

Annals of American Academy of Political & Social Science (in press)

formerly Geoengineering and the Science Communication Environment: A Cross-Cultural Experiment CCP Working Paper No. 92

## **Geoengineering and Climate Change Polarization: Testing a Two-channel Model of Science Communication**

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*Acknowledgments.* Research for this paper was funded by the [Cultural Cognition Lab at Yale Law School](#) and by the [Center for Applied Research at the University of Oklahoma](#). The authors are grateful to Maggie Wittlin for helpful comments on the design and on an earlier draft. Correspondence concerning this article should be addressed to Dan M. Kahan, Yale Law School, PO Box 208215, New Haven, CT 06520. Email: [dan.kahan@yale.edu](mailto:dan.kahan@yale.edu).

## Abstract

We conducted a two-nation study (United States,  $n = 1500$ ; England,  $n = 1500$ ) to test a novel theory of science communication. The *cultural cognition thesis* posits that individuals make extensive reliance on cultural meanings in forming perceptions of risk. The logic of the cultural cognition thesis suggests the potential value of a distinctive *two-channel* science communication strategy that combines information content (“Channel 1”) with cultural meanings (“Channel 2”) selected to promote open-minded assessment of information across diverse communities. In the study, scientific information content on climate change was held constant while the cultural meaning of that information was experimentally manipulated. Consistent with the study hypotheses, we found that making citizens aware of the potential contribution of *geoengineering* as a supplement to restriction of CO<sub>2</sub> emissions helps to offset cultural polarization over the validity of climate-change science. We also tested the hypothesis, derived from competing models of science communication, that exposure to information on geoengineering would provoke discounting of climate-change risks generally. Contrary to this hypothesis, we found that subjects exposed to information about geoengineering were slightly more concerned about climate change risks than those assigned to a control condition.

## Introduction

The investigation of *geoengineering* has begun in earnest. From the erection of towering “carbon scrubbers” to the launching of nanotechnology solar reflectors; from seeding the ocean with iron pellets to injecting aerosol particulates into the stratosphere—“ ‘geoengineering’ refers to deliberate, large-scale manipulations of Earth’s environment designed to offset some of the harmful consequences of [greenhouse-gas induced] climate change” (National Research Council 2010). Impetus for the development of such technologies comes from mounting evidence of both the inability of industrial societies to muster the political will to curb CO<sub>2</sub> emissions and the likely negligible effect of such limits even if widely adopted (“Time to act” 2009; Morton 2009; Pearce 2013). The U.S. National Academy of Sciences (National Research Council 2010, 2011) and the Royal Society (2009) in the U.K. and are among the preeminent scientific authorities that have issued preliminary reports calling for stepped up research efforts to develop geoengineering—and to assess the risks that resorting to it might itself pose to the physical environment. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) likewise incorporates alternative geoengineering-development scenarios into its climate models (IPCC 2013).

This paper addresses the contribution geoengineering might make to another environment: the deliberative one in which democratic societies like the United States and Great Britain make sense of scientific evidence relating to climate change. The scientific exploration of geoengineering as a policy response, we conclude, could have an important impact on public debate not just because of the factual information it is likely to yield but also because of the cultural message it is likely to express about what it *means* to regard climate change as a serious problem.

Guided by a theory of how cultural meanings influence public perceptions of risk, we conducted a study to assess how being made aware of geoengineering might affect the receptivity of citizens to sound scientific information on climate change. The study subjects consisted of two large and diverse samples, one from the United States and the other from England. Consistent with the study hypotheses, we found

that groups of citizens disposed by opposing cultural values to form conflicting assessments of the risks of climate change became less polarized over scientific evidence when they learned that geoengineering is under consideration as a potential solution.

Following a brief discussion of the theoretical framework that informed its design, we describe the study and report the results. We then discuss the implications of our findings for the role of geoengineering in debates over climate change, and for the importance of taking cultural meanings into account in science communication generally.

