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Exploring public perception of environmental technology over time

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This paper analyses how new information shapes public perception of a controversially discussed technology over time. The test case analysed in this paper is solar radiation management (SRM), a potentially risky, environmental engineering technology, which aims to fight climate change by the injection of sulphate aerosols into the stratosphere. Using panel survey data, we show that most respondents initially show strong negative emotions towards SRM and reject the technology. However, public perception is not stable over time as emotions cool off and acceptance increases. The increase in acceptance is greater, the longer the cooling-off period between two surveys. Furthermore, we show that the cooling-off effect is more pronounced for more impulsive respondents.

Keywords: climate engineering; climate policy; public perception; cooling-off

1. Introduction

Public perception of environmental technology is shaped by a variety of factors, such as an individual's attitudes towards the environment, perceived seriousness of climate change, risk and benefit perception, and emotions towards the technology (e.g. Merk *et al*. 2015). In particular, negative emotions have been shown to be an important driver of public opposition (Van Stekelenburg and Klandermans 2013) and feelings of deprivation, such as anger, are particularly important in sparking opposition (Walker and Smith 2002).

Yet, emotions and feelings can be temporary and change over time. Consequently, existing one-shot public perception surveys might have either over- or underestimated the public acceptance of environmental technologies. On the one hand, public opposition, if caused by emotional processes, might ebb away over time as negative emotions cool down. Accordingly, a technology might be accepted (opposed) by the public in the first place, but widely opposed (accepted) after a while. On the other hand, an increase in negative emotions over time could lead to an increasing, even stabilising and permanent, opposition towards the technology.

In fact, there is some evidence from the field that cooling-off periods can change behaviour and limit potentially detrimental effects of negative emotions. A prominent historical example in this regard is the custom of the British and Prussian armies of allowing complaints only the day after an incident, so that soldiers are forced to rethink their complaints for a night.[1] In a similar vein, divorce petitions in South Korea can only be filed after a cooling-off period. This practice has led to a significant decrease in

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divorce rates (Lee 2013). Laboratory experiments have more directly tested for the role of emotions in changing behaviour. In particular, cooling-off periods changed the behaviour of respondents when playing ultimatum games (Grimm and Mengel 2011), and they also reduced respondents' self-reported negative emotions and led to a change in punishment behaviour (Wang *et al*. 2011). These examples show that cooling-off periods can change human behaviour and make decisions less dependent on temporary emotions. Therefore, public opposition towards environmental technology, if caused by emotional decision-making, might ebb away over time when rethought.

This paper asks how cooling-off periods after the reception of new information shape public perception of a controversially discussed environmental technology. In particular, we analyse how both negative and positive emotions, as well as cognitive factors, affect public perception over time. The technology we consider for this exercise is solar radiation management (SRM) via the injection of sulphate aerosols into the stratosphere.[2] Among scientists, SRM is a controversially debated climate engineering (CE) technique. On the one hand, SRM is supposed to be very effective in counteracting global warming; on the other hand, it involves large risks and uncertainties (Royal Society 2009; National Research Council Division on Earth and Life Studies 2015). Because the technology involves a deliberate manipulation of the earth's environmental system, information on public perception is one important prerequisite for making informed decisions on research and deployment (e.g., Merk *et al*. 2015). Public opinion polls show that the majority of respondents oppose SRM after being informed about it for the first time (Bellamy and Hulme 2011; Borick and Rabe 2012; Braun *et al.* 2014; Macnaghten and Szerszynski 2013). Based on the empirical evidence available, one could conclude that public opposition against SRM is probably too strong to consider it to be an acceptable part of a climate policy portfolio. However, in the surveys conducted so far, respondents had to state their acceptance right after they had heard about SRM for the first time. Yet, eliciting public opposition reliably is important, since public opposition might have far-reaching implications not only for research and deployment of CE but also for future design of climate policy. Understanding public opposition to CE, and in particular SRM, seems critically important given the need for profound societal changes associated with mitigation and adaption measures in case CE is considered unacceptable by the public. Therefore, it seems especially important to understand whether and how the perception of SRM is influenced over time.

In general, SRM is a particularly interesting case to test for the influence of emotional and cognitive processes on public perception over time. In contrast to other controversially discussed technologies, such as genetic crop modification techniques, SRM is currently rather unknown to the broader public and is not very often covered by the media (Merk *et al.* 2015; Weitze *et al.* 2012). Therefore, respondents' perceptions of SRM is likely to rely heavily on the information that they receive in the survey. Furthermore, perception of SRM is unlikely to have stabilised yet. In fact, experimental survey evidence suggests that the provision of additional information strongly decreases the acceptance of SRM (Braun *et al.* 2014). Therefore, we expect that cooling-off periods (after the reception of new information) will also influence the perception of SRM.

Our study uses panel survey data from more than 1,000 respondents to analyse the acceptance of SRM in Germany over time. We add to the literature in three respects: first, we provide evidence on how a cooling-off period affects acceptance of SRM and identify potential drivers of change. In particular, we test whether emotions drive acceptance and whether the cooling-off of such emotions changes acceptance over time. Second, we analyse whether the length of the cooling-off period affects acceptance. Our three sub-

samples allow us to analyse the effect of three different time lengths of cooling-off periods. Third, we test whether not only emotions but also cognitive reflection or impatient behaviour drive changes in acceptance.

