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LETTER

Knowledge about aerosol injection does not reduce individual mitigation efforts

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Abstract

Stratospheric aerosol injection (SAI) is a climate engineering method that is reputed to be very effective in cooling the planet but is also thought to involve major risks and side effects. As a new option in the bid to counter climate change, it has attracted an increasing amount of research and the debate on its potential gained momentum after it was referred to in the 5th IPCC assessment report (IPCC 2013). One major objection to SAI and the research done on it is that it could undermine commitment to the mitigation of greenhouse gases. Policymakers, interest groups or individuals might wrongly perceive SAI as an easy fix for climate change and accordingly reduce their mitigation efforts. This is the first study to provide an empirical evaluation of this claim for individuals. In a large-scale framed field experiment with more than 650 participants, we provide evidence that people do not back-pedal on mitigation when they are told that the climate change problem could be partly addressed via SAI. Instead, we observe that people who have been informed about SAI mitigate more than people who have not. Our data suggest that the increase is driven by a perception of SAI as potential threat.

1. Introduction

Concern that mitigation efforts might decrease once stratospheric aerosol injection (SAI) was discussed as an option in the fight against climate change is strong both in scientific debate (Schneider 2001, Lawrence and Crutzen 2013) and among lay persons (Ipsos MORI 2010, Mercer *et al* 2011, Corner and Pidgeon 2014, Merk *et al* 2015, Wibeck *et al* 2015, Winickoff *et al* 2015). In scientific debate, this concern is referred to as 'risk compensation', 'moral hazard' or 'mitigation obstruction' (Betz and Cacean 2012, Keith 2013, Morrow 2014). Lay persons participating in surveys or focus groups have found the risk-compensation argument convincing and fear that SAI might be used as an excuse to continue with carbon-intensive lifestyles (Ipsos MORI 2010, Mercer *et al* 2011, Corner and Pidgeon 2014, Merk *et al* 2015, Wibeck *et al* 2015, Winickoff *et al* 2015). The validity of this concern is underlined by many theoretical arguments (for an overview see Lin 2012, Morrow 2014). It is said, for example, that optimism bias and overconfidence can be expected to lead to the perception of SAI as a viable technological fix for climate change, an attitude that creates an illusion of control (Lin 2012). People also tend to readily accept arguments exonerating them from their responsibility for climate change and wrongly justifying a mitigation cutback (Morrow 2014).

2. Theory

Despite the prominence and persuasiveness of the risk-compensation argument, there has as yet been no rigorous assessment of whether people actually reduce mitigation. Prior studies have dealt only indirectly with risk compensation, discussing the perception of climate engineering (CE), of SAI or of the risk-compensation argument. Nonetheless, these studies

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provide helpful insights into people's perceptions of mitigation and SAI, and a number of them cast doubt on the validity of the risk-compensation argument. Participants in group discussions have stated that mitigation should remain a priority (Ipsos MORI 2010, IAGP 2014, Bellamy *et al* 2015). In a survey study, most respondents were against SAI being used as a way of continuing with carbon-intensive lifestyles (Mercer *et al* 2011). Furthermore, in two focus groups participants were in favour of increasing mitigation efforts once they had learned about SAI (Shepherd 2009, Wibeck *et al* 2015). These findings indicate no decrease in the perceived importance of mitigation as a result of knowledge about SAI and accordingly question the validity of the risk-compensation argument. What it is that actually drives such behaviour has so far remained a matter for speculation.

