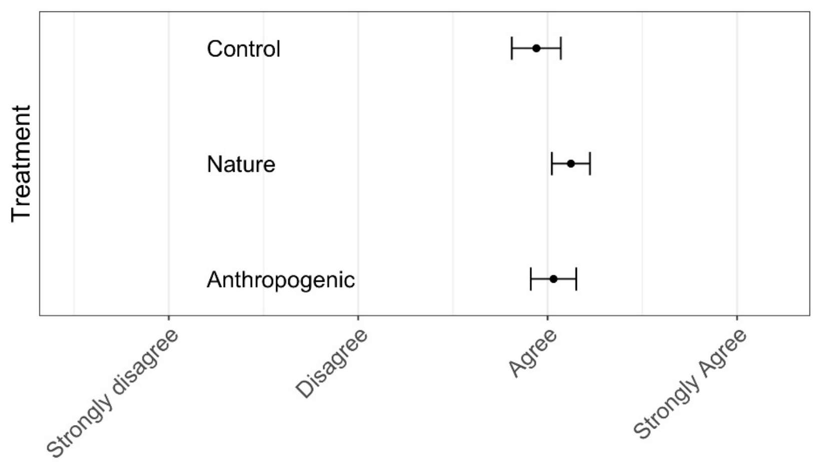


Figure 11: Effect of treatments on familiarity with solar geoengineering.

More surprisingly, as illustrated in Figures 12a and 12b, the presentation of solar geoengineering as a natural or anthropogenic process has no significant 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.



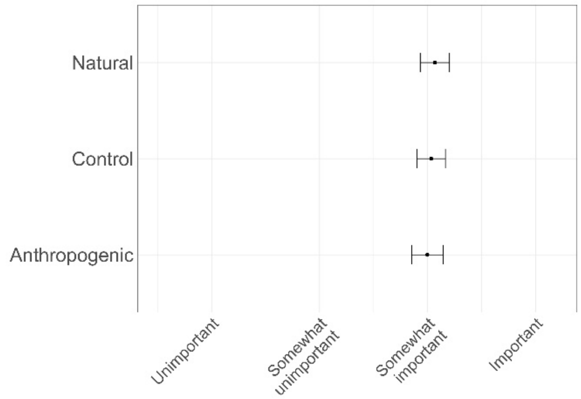
(a) Effect of treatments on support for use of solar geoengineering



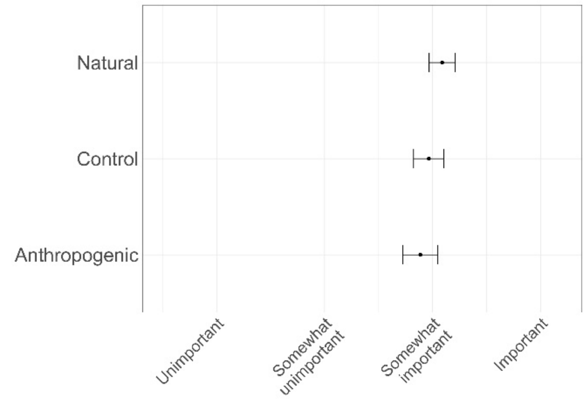
(b) Effect of treatments on support for research of solar geoengineering

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

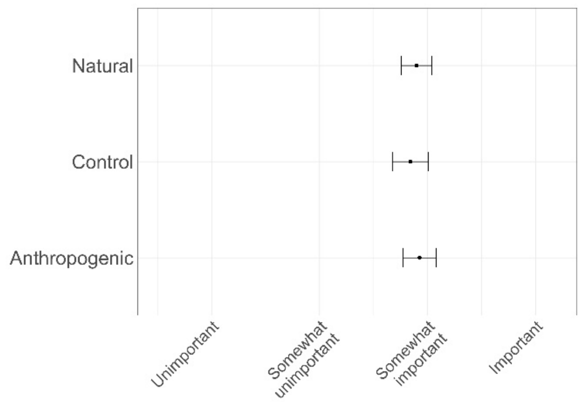
The limited effect extended to the drivers of support for use and research (Figure 13).