Our results provide evidence for the existence of a cooling-off effect. We find that acceptance of SRM increases over time and that the increase becomes larger, the longer the cooling-off period is. For the shortest cooling-off period of one month, 26% of respondents stated a higher level of support for SRM in the second panel wave than in the first. For the longest cooling-off period of 18 months, 45% of respondents increased their support for SRM. We also find that informing lay people for the first time about SRM leads to strong emotions and that the attenuation of these emotions over time drives the observed increase in acceptance. In addition, other individual specific factors, such as cognitive reflection and impatience, are correlated with the observed changes in acceptance. Higher levels of reflectivity and lower levels of impulsivity lead to smaller changes in acceptance over time.

The remainder of the paper is structured as follows. Section 2 surveys the previous literature and relates it to our research questions. Section 3 outlines the survey design and the data, while Section 4 presents the methodological approach. Section 5 describes the results of our empirical analysis. Section 6 discusses and concludes.

2. Previous literature

So far, a cooling-off effect has been observed only in fields other than environmental technologies. Walgrave *et al.* (2011), for example, find a declining protest cycle in demonstrations against the Iraq-war between 2003 and 2006. However, the causes for this decline remain unclear and the authors do not analyse potential cooling-off effects further. Cramton, Gunderson, and Tracy (1999) analyse the cooling-off effect in a field study on wage negotiations between unions and firms in Canada. They find that cooling-off periods reduce the strike incidence of labour unions, since some potential strikes settle during the mandatory cooling-off period. Lee (2013) analyses the effect of a mandatory waiting period on the divorce rate in South Korea and finds that a cooling-off period significantly decreases the divorce rate. Faas and Blumenberg (2013) shed light on the public protest against the development of the train station in Stuttgart, Germany, between 2010 and 2012. They use, as we do, data from repeated online surveys. They find that the share of supporters remains nearly the same over time, but that negative emotions decrease over time.[3] However, they do not run a regression analysis and they do not analyse the relationship between support and emotions (over time).

Besides these observations from the field, studies analysed the cooling-off effect in controlled laboratory experiments, with students playing ultimatum games, providing mixed evidence. Bosman, Sonnemans, and Zeelenberg (2001) show that unfair offers sparked negative emotions in ultimatum games, which then lead to the rejection of unfair offers. However, they find no evidence for the existence of a cooling-off effect. A time delay of one hour between offer and decision affected neither emotions nor decisions. In contrast, more recently, Grimm and Mengel (2011) find that a time-delay of 10 minutes already increases acceptance rates for unfair offers significantly. This effect is more pronounced for men than woman (Espinosa and Kovarik 2015). Similarly, Oechssler, Roider, and Schmitz (2015) find that a cooling-off period of 24 hours lowers rejection rates in ultimatum games. They also find evidence that the cooling-off effect is more pronounced for impulsive decision-makers (although the effect is not significant).

Regarding the role of emotions, in their laboratory experiments, both Grimm and Mengel (2011) and Oechssler, Roider, and Schmitz (2015) do not measure emotions explicitly, but rather assume that cooling-off is caused by a change in (negative) emotions and that particularly negative emotions drive participants' decisions. Bosman, Sonnemans, and Zeelenberg (2001), in contrast, measure respondents' emotions and confirm that negative emotions drive the rejection rate in ultimatum games. Similarly, Wang *et al.* (2011) and Neo *et al*. (2013) find that cooling-off reduces negative emotions and decreases the punishment rate in ultimatum games. In addition, Wang *et al.* (2011) also find that the length of the cooling-off periods influences the punishment rate.

Turning to CE research, quite a number of studies have investigated public perception of CE technologies (e.g., Merk *et al.* 2015; Mercer, Keith, and Sharp 2011; Spence *et al.* 2010). All these studies find that people are generally sceptical about SRM; acceptance rates are, therefore, low. However, there is yet no evidence on the longer-term evolution of public acceptance of SRM or any other CE technique. It is also unclear whether emotions influence acceptance and, furthermore, whether an emotional cooling-off influences acceptance over time.

In general, public perception can change over time due to cognitive or emotional processes. Response to survey items may involve different cognitive processes, in particular heuristic and systematic processes (Chaiken, Liberman, and Eagly 1989; Lieberman, Schreiber, and Ochsner 2003). Heuristic processes are based on information which comes easily to mind, whereas systematic processes integrate all relevant information available (Trope and Liberman 1996). Since we present information only in the first but not in the follow-up surveys, responses in the first survey may be based on systematic cognitive processes to a larger extent. Changes in acceptance may, therefore, be caused by a switch in the dominant cognitive processes. Also, emotional processes may induce a change in acceptance over time. According to the process model of emotion regulation (Gross 1998), two major causes can be identified which may cause a cooling off of negative emotions in our study: deployment of attention and change of cognition, i.e. reappraisal of obtained information. Our study is not designed to explicitly differentiate which of these processes is dominant for our respondents. In our study, most respondents did not receive any additional information on SRM during the cooling-off period such that we can expect deployment of attention reappraisal to play a minor role. However, deployment of attention should be effective under this condition. In fact, several studies found that an important condition for deployment of emotional attention to work is a distraction from the stimuli which triggered these emotions (Derryberry and Rothbart 1988; Goleman 1995). In reality, such distraction cannot be guaranteed as a new technology may induce increasing media coverage or personal discussions over time. Such effects are difficult to predict and not covered by our study.