## **Theoretical background**

### *Three models of risk perception*

The scholarly literature on risk perception and communication is dominated by two models (Kahan, Slovic, Braman & Gastil 2006). The first is the *rational-weigher* model, which posits that members of the public, in aggregate and over time, can be expected to process information about risk in a manner that promotes their expected utility (Starr 1969). The second is the *irrational-weigher* model, which asserts that ordinary members of the public lack the ability to reliably advance their expected utility because their assessment of risk information is constrained by cognitive biases and other manifestations of bounded rationality (Kahneman 2003; Sunstein 2005; Weber 2006).

Neither of these models cogently explains public conflict over climate change—or a host of other putative societal risks, such as nuclear power, the vaccination of teenage girls for HPV, and the removal of restrictions on carrying concealed handguns in public. Such disputes conspicuously feature *partisan* divisions over *facts* that admit of scientific investigation. Nothing in the rational-weigher model predicts that people with different values or opposing political commitments will draw radically different inferences from common information. Likewise, nothing in the irrational-weigher model suggests that people who subscribe to one set of values are any more or less bounded in their rationality than those who subscribe to any other, or that cognitive biases will produce systematic divisions of opinion among such groups.

One explanation for such conflict is *the cultural cognition thesis* (CCT). CCT says that cultural values are *cognitively prior* to facts in public risk conflicts: as a result of a complex of interrelated psychological mechanisms, groups of individuals will credit and dismiss evidence of risk in patterns that reflect and reinforce their distinctive understandings of how society should be organized (Kahan, Braman, Cohen, Gastil & Slovic 2010; Jenkins-Smith & Herron 2009). Thus, persons with *individualistic* values can be expected to be relatively dismissive of environmental and technological risks, which if widely accepted would justify restricting commerce and industry, activities that people with such values hold in high regard. The same goes for individuals with *hierarchical* values, who see assertions of environmental risk as indictments of social elites. Individuals with *egalitarian* and *communitarian* values, in contrast, see commerce and industry as sources of unjust disparity and symbols of noxious self-seeking, and thus readily credit assertions that these activities are hazardous and therefore worthy of regulation (Douglass & Wildavsky 1982). Observational and experimental studies have linked these and comparable sets of outlooks to myriad risk controversies, including the one over climate change (Kahan 2012).

Individuals, on the CCT account, behave not as expected-utility weighers—rational or irrational—but rather as *cultural evaluators* of risk information (Kahan, Slovic, Braman & Gastil 2006). The beliefs any individual forms on societal risks like climate change—whether right or wrong—do not meaningfully affect his or her personal exposure to those risks. However, precisely because positions on those issues are commonly understood to cohere with allegiance to one or another cultural style, taking a position at odds with the dominant view in his or her cultural group is likely to compromise that individual's relationship with others on whom that individual depends for emotional and material support. As *individuals*, citizens are thus likely to do better in their daily lives when they adopt toward putative hazards the stances that express their commitment to values that they share with others, irrespective of the fit between those beliefs and the actuarial magnitudes and probabilities of those risks.

The cultural evaluator model takes issue with the irrational-weigher assumption that popular conflict over risk stems from overreliance on heuristic forms of information processing (Lodge & Taber 2013; Sunstein 2006). Empirical evidence suggests that culturally diverse citizens are indeed reliably

guided toward opposing stances by unconscious processing of cues, such as the emotional resonances of arguments and the apparent values of risk communicators (Kahan, Jenkins-Smith & Braman 2011; Jenkins-Smith & Herron 2009; Jenkins-Smith 2001).

But contrary to the picture painted by the irrational-weigher model, ordinary citizens who are equipped and disposed to appraise information in a reflective, analytic manner are not more likely to form beliefs consistent with the best available evidence on risk. Instead they often become even more culturally polarized because of the special capacity they have to search out and interpret evidence in patterns that sustain the convergence between their risk perceptions and their group identities (Kahan, Peters, Wittlin, Slovic, Ouellette, Braman & Mandel 2012; Kahan 2013; Kahan, Peters, Dawson & Slovic 2013).