There are three reasons why knowledge of SAI might not lead to risk compensation and might indeed even cause an increase in mitigation. First, risk compensation can only occur if its basic assumption is fulfilled, i.e. SAI is perceived as an effective method against climate change (Hedlund 2000, Lin 2012, Corner and Pidgeon 2014). This assumption has not yet been tested empirically. Second, information on SAI might function as a clarion call; when they learn that such massive interventions as SAI are under consideration, people might take the threat of climate change more seriously and thus mitigate more (Reynolds 2015). One survey experiment found that subjects who were informed about CE were slightly more concerned about climate change than subjects in the control group (Kahan *et al* 2015). Third, an increase in mitigation could also be caused by the perception of SAI as a threat. Research on acceptance shows that individuals respond very negatively to the idea of SAI and support for it is low (Borick and Rabe 2012, Macnaghten and Szerszynski 2013, Wright *et al* 2014, Merk *et al* 2015). As a policy option against climate change, mitigation is preferred over CE (US GAO 2011, Pidgeon *et al* 2012, Wibeck *et al* 2015). Accordingly, people may mitigate more, so as to prevent the deployment of SAI.

3. Method

We conducted a framed-field experiment to find out whether people actually compensate a potential risk reduction from SAI and mitigate less. As mitigation behaviour we observe how many voluntary carbon offsets (VCO) subjects bought during the experiment.

The experiment consisted of three treatment groups that subjects were randomly assigned to: BASE ($N = 243$), SAI ($N = 211$) and AUG ($N = 204$). The treatments contained different blocks of information. All subjects received information about the effect of greenhouse gases on the climate and on currently observed climate change. This information was based on the official German translation of the main findings of the IPCC's 5th assessment report (BMUB 2014). In addition, mitigation and adaptation were referred to as two ways of dealing with climate change (see supplementary material for information material).

Subjects in BASE received no further information. Subjects in SAI were additionally informed about the injection of aerosols into the stratosphere as a third way of dealing with climate change alongside mitigation and adaptation. The basic principles of SAI were set out along with the risks and benefits involved according to current scientific knowledge (e.g., Crutzen 2006, Robock 2008, Rickels *et al* 2011). Subjects in AUG were provided the information from BASE augmented with additional information on expected future climate changes (IPCC 2014). The AUG treatment ensures that any differences in behaviour between BASE and SAI will be due to the qualitative effect of the information on SAI and not to changes in the amount of information or in the time spent reading about climate change.

After having received the information, all subjects were told about the possibility of supporting climate mitigation projects by purchasing VCOs (similar to Löschel *et al* 2013 and Diederich and Goeschl 2014; see supplementary material for experimental script). Subjects could use their endowment of €10 to purchase offsets, each mitigating 50 kg CO_2; this means that we do not merely rely on statements of intent but evaluate actual decisions. The offsets were offered at a reduced price of €1, amounting to a subsidy of €0.15 per offset paid by the researchers. The subsidy incentivised subjects to make any planned purchases of offsets during the experiment instead of postponing them until later. This made it possible for us to observe any changes in planned behaviour concerning the purchase of VCOs. Before the purchase, subjects had to correctly answer four questions designed to check whether they had understood the choice situation and its consequences. Subjects who failed to answer the control questions correctly in fewer than four attempts were not allowed to continue with the survey. Any endowment remaining after the purchase was credited to the subjects' accounts with the online panel. After the experiment, subjects were sent a link to a confirmation of purchase for the offsets.

The survey and the experiment consisted of six parts: (1) information blocks according to treatment, (2) questions on climate change perception, (3) information on, and purchase of VCOs, (4) questions on purchasing motives and on perception of the information text, (5) questions on attitudes towards climate change, mitigation and SAI research, (6) socio-demographic questions. The sequence of items within the blocks of questions was randomised to avoid order effects. The variables used in the analysis are listed in the supplementary material. Principal component analysis was used to combine items assessing the perception of climate change risks into one factor.

The experiment was administered online. Recruitment was performed from the German internet population using an online panel. Participants were sampled using quotas for the characteristics gender, age and state (Land) of residence.