Summing up, there is some evidence both from the lab and from the field for the existence of a cooling-off effect after the reception of new information. Our study builds upon these findings and contributes to the existing literature in various ways. Novel to the literature, we provide first insights on the long-term public perception of SRM, which has not been elicited before. Using panel survey data from more than 1,000 respondents from Germany, we track public perception of lay people over time. New to the literature, we analyse how cooling-off periods after the reception of new information shape public perception of SRM. In addition, we also provide new evidence on how different lengths of cooling-off periods affect acceptance. For doing so, we use a consistent survey design and a comprehensive regression framework to quantify how acceptance changes over time. So far, systematic evidence on the drivers of change is very limited. For example, none of the previous studies analyse the influence of positive emotions. We, therefore,

analyse the influence of both positive and negative emotions and control for other factors such as cognitive reflection and condition on potentially important individual-specific factors that might drive a respondent's change in acceptance.

3. Data and survey design

Our study uses data from two waves of three representative online surveys on SRM. We conducted the first wave at three points in time (survey (1) in July 2014, survey (2) in August 2013 and survey (3) in December 2012) to investigate potential differences in the rate of change depending on the time-span between the first and the second surveys. In the following, we refer to the first wave of each survey as date '$t-1$' surveys. All three surveys were repeated with the same respondents in August 2014. In the following, we refer to the second wave of each survey date t surveys. Table 1 provides an overview.

All respondents aged 18 or above were recruited through a professional online panel and randomly assigned to one of the three surveys. They were sampled using quotas for gender, age and place of residence (federal state). In total, our working sample for t and $t-1$ includes 1,118 respondents.

All surveys of a wave were structured identically and differed only with respect to the time of elicitation. The surveys were structured as follows:

In the first part of the surveys conducted in $t-1$, we elicited respondents' perception of the seriousness of climate change and their ecological values. The ecological values were measured by five items from the New Ecological Paradigm Scale (NEP, Dunlap *et al.* 2000). Then, respondents were asked about their awareness of SRM, i.e., whether they had heard (a little) about SRM before or not.

In the second part of the surveys in $t-1$, all respondents were shown an information video about SRM (the content is provided in the appendix [online supplemental data]). The video provided respondents with information on SRM using animated graphics. The animations were supported by verbal explanations spoken by a professional radio presenter. Respondents who were not able to listen to or to play the video were excluded at the beginning of the survey. It was not possible to fast-forward the video or skip parts of it. The video first provided respondents with information on anthropogenic climate change and its likely consequences and explained the two-degree target. The video then introduced mitigation, adaptation and SRM as three possibilities for tackling climate change. Subsequently, the video explained SRM in more detail, i.e., its underlying mechanisms and its impact on climate change, the current state of research and the potential benefits and risks of SRM. The information was based on peer-reviewed papers and scientific reports (taken from, e.g., Crutzen 2006; IPCC 2007, 2012; Keith, Parson, and Morgan 2010; Royal Society 2009). External experts checked the information for correctness and clarity. After watching the video, we asked respondents about the clarity of the information provided on the video. For each survey, more than 98% of the respondents indicated that they had understood the video well or very well.

Table 1. Survey structure.

Survey	Date of first wave $t-1$	Date of second wave t	Time between $t-1$ and t	Respondents
Survey 1	July 2014	August 2014	1 month	676
Survey 2	August 2013	August 2014	1 year	213
Survey 3	December 2012	August 2014	1½ years	229

In the third part of the surveys in $t-1$, we proceeded to elicit the respondents' acceptance of SRM. Respondents were asked about their level of agreement (or otherwise) "to use SRM to counteract climate change". Potential answers ranged from 1 (strongly disagree) to 4 (strongly agree). Next, we elicited respondents' attitudes toward a measure such as "SRM is the easy way out". We also measured trust in various actors or institutions to act in the interests of society and the environment. Thereafter, we elicited respondents' egoistic, altruistic and security values. These values were measured using items from the Schwartz Personal Value Questionnaire (PVQ5X, Schwartz, Cieciuch, and Vecchione 2012). Subsequently, we then elicited respondents' emotional responses to SRM. Respondents were asked how strongly they experienced various positive reactions (delight, satisfaction, hopefulness, relief) and negative responses (worry, fear, sadness, anger, annoyance) when thinking about SRM, using a scale from 1 (not at all) to 4 (strongly). In our analysis, we summarised negative and positive emotions in a composite index. Next, respondents of survey (1) completed the cognitive reflection test (CRT) (Frederick 2005), a test on their level of impulsivity using the short version of the Barratt Impulsiveness Scale (Patton, Stanford, and Barratt 1995; Steinberg *et al.* 2013). The CRT indicates whether a respondent is a rather intuitive (low CRT score) or a rather reflective person (high CRT score). Finally, we collected information from all respondents on their personal characteristics such as gender and education.

For the repeated surveys conducted at time t, we first showed respondents a screenshot of the video that was embedded in the initial surveys at $t-1$ and asked them whether they could remember seeing the video in $t-1$. Respondents who did not remember seeing the video on SRM were excluded from the survey in t.[4] The remaining respondents proceeded and repeated most of the questions from the surveys in $t-1$. In addition, we asked respondents whether they informed themselves about SRM and/or on climate change between $t-1$ and t. We also asked them to state how their level of knowledge on SRM changed between $t-1$ and t. Finally, we again elicited respondents' perceptions of the seriousness of climate change and repeated some questions on the personal characteristics. Table A-1 in the appendix (online supplemental data) reports all survey items used in our analysis and the scales on which they are measured.