### *Two channels of science communication*

The rational- and irrational-weigher models of risk perception generate competing prescriptions for science communication. The former posits that individuals can be expected, eventually, to form empirically sound positions so long as they are furnished with sufficient and sufficiently accurate information (*e.g.*, Viscusi 1983; Philipson & Posner 1993). The latter asserts that the attempts to educate the public about risk are at best futile, since the public lacks the knowledge and capacity to comprehend; at worst such efforts are self-defeating, since ordinary individuals are prone to overreact on the basis of fear and other affective influences on judgment. The better strategy is to steer risk policymaking away from democratically accountable actors to politically insulated experts and to “change the subject” when risk issues arise in public debate (Sunstein 2005, p. 125; see also Breyer 1993).

The cultural-evaluator model associated with CCT offers a more nuanced account. It recognizes that *when* empirical claims about societal risk become suffused with antagonistic cultural meanings, intensified efforts to disseminate sound information are unlikely to generate consensus and can even stimulate conflict.

But those instances are exceptional—indeed, pathological. There are vastly more risk issues—from the hazards of power lines to the side-effects of antibiotics to the tumor-stimulating consequences of cell phones—that avoid becoming broadly entangled with antagonistic cultural meanings. Using the same

ability that they reliably employ to seek and follow expert medical treatment when they are ill or expert auto-mechanic service when their car breaks down, the vast majority of ordinary citizens can be counted on in these “normal,” non-pathological cases to discern and conform their beliefs to the best available scientific evidence (Keil 2010).

The cultural-evaluator model therefore counsels a *two-channel* strategy of science communication. *Channel 1* is focused on information content and is informed by the best available understandings of how to convey empirically sound evidence, the basis and significance of which are readily accessible to ordinary citizens (*e.g.*, Gigerenzer 2000; Spiegelhalter, Pearson & Short 2011). *Channel 2* focuses on cultural meanings: the myriad cues—from group affinities and antipathies to positive and negative affective resonances to congenial or hostile narrative structures—that individuals unconsciously rely on to determine whether a particular stance toward a putative risk is consistent with their defining commitments. To be effective, science communication must successfully negotiate both channels. That is, in addition to furnishing individuals with valid and pertinent information about how the world works, it must avail itself of the cues necessary to assure individuals that assenting to that information will not estrange them from their communities (Kahan, Slovic, Braman & Gastil 2006; Nisbet 2009).

## Study

We designed a study to test the two-channel science communication strategy associated with CCT and the cultural-evaluator model. The goal was to determine whether making *geoengineering* salient as a potential solution to the risks associated with climate would convey via Channel 2 cultural meanings that neutralize or dampen defensive resistance to sound information transmitted via Channel 1.

### *Sample*

The sample consisted of approximately 3,000 individuals, half drawn from a nationally representative U.S. panel and half from a nationally representative English one.<sup>1</sup> The subjects' values were measured with two “worldview” scales—Hierarchy-egalitarianism (“Hierarchy”), and Individualism-communitarianism (“Individualism”)—used in studies of cultural cognition (Kahan 2012).

### *Design*

The study subjects were instructed to read an excerpt from an article published in the journal “*Nature Science*.” The *Nature Science* article, a composite of actual ones published in *Nature* (Allen, Frame, Huntingford, Jones, Lowe, Meinshausen & Meinshausen 2009) and the *Proceedings of the National Academies of Science* (Solomon, Plattner, Knutti & Friedlingstein 2009), reported evidence suggesting that previous estimates of atmospheric CO<sub>2</sub> dissipation had been overly optimistic. The new evidence, according to the article, suggested that the staggered introduction of emission limits and the eventual capping of them at 450-600 ppm would be insufficient to avert a string of environmental catastrophes. Rising sea levels would still submerge “coastal and island” regions across the world. At the same time, “persistent decreases in dry-season rainfall” would inflict conditions “comparable to the 1930s North American Dust Bowl” across the interiors of multiple continents. Indeed, the new evidence implied that “irreversible climate changes due to CO<sub>2</sub> emissions have already taken place,” and that “even if we could halt human carbon emissions today, the world would face risks of climate change for well over 1,000 years” (Figure 1).