The final sample consisted of 658 cases. 1262 subjects completed the experiment. Subjects were excluded from the analysis based on the following criteria: (1) giving identical responses in three or more blocks of questions; (2) taking less than 12 min to complete the experiment; (3) answering 'don't know' to at least one of the main explanatory variables used in the analysis. Of the 1262 subjects in the experiment, 19 were excluded because of the first criterion. The second criterion lead to the exclusion of 375 subjects, and 210 subjects were excluded based on the third criterion. The number of exclusions based on the second criterion—the minimum completion time—is high. This is probably due to the substantial remuneration, which subjects only received when they completed the experiment. The exclusion is justified as there is strong evidence that subjects who finished in less than 12 min did not carefully read the information provided.

The average age of subjects in the final sample was 49 (18–86 years). 46 percent of the subjects were female. 51 percent of the subjects had a high level of education, whereas 49 percent of the subjects had completed only lower secondary education or had no school leavers' certificate. The fieldwork was conducted within a period of four weeks in March and April 2015.

4. Results

A first look at the summary statistics reveals no significant difference in average VCO purchases between treatments (Wilcoxon rank-sum tests, $p > 0.105$). On average, subjects buy four offsets in the BASE treatment (95% confidence interval (CI) [3.51, 4.49]), 4.59 offsets in the SAI treatment (95% CI [4.06, 5.13]), and 4.22 offsets in the AUG treatment (95% CI [3.70, 4.74]).

To control for the influence of other factors on the mitigation decision, we run a Tobit regression (table 1). When we include the controls, we find that learning about the SAI option increases offset purchases significantly ($p = 0.011$). By contrast, merely reading a longer text on the effects of climate change in the AUG treatment does not influence offset purchases over and against the BASE treatment ($p = 0.913$). Accordingly, it is the information content of the SAI treatment that drives the observed increase in offset purchases and not the additional quantity of general information on climate change (Wald test, $p = 0.020$).

As control variables we include the perception of climate change risks and mitigation, the influence of the study's experimental purchase mechanism, the perceived effectiveness of offsets, and socio-demographic variables. This ensures that these factors do not drive the results or obscure the treatment effect.

Table 1. Tobit regression explaining the amount of purchased VCOs.

Dependent variable: amount of purchased VCOs	Average marginal effect (AME)	Standard error
Treatment group		
SAI	0.774^{**}	(0.305)
AUG	0.033	(0.307)
Climate change		
(1) Perception of impacts	0.029	(0.128)
(2) Daily mitigation	0.016	(0.145)
(3) Moral obligation to mitigate	0.782^{***}	(0.148)
Experiment characteristics		
(4) VCO effectiveness	1.145^{***}	(0.134)
(5) Indirect purchase of VCOs	1.061^{***}	(0.136)
(6) Payment via panel points	0.088	(0.140)
Socio-demographic variables		
Female	0.115	(0.261)
Age	0.016^{*}	(0.008)
Higher education	1.012^{***}	(0.259)
Pseudo R^2	0.0953	
N	658	

Note: SAI, AUG, female and higher education are dummy variables; all others except awareness of climate change impacts are standardised. (1) factor of the variables perception of climate change impacts 'today'/'in 25 years' for people in 'my environment including myself'/'in industrialized countries'/'in developing countries' (2) 'In your daily life, how often do you try to cut down on greenhouse gas emissions?'; (3) 'I feel morally obliged to help mitigate climate change.' (4) Perceived effectiveness of voluntary carbon offsets; influence on purchase decision of: (5) 'The IfW is handling the purchase, not me.' and (6) 'My remaining endowment can only be cashed in via the online panel.' For full description of variables, see supplementary table A1. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

The following control variables influence the purchase decisions significantly; The direction of their effect is as expected. Subjects who feel morally obliged to help mitigate climate change buy more offsets (see table 1; $p < 0.001$). Subjects who believe that offsets are an effective way of mitigating climate change also purchase more offsets ($p < 0.001$). Subjects who would rather buy offsets directly purchase fewer of them than those who prefer buying through us ($p < 0.001$). Finally, a high level of education increases VCO purchases ($p < 0.001$).