4. Methodology

Our analysis proceeds in three steps. In the first step, we use a descriptive analysis to compare respondent i's acceptance and emotions for the three surveys in $t-1$ (either July 2014, August 2013 or December 2012) and t (August 2014). In the second step, we use a regression framework to identify potential drivers of a respondent's change in acceptance. In particular, we add respondents' emotions to the regression framework to test whether emotions drive observed changes in acceptance (research question 1). We also test for the influence of personal characteristics and socio-demographic factors. In a third step, we restrict our analysis to survey (1), and test whether cognitive reflection or impatient behaviour drives the change in acceptance (research question 2).

To analyse determinants of a respondent's change in acceptance (research question 1), we first estimate the following equation:

$$\Delta acceptance_i = \alpha + \beta survey_i + \gamma \Delta X_i + \delta Y_{i,t-1} + \varepsilon_{i,\,t} \tag{1}$$

with

$$\Delta acceptance_i = acceptance_{i,t} - acceptance_{i,t-1}$$

and

$$\Delta X_i = X_{i,t} - X_{i,t-1}$$

In Equation (1), the dependent variable Δ*acceptance* is defined as the difference between acceptance at time t and $t - 1$. Acceptance measures respondent i's level of acceptance. It takes ordered values from 1 (strongly disagree) to 4 (strongly agree). Accordingly, a positive (negative) value of Δ*acceptance* means that individual i's acceptance of SRM has increased (decreased) between $t - 1$ and t. The sign of Δ*acceptance* does not make a statement about the level of acceptance but only about its change over time. For instance, Δ*acceptance* might be positive even if an individual still somewhat disagrees with the use of SRM at time t. The vector *survey* is a set of dummy variables for the different surveys. These dummies take into account that the date of the first elicitation differs between surveys. ΔX is the change in emotions (negative and positive) between t and $t - 1$. Y is a vector of personal characteristics measured in $t - 1$ (acceptance, negative emotions, positive emotions, perceived seriousness of climate change, ecological values (NEP), egoistic values, altruistic values, attitude towards SRM, gender and education).

To investigate the effect of cognitive reflection and impulsivity on the change in acceptance (research question 2), we restrict the analysis to respondents of survey (1) and estimate the following equation:

$$\Delta acceptance_i = \alpha + \gamma \Delta X_i + \delta Y_{i,\,t-1} + \vartheta Z_i + \varepsilon_{i,\,t} \tag{2}$$

Unlike Equation (1), Equation (2) contains the additional vector Z capturing cognitive reflection and impulsivity-non-patience measured in $t - 1$.

In all cases, the responses for ecological values (NEP), egoistic values, altruistic values and impulsivity are standardised indices. Variable definitions can be found in Table A-1 in the appendix (online supplemental data) and summary statistics can be found in Table A-2 in the appendix (online supplemental data).

5. Results

5.1 Descriptive results

We find for all three surveys that the acceptance of SRM differs significantly between the first and the second elicitation (t-tests reveal p values of 0.000 for all three surveys). The average acceptance of SRM increased between the first elicitation in $t - 1$ (either July 2014 for survey (1), August 2013 for survey (2) or December 2012 for survey (3)) and the second elicitation in t (August 2014). However, the size of the increase varies strongly between the three surveys. For survey (1), the share of respondents who agree with the use of SRM increased from 28% to 36% between July 2014 and August 2014. For survey (2), the share of respondents who agree with the use of SRM increased from 27% to 47% between August 2013 and August 2014. For survey (3), the share of respondents who agreed with the use of SRM increased from 25% to 45% between December 2012 and August 2014.

These results show first that the average acceptance of SRM is similar for all three surveys at the initial date of elicitation in $t - 1$ (25%–28%). Thus, the different initial date of elicitation does not seem to influence the acceptance of SRM in $t - 1$ strongly. Second, the average acceptance increases between the first and the second date of

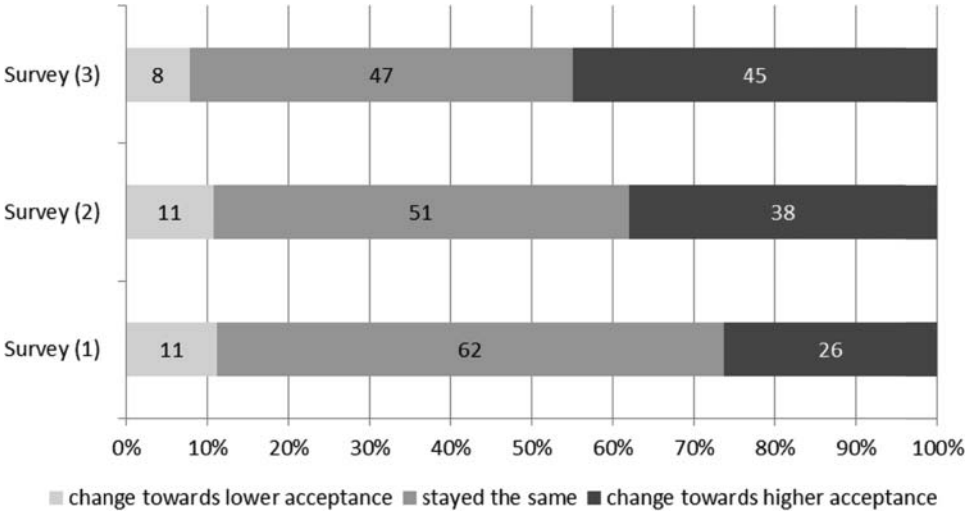

Figure 1. Change in acceptance between t and $t-1$.

elicitation. This result holds for all three surveys. Third, the increase in acceptance between the first and the second date of elicitation is greater for longer time gaps between $t-1$ and t. The increase is only 7% for survey (1) with the shortest time span and 20% each for surveys (2) and (3).