After reading the *Nature Science* article, subjects reported their assessments of the information it contained. On a six-point scale, subjects indicated their level of disagreement or agreement with statements such as “[c]omputer models like those relied on in the study are not a reliable basis for predicting the impact of CO<sub>2</sub> on the climate”; “[m]ore studies must be done before policymakers rely on the findings

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<sup>1</sup> Additional information relating to the study sample, and the experimental stimuli and measures appears in the Supplemental Information.



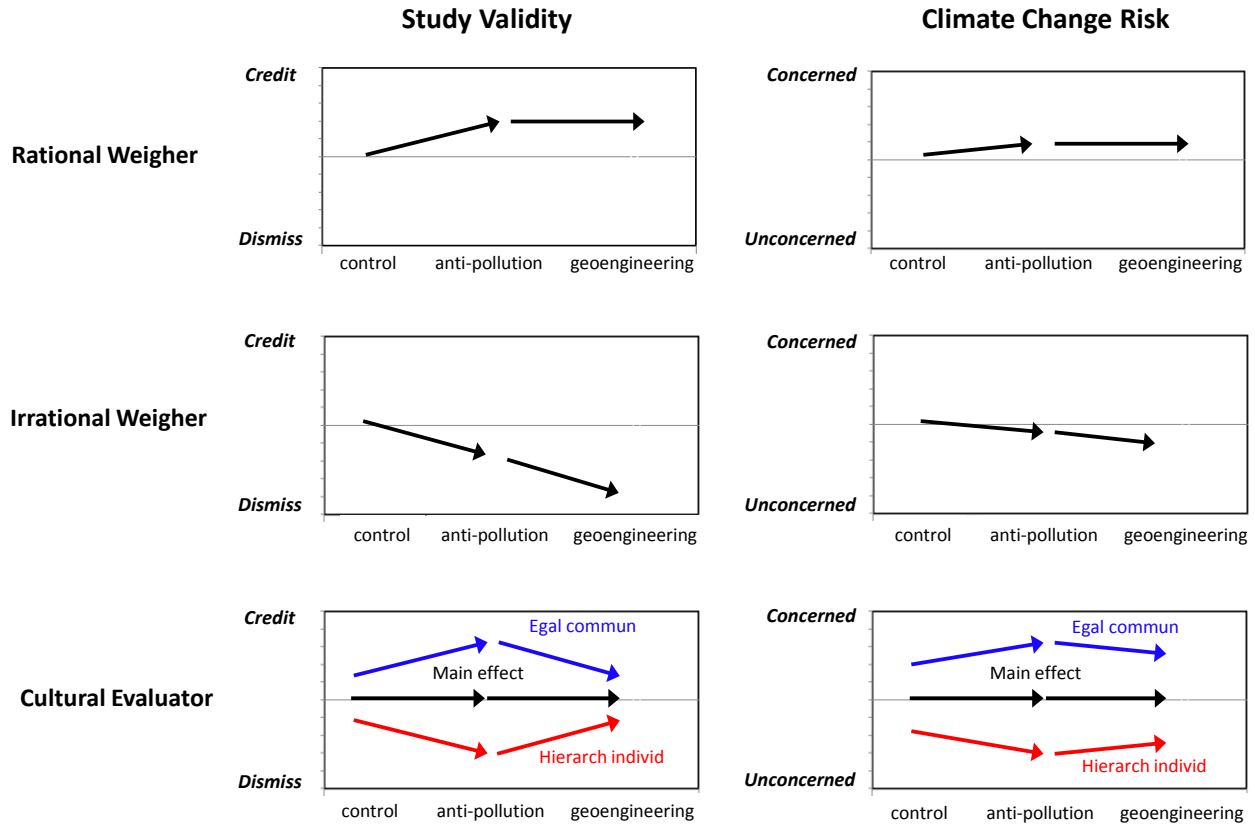
of the *Nature Science* study”; and “[t]he scientists who did the study were biased.” They also indicated “how convincing” they found the study on a scale of 0 (“completely unconvincing”) to 10 (“completely convincing”). Responses to the items formed a reliable scale ( $\alpha = 0.84$ ), which we labeled *study\_validity* and coded to reflect how disposed subjects were to credit the study.