The treatment effect of SAI information on offset purchases is substantial compared to other factors. On average, subjects buy 0.8 VCOs more when they have been informed about SAI. Compared to other factors, this effect is similar to an increase in perceived VCO effectiveness of half a standard deviation or to an increase of one standard deviation in the perceived moral obligation to mitigate.

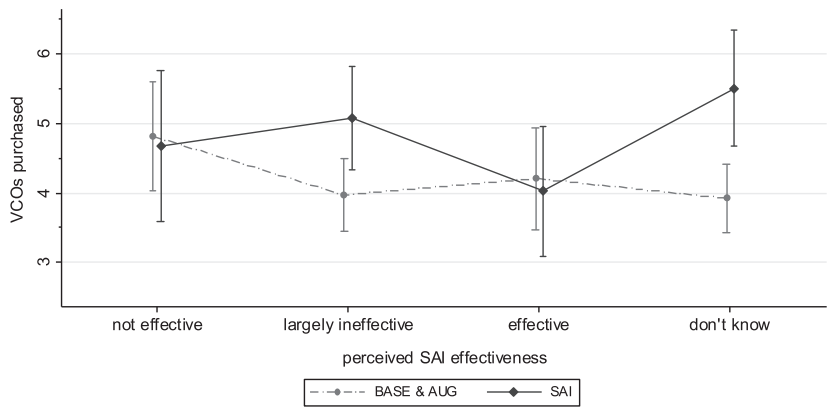

Figure 1. Effect of SAI treatment depending on perceived effectiveness of SAI. Note: predicted margins from a Tobit regression including the control variables of the regression presented in table 1 additionally including interaction effects between SAI and perceived effectiveness of SAI (see supplementary table A2 for full results).

In the final step of the analysis, we test the potential reasons for the absence of risk compensation and for the observed increase in purchases. To this end, we look at the three potential reasons we identified before and how they interact with the SAI information treatment. This reveals whether subjects in the SAI treatment buy more VCOs generally or only under certain conditions. Since behaviour in BASE and AUG is not significantly different, we pool the data from these treatments in the following analyses.

First, risk-compensation arguments require that SAI be perceived as an effective measure against climate change risks. Figure 1 plots the effect of the SAI treatment on offset purchases for different levels of perceived SAI effectiveness. As expected, subjects who perceive SAI to be ineffective do not change their mitigation behaviour after learning about SAI compared to those in BASE ($p = 0.826$). Contrary to what risk-compensation arguments suggest, subjects who think SAI is effective do not reduce their mitigation ($p = 0.765$). An increase in offset purchases is observed for those who think SAI is largely ineffective ($p = 0.018$) or who feel unable to assess SAI's effectiveness ($p = 0.001$).

Second, information on SAI may increase the perceived threat of climate change. After learning about SAI, subjects in the SAI treatment expect more negative impacts from climate change on average (mean: 0.09, 95% CI [−0.04, 0.22]) than subjects in the BASE or AUG treatment (mean: −0.04, 95% CI [−0.14, 0.05], Wilcoxon rank-sum test $p = 0.096$). When asked directly, 42 percent in the SAI treatment are more alarmed about climate change after learning about SAI, while only three percent are less alarmed. 55 percent state no changes in their perception of climate change. This variable's interaction effect with the treatment shows that those who are more alarmed buy more VCOs (average marginal effect (AME) = 0.67, $p = 0.083$; results see supplementary table A3). However, subjects who are just as alarmed about climate change as they were before learning about SAI also buy significantly more VCOs (AME = 0.81, $p = 0.017$). This indicates that though SAI slightly increases awareness of climate change risks, this increased awareness does not drive the increase in VCO purchases.