We next calculate the share of respondents whose level of acceptance increased over time, decreased or remained unchanged. To do so, we subtract the stated acceptance in t from the stated acceptance in $t-1$. Recall that acceptance takes ordered values from 1 (strongly disagree) to 4 (strongly agree). Positive values therefore indicate an increase in the level of acceptance, whereas negative values indicate a decrease. Figure 1 shows the share of respondents who changed their level of support for SRM between t and $t-1$.

We find for survey (1) that 26% of respondents stated a higher level of support for SRM in August 2014 than in July 2014. Thus, more than a quarter of respondents increased their support for SRM within a month. For survey (2), 38% of respondents increased their support for SRM. Here, the time gap between the two dates of elicitation was one year. For survey (3), 45% of respondents increased their support for SRM. For survey (3), the time gap was almost 1½ years. Thus, we find again that the increase in support is greater, the longer the time gap between t and $t-1$. In contrast, the share of respondents whose support for SRM decreased is similar for all three surveys (11% for survey (1), 11% for survey (2) and 9% for survey (3)).

Not only did acceptance change between $t-1$ and t, but respondents' emotions towards SRM also changed over time. Figure 2 illustrates that the negative emotions of respondents towards SRM decreased over time. The decrease in negative emotions is greatest for survey (3) (-0.2065 points) and smallest for survey (1) (-0.0036 points). This mirrors our findings on the increase in acceptance between t and $t-1$.

Our findings on the change in positive emotions towards SRM are ambiguous. While positive emotions towards SRM increased over time for survey (1) and survey (2), positive emotions decreased for survey (3). Overall, the summary statistics for positive emotions reveal that respondents do not feel very positive about SRM at any time. The average respondent in all three surveys disagreed at any time with having positive

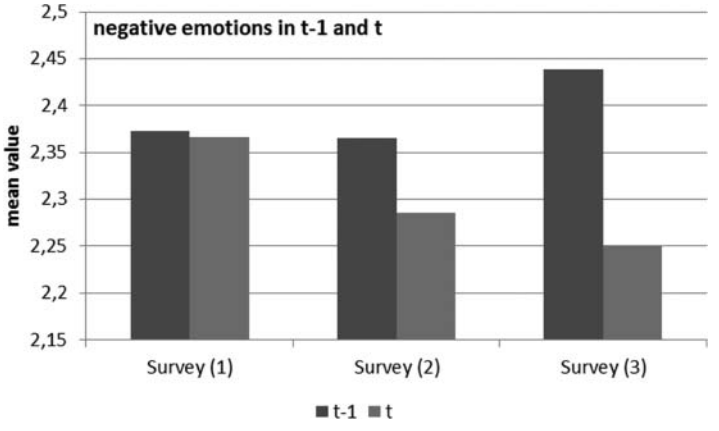

Figure 2. Negative emotions towards SRM in t and $t-1$. Respondents were asked how strongly they experienced various negative responses (worry, fear, sadness, anger, annoyance) when thinking about SRM, using a scale from 1 (not at all) to 4 (strongly). In our analysis, we summarised negative emotions in a composite index.

feelings about SRM. Table A-2 (online supplemental data) provides summary statistics for negative emotions in $t-1$ and t.

5.2. Regression analysis

5.2.1. Determinants of change in acceptance

Building on our descriptive findings, we run OLS regressions to determine the strength of the effect of change in acceptance separately for each survey and to determine potential drivers of this effect, such as a change of emotions over time. Table 2 summarises the regression results. To facilitate the comparison of the effect that the different variables have on the change in acceptance, the regression tables also report the standardised coefficients in squared brackets. We find that the overall change in acceptance is smallest for survey (1). Here, acceptance increases only by 0.230 standard deviations between July 2014 and August 2014. The change is significantly higher for survey (2) ($0.267 + 0.230 = 0.497$ standard deviations) and strongest for survey (3) (0.577 standard deviations) (column 1). These numbers mirror our descriptive findings from Section 5.1.

In the next step, we add sequentially potential determinants to our regression in order to analyse the drivers of the change in acceptance. We start by adding the change in emotions over time to the regression framework (column 2). We do so to test whether an emotional cool down led to a change in acceptance – or in other words, whether the stated acceptance in $t-1$ was driven by an emotional overreaction (research question 1). We find that the change in both (negative and positive) emotions over time is a significant determinant. Respondents who feel less negative (more positive) about SRM in t than in $t-1$ were also more willing to accept the use of SRM in t than in $t-1$. Thus, we find clear support for the existence of a cooling-off effect on emotions. Interestingly, we find that a one standard deviation increase in the change in positive emotions has a larger effect than a one standard deviation increase in the change in negative emotions. The former increases the change in acceptance by 0.290 standard deviations, whereas the

Table 2. OLS regression results.