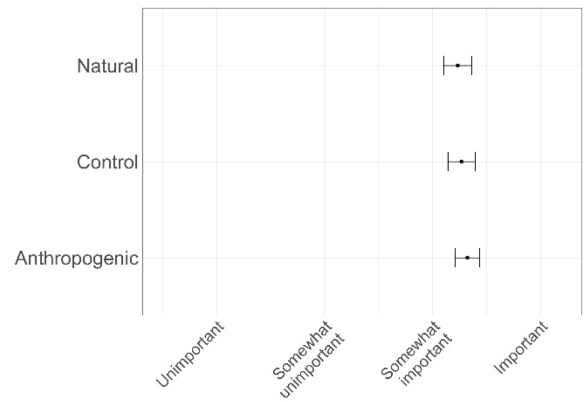
(a) Importance of speed



(b) Importance of cost



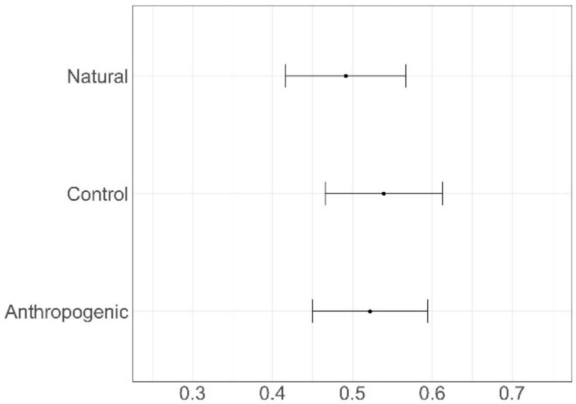
(c) Importance of moral hazard



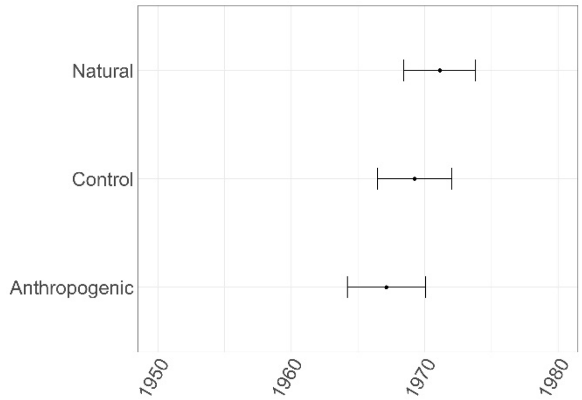
(d) Importance of unpredictability

Figure 13: Importance of primary factors by treatment

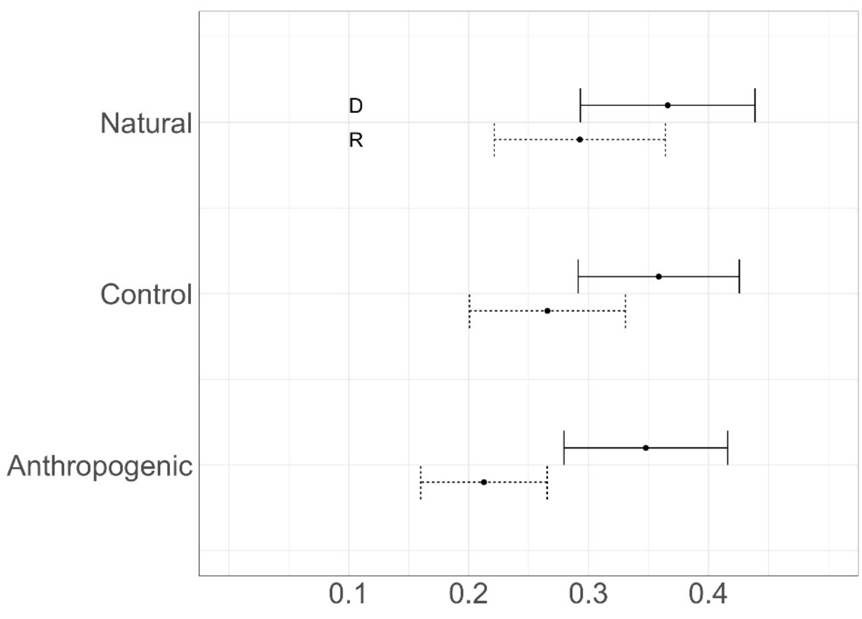
Randomization of the treatment precludes confounding, and as Figure 14 shows, the treated and controlled samples have similar distributions of characteristics affecting attitudes toward the use and research of solar geoengineering. Additionally, because we rely on a within-subjects design, the risks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



(a) Proportion female by treatment



(b) Distribution of birth year by treatment



(c) Party distributions by treatment

Figure 14: Distribution of treatment group characteristics

Note: In panel (c), the solid lines indicate the proportion identifying as Democrats (D), and the dotted lines indicate the proportion identifying as Republicans (R).

Online Supplemental Material References

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