Third, the increase in purchases might be caused by the perception of SAI as a threat and thus by a lack of acceptance of the technology. Subjects in the SAI treatment were asked about the acceptability of SAI research in the lab. This item is a strong indicator of acceptance because lab research is still a long way from deployment; not accepting lab research implies strong opposition to SAI. On average, subjects who disagree with the conduct of lab research and those who 'don't know' buy more offsets ($p = 0.082$ and $p = 0.015$, respectively) than subjects in the BASE and the AUG treatment (figure 2). Interestingly, subjects in the SAI treatment who have no objection to SAI lab research also buy more offsets on average ($p = 0.015$).

5. Conclusion and discussion

To sum up, we find no evidence for risk compensation at an individual level as a reaction to information on SAI. Furthermore, we find no reduction in mitigation for those who perceive SAI as an effective method against climate change, even though they should be the ones most likely to reduce mitigation. Instead, our results empirically support the intuition that subjects who have been informed about SAI will mitigate more (Shepherd 2009, Betz and Cacean 2012, IASS 2014, Wibeck *et al* 2015).

We examine two potential explanations for an increase in the mitigation levels. We find that though for many subjects information on SAI increases concern about climate change, this increased concern does not drive the increase in VCO purchases.

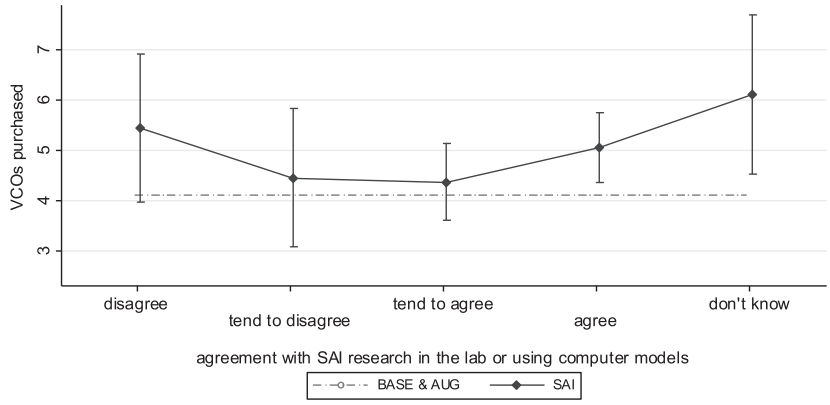

Figure 2. Effect of SAI treatment depending on attitude towards SAI research. Note: predicted margins from a Tobit regression including the control variables of the regression presented in table 1 additionally including interaction effects between SAI and the acceptance of SAI research in the lab (see supplementary table A4 for full results).

Essentially, we find that subjects who perceive the deployment of SAI as an actual threat increase mitigation to prevent a level of climate change that would make the deployment of SAI more likely. This is reflected in the increase in mitigation by individuals who are uncertain about SAI effectiveness, who think it is largely ineffective, who reject SAI research or who are uncertain about SAI research. Correspondingly, those who think that SAI would not be effective at all do not buy more VCOs because they do not think the deployment of SAI is at all likely. Future research should examine this argument more closely.

In addition, subjects who agree with SAI research increase mitigation as well, even though they do not reject the idea out of hand. This is in line with previous findings: on the one hand, the acceptance of SAI research does not automatically imply the acceptance of deployment (Pidgeon *et al* 2013). SAI is perceived ambiguously as an emergency measure whose deployment should be prevented (Merk *et al* 2015). People may thus increase mitigation because the deployment of SAI could be prevented if mitigation levels were higher. On the other hand, people think that just one method alone will not be enough to solve climate change and any progress on CE should be conditional on reaching mitigation targets (Ipsos MORI 2010, Winickoff *et al* 2015).

Our findings suggest that research on SAI and public engagement with it is not likely to undermine current mitigation efforts by individuals. Our results, however, depend on the information we provided our subjects with and people may react differently to other framings. With this limitation in mind, our results show that the occurrence of risk compensation remains an open question and the debate about it is far from being settled. In addition, our results do not affect the argument that other actors like policymakers or interest groups might reduce mitigation efforts because of SAI. This should be addressed by future research.

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