Change in acceptance	(1)	(2)	(3)	(4)	(5)
Constant	0.176***	0.166***	1.413***	0.749***	0.670***
	(0.026)	(0.025)	(0.095)	(0.174)	(0.177)
	[0.230]	[0.217]	[1.849]	[0.980]	[0.875]
Survey (1)	omitted	omitted	omitted	omitted	omitted
Survey (2)	0.204**	0.121**	0.089*	0.074*	0.080*
	(0.066)	(0.057)	(0.045)	(0.044)	(0.046)
	[0.267]	[0.160]	[0.117]	[0.098]	[0.106]
Survey (3)	0.265***	0.250***	0.133**	0.140***	0.145***
	(0.060)	(0.055)	(0.043)	(0.042)	(0.042)
	[0.347]	[0.328]	[0.174]	[0.184]	[0.191]
Change in negative emotions		−0.234***	−0.261***	−0.281***	−0.279***
		(0.030)	(0.026)	(0.025)	(0.025)
		[−0.227]	[−0.253]	[−0.272]	[−0.270]
Change in positive emotions		0.371***	0.480***	0.479***	0.475***
		(0.043)	(0.037)	(0.036)	(0.036)
		[0.290]	[0.376]	[0.374]	[0.372]
Acceptance t-1			−0.686***	−0.714***	−0.714***
			(0.031)	(0.030)	(0.030)
			[−0.823]	[−0.855]	[−0.856]
Negative emotions t-1			−0.246***	−0.295***	−0.293***
			(0.024)	(0.025)	(0.026)
			[−0.272]	[−0.327]	[−0.324]
Positive emotions t-1			0.454***	0.447***	0.438***
			(0.039)	(0.037)	(0.038)
			[0.427]	[0.420]	[0.412]
Attitudes				0.149***	0.181***
Climate change seriousness t-1				(0.247)	(0.026)
				[0.145]	[0.177]
SRM is the easy way out t-1				0.039*	0.037*
				(0.021)	(0.021)
				[0.044]	[0.042]
Values				−0.020	−0.036
NEP t-1				(0.036)	(0.036)
				[−0.014]	[−0.025]
				0.098**	0.093**
Altruistic t-1				(0.033)	(0.034)
				[0.066]	[0.062]
				0.019	0.020
Egoistic t-1				(0.025)	(0.026)
				[0.017]	[0.018]
Demographics				0.067*	0.060*
Female				(0.032)	(0.033)
				[0.088]	[0.079]
Education				−0.041***	−0.042***

(*continued*)

Table 2. (*Continued*)

Change in acceptance	(1)	(2)	(3)	(4)	(5)
				(0.011)	(0.011)
				[−0.076]	[−0.076]
Knowledge controls					−0.069**
Change climate change seriousness					(0.033)
					[−0.054]
Informed about climate change					−0.042
					(0.041)
					[−0.055]
Informed about SRM					0.069
					(0.059)
					[0.091]
Change in knowledge on SRM					−0.044
					(0.039)
					[−0.028]
Observations	1118	1118	1118	1118	1113
Adjusted R^2	0.021	0.175	0.467	0.505	0.506

Standard errors in parentheses (). Standardised coefficients in squared brackets []. Coefficients of dummy variables are computed by Y-Standardisation. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

latter reduces the change in acceptance by only 0.227 standard deviations. This indicates that the relevance of an emotional cooling-down by negative emotions is less than of an increase in positive emotions over time.

In the next step, we add the initial values in $t - 1$ of acceptance and emotions to our regression framework (column 3). We do so to control for the initial level of acceptance and emotions in $t - 1$, as the change in acceptance might be greater for respondents who stated more extreme values in $t - 1$. We find that the starting value of acceptance has a statistically significant negative effect on the change in acceptance. Respondents who stated a higher level of acceptance in $t - 1$ show a smaller increase in acceptance between t and $t - 1$. The same is true for respondents who stated strong negative emotions towards SRM in $t - 1$. In contrast, respondents who felt positive about SRM in $t - 1$ show a stronger increase in acceptance between t and $t - 1$. The change in emotions, in particular of positive emotions, remains a statistically significant determinant of the change in acceptance. Therefore, we find that not only the change in emotions but also the initial levels of emotions and acceptance influence the change in acceptance over time.

In the next step, we add other potential determinants such as values or personal characteristics to our regression framework (column 4). We find that the perception of seriousness of climate change determines the change in acceptance over time. Respondents who perceived climate change as more severe in $t - 1$ show a significantly stronger increase in acceptance between $t - 1$ and t. Precisely, a one standard deviation increase of perceived climate change seriousness increases change in acceptance by 0.177 standard deviations.

Similarly, respondents who stated a higher agreement with the statement that "SRM is the easy way out" in $t - 1$ show a significantly stronger increase in acceptance (0.042

standard deviations). The acceptance of more altruistic respondents also increased over time. In contrast, we do not find a corresponding effect for more egoistic respondents or respondents with a high NEP score.

With respect to the socio-demographic variables, we find that the level of acceptance increased more for women than for men. Education has a significant impact on the change in acceptance over time. The increase in acceptance is lower for respondents with higher levels of education.

In a sensitivity analysis, we add four more control variables to analyse whether a change in knowledge of either SRM or climate change might have caused the observed change in acceptance. For doing so, we include two climate change control variables, i.e. variables that indicate whether respondents informed themselves about climate change between $t - 1$ and t and whether they perceive climate change as more severe in t than $t - 1$. In addition, we also include two SRM control variables, i.e. variables that indicate whether respondents' self-reported level of knowledge on SRM changed and whether they informed themselves about SRM between $t - 1$ and t. The results are provided in Table 1, column 5.

We find that the cooling-off effect remains robust to the inclusion of these additional control variables. The observed changes in positive and negative emotions are still significantly determining the change in acceptance and the standardised coefficient of change in negative emotions decreases only marginally with the inclusion of the additional knowledge control variables (from 0.374 to 0.372). This indicates that the relevance of an emotional cooling-down by negative emotions is less than of an increase in positive emotions over time.

Moreover, we find that the change in perception of climate change's seriousness between $t - 1$ and t is a statistically significant determinant of change in acceptance. Respondents who perceive climate change as more severe in t than in $t - 1$ are also more willing to accept the use of SRM in t than in $t - 1$. In contrast, all other three control variables remain statistically insignificant.

Overall, we find that the change in acceptance over time varies with individual specific factors. Our regression results support the existence of cooling-off. The cooling-off of negative emotions is an important driver of the observed increase in acceptance over time. The same also holds for changes in positive emotions. Other factors, such as gender or education, also affect the change in acceptance over time.

5.2.2. The effect of cognitive reflection and impulsivity

In the following, our analysis focuses on responses to survey (1) which contains data on respondents' cognitive reflection and impulsivity. We use this information to test whether more rational and reflective or more impatient and impulsive respondents behave differently regarding the change in acceptance over time (research question 2). The change in acceptance might not only be driven by an emotional component but also by a person's level of rationality or impulsivity. Table 3 shows the results.

In a first step, we add cognitive reflection and impulsivity to our regression framework (column 2). We find that the change in negative and positive emotions, the initial levels of negative and positive emotions and acceptance remain significant determinants of a change in acceptance. In particular, the size of the effect of change in positive emotions (standardised coefficient of 0.310) reveals a greater impact than of change in negative emotions (−0.224). This shows that the relevance of an increase in positive emotions

Table 3. OLS regression results for survey (1).

Change in acceptance	(1)	(2)	(3)
Constant	1.267***	1.748***	1.103***
	(0.137)	(0.182)	(0.248)
	[1.863]	[2.570]	[1.621]
Change in negative emotions	−0.219***	−0.220***	−0.250***
	(0.037)	(0.036)	(0.035)
	[−0.224]	[−0.226]	[−0.257]
Change in positive emotions	0.389***	0.369***	0.382***
	(0.058)	(0.055)	(0.053)
	[0.310]	[0.294]	[0.304]
Acceptance t-1	−0.598***	−0.618***	−0.651***
	(0.040)	(0.039)	(0.039)
	[−0.796]	[−0.821]	[−0.866]
Negative emotions t-1	−0.216***	−0.224***	−0.278***
	(0.034)	(0.034)	(0.034)
	[−0.269]	[−0.279]	[−0.346]
Positive emotions t-1	0.389***	0.378***	0.387***
	(0.057)	(0.055)	(0.054)
	[0.393]	[0.381]	[0.391]
Cognitive reflection t-1		−0.088***	−0.065***
		(0.020)	(0.020)
		[−0.143]	[−0.106]
Impulsivity t-1		0.100**	0.102**
		(0.036)	(0.036)
		[0.085]	[0.087]
Attitudes			0.142***
Climate change			(0.032)
seriousness t-1			[0.157]
SRM is the easy way out t-1			0.037
			(0.028)
			[0.046]
Values			−0.017
NEP t-1			(0.047)
			[−0.014]
			0.081*
Altruistic t-1			(0.045)
			[0.060]
			0.020
Egoistic t-1			(0.035)
			[0.019]
Demographics			0.074*
Female			(0.044)
			[0.109]
Education			−0.032**
			(0.016)
			[−0.066]
Observations	613	613	613
Adjusted R^2	0.3519	0.3779	0.4124

Standard errors in parentheses (). Standardised coefficients in squared brackets []. Coefficients of dummy variables are computed by Y-standardisation. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

over time on change in acceptance is more relevant than a cooling-off of negative emotions, even when controlling for the influence of cognitive factors.

In addition, cognitive reflection and impulsivity also have a significant impact. Acceptance of more reflective respondents (higher CRT score) increases less than that of less reflective ones. Also, the acceptance of more patient respondents increased significantly less than that of impatient respondents. Herby, the influence of cognitive reflection on change in acceptance is greater (−0.143) than of impulsivity (−0.085).

Overall, we therefore find that higher levels of reflectivity, as well as lower levels of impulsivity, lead to smaller changes in acceptance over time. In addition, we also confirm the results from Table 1, namely that emotional reactions drive the change in acceptance over time.

6. Discussion and conclusion

SRM is a controversially discussed climate engineering technology that counteracts climate change by technically cooling down the planet. First survey evidence indicates that SRM is rejected by a large majority of respondents (Braun *et al.* 2014; Mercer, Keith, and Sharp 2011; Merk *et al.* 2015). A public rejection of SRM might have far-reaching implications not only for research and deployment of SRM and other CE technologies but also for future design of climate policy. Thus, understanding public perception of CE, and in particular SRM, seems critically important given the need for profound societal changes associated with mitigation and adaption measures in case CE is considered unacceptable by the public.

Yet, existing one-shot public perception surveys, in which respondents had to state their acceptance right after they had heard about SRM for the first time, might have overestimated the public opposition towards SRM. In fact, evidence, from other fields than environmental technology, suggests that public opposition might at times be only a temporary phenomenon, especially if it is driven by negative emotions. In particular, negative emotions may cool off over time, leading to declining public opposition. While such cooling-off in emotions has been documented for ultimatum games in the laboratory, there is as yet no consistent empirical field evidence on how cooling-off periods, and in particular their lengths, affect public opposition of environmental technology.

This paper uses panel survey data from more than 1,000 respondents to analyse how cooling-off periods after the reception of new information shape public perception of a controversially discussed environmental technology, namely SRM. In particular, we analyse and compare the effect of change in both negative and positive emotions, as well as of cognitive factors, on public perception over time.

The case of SRM is particularly interesting to test for the interplay of emerging perceptions, emotions and cognitive factors, since most people have never heard of SRM and media coverage is still low (Mercer, Keith, and Sharp 2011; Merk *et al.* 2015). In contrast to other, widely known, technologies such as genetic engineering of crops, we expect public perception of SRM to rely on the information that respondents receive about SRM. Also, we expect respondents' perceptions of SRM not to be stabilised yet (as might be the case for other, more known, technologies). These characteristics makes SRM an optimal test case for analysing how cooling-off periods after the reception of new information shape public perception.

Our results provide evidence for the existence of a cooling-off effect in the field. We find that acceptance of SRM increases indeed over time and that the increase becomes

larger, the longer the cooling-off period. We find further that informing lay people for the first time about SRM leads to strong emotions and that the change in both negative and positive emotions over time drives the observed increase in acceptance. Interestingly, changes in positive emotions are even more important than changes in negative emotions, in driving the increase in acceptance.

We also find, in line with Oechssler, Roider, and Schmitz (2015), that the cooling-off effect is more pronounced for more impulsive respondents. In addition, we show that not only lower levels of impulsivity but also higher levels of cognitive reflection lead to smaller changes in acceptance over time. These findings confirm Frederick (2005), who showed that cognitive reflection correlates with time preferences. Our findings indicate that more reflective and more patient respondents already reveal stabilised perceptions of SRM and cannot be easily influenced.

We also show that the perception of seriousness of climate change determines the change in acceptance over time. Respondents who perceived climate change as more severe in $t-1$ show a significantly stronger increase in acceptance between $t-1$ and t. Interestingly, we do not find a corresponding effect for respondents with a high NEP score. This indicates that the perception of SRM differs between respondents, who perceive climate change as a serious problem, and respondents, who score high on the NEP, i.e., respondents who emphasise the limits of resources and growth. These findings might mirror a divide between green rationalist and green romantics (Symons and Karlsson 2015).

Overall, our results suggest that initial opposition towards SRM does not need to be permanent, even though the existing literature reports unambiguously that a vast majority of respondents strongly oppose SRM after the reception of new information (e.g. Mercer, Keith, and Sharp 2011; Merk *et al.* 2015). Given our results, these findings should be interpreted with some caution. We therefore recommend eliciting public attitudes over a longer time period to obtain a broader picture of public acceptance. Also, our results show that the change in acceptance over time depends on the characteristics of respondents. In particular, more rational and patient respondents reveal a more stable acceptance of SRM over time and are not easily influenced by cooling-off periods.

Future research might build productively on our work, addressing several caveats of our analyses. First, it must be noted that our findings may not be transferred one-to-one to other technologies. Other controversially discussed technologies, such as genetic engineering of crops, which are also rejected by the majority of respondents in Germany, are in contrast to SRM, better known among the German population and have been widely discussed in the media (see e.g. Weitze *et al.* 2012). This suggests, tentatively, that public opposition to genetic crop modification techniques is already more stabilised and may not be easily influenced by cooling-off periods. For future research, it would be interesting to compare how cooling-off effects the perception of environmental technologies that differ in their characteristics, such as level of awareness.

Second, the information for our respondents is mostly drawn from the video shown in the first survey wave, as SRM is currently mostly discussed by academics, governments and NGOs, but not by the broader public. However, respondents might have received additional and unbalanced information about SRM during the time span between the first and second survey waves. This potential change in knowledge, rather than an emotional cooling-off effect, might have driven the observed change in acceptance. To address this issue, we added a range of control variables to our regression framework. These controls indicate, for instance, whether respondents' knowledge on SRM changed between the first and second survey waves and whether their perceived seriousness of climate change

differed between the two survey waves. Our cooling-off effect survives the inclusion of these control variables. Nevertheless, we cannot conclusively rule out that other unobserved influences between the first and second survey waves might have influenced respondents' perceptions of SRM over time.

Third, our analysis only shows that cooling-off takes place after people receive new information. In real life, opposition against new technologies is often driven by conflict events and the resulting cognitive and emotional processes may be rather different in such cases. Moreover, our study does not disentangle which specific emotional and cognitive processes are responsible for cooling-off. Given that we obtain evidence for the existence of cooling-off, future research should develop survey designs which can separate the impact of the single processes.

Fourth, survey data should generally be interpreted cautiously as it can only provide an incomplete snapshot of public perception. For instance, the choices of survey respondents are limited to a set of pre-specified options. To address this limitation, we paid specific attention to asking balanced questions without leading cues. We also included a "don't know" option in every item to signal that not answering was acceptable. We randomised the sequence of items within the questions. We also consulted with experts on survey design to ensure that our questionnaire met current quality standards.

Despite these limitations, our paper makes a valuable contribution to the emerging public debate on SRM and provides very first insights on the longer-term evolution of SRM perception.

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Supplemental data

Supplemental data for this article can be accessed here.

Notes

1. Even today, this custom holds for the Military Complaints Regulations of the German Armed Forces.
2. For simplicity, we refer to solar radiation management via stratospheric sulfate injection as SRM in this paper.
3. This result holds for the time prior to the mediation in 2010/2011.
4. Respondents' knowledge of SRM is mostly based on the information video, which was incorporated into the initial survey at time $t - 1$. Therefore, respondents who could not

remember seeing the video in the survey at time $t - 1$ or remember the term SRM are also likely to not remember the information they received about SRM. They might therefore be unable to state their perception of SRM in the repeated survey in t.

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