We also collected information on our subjects’ beliefs about climate change. They thus indicated “how much risk” they perceived “climate change poses to human health, safety, or prosperity” on a scale of 0 (“no risk at all”) to 10 (“extreme risk”). They also indicated on a six-point scale the level of their disagreement or agreement with statements such as “[a]verage global temperatures are increasing”; “[h]uman activity is causing global temperatures to rise”; and “unless steps are taken to counteract global warming, there will be bad consequences for human beings.” These items, too, formed a reliable scale ( $\alpha = 0.93$ ), which we labeled *cc\_risk*, and coded to reflect how disposed subjects were to be concerned about climate-change risks.

The study involved an experimental manipulation as well. Before reading the *Nature Science* article and responding to the various items on the soundness of the study and on climate change, our subjects were divided into three groups, each of which was instructed to read a news report. In the “anti-pollution” condition, subjects read a story in which members of the “American Academy of Geophysical Scientists,” responding to the *Nature Science* article, called for adoption an atmospheric-CO<sub>2</sub> ceiling even lower than the 450 ppm threshold described as “a target” level “approved by the United Nations.” In the “geoengineering” condition, in contrast, subjects read a news story in which members of the AAGS called for greater investments in geoengineering as a necessary and more effective alternative to even stricter CO<sub>2</sub>-emission limits. Finally, in the “control” condition, subjects read a story about a municipal board’s adoption of a measure requiring developers to post bonds to cover the cost of traffic lights necessitated by commercial property developments (Figure 1).



news stories small. But under the rational-weighter model, one would certainly not expect anti-pollution and geoengineering subjects to be *less* concerned about climate change risks than ones in the control condition.



**Figure 2. Summary of hypotheses.** The three models of risk perception generate opposing hypotheses about the impact of the experimental manipulation. The rational-weighter model predicts that subjects in the anti-pollution and geoengineering conditions will see the *Nature Science* study as more valid than do subjects in the control condition. The irrational-weighter model predicts the opposite. The cultural evaluator model predicts that the impact of the manipulation on assessments of the *Nature Science* study will interact with subjects' values and that polarization will be larger in the anti-pollution condition than in the geoengineering condition. The offsetting effects of the manipulation on subjects of opposing cultural views is expected to result no net main effect in the anti-pollution condition and either no or a very small positive main effect in the geoengineering condition.

One might predict this result, however, if one anticipated that the subjects would react *irrationally*. Many scholars believe that ordinary citizens are motivated to resist dire information about climate-change risks in order to reduce fear or anxiety (Shepherd & Kay 2012; Lorezoni, Nicholson-Cole & Whitmarsh 2007). In a similar vein, others have warned that exposure to information on geoengineering might suppress public concern over climate change by gratifying the public demand to believe that rising

atmospheric CO<sub>2</sub> levels do not pose a serious danger—a dynamic referred to as a “moral hazard effect” (Lin in press; Hamilton 2013; National Environmental Research Council 2010; Parson 2006).

Both of these expectations reflect the irrational-weigher theory. If one accepts that model, then, one might predict that subjects in the anti-pollution condition—their anxieties freshly stoked by the alarm of the AAGS scientists in the news story—to be *less* inclined to credit the *Nature Science* study, and more skeptical of climate-change risk generally, than their less perturbed counterparts in the control condition. Buffeted by reinforcing waves of denial (in reaction to the *Nature Science* study) and false hope (in reaction to the geoengineering news story), geoengineering condition subjects could be expected, on this (il)logic, to be even more dismissive.

Unlike the rational- and irrational-weigher models, the cultural evaluator model predicts that the impact of the experimental manipulation will depend on subjects’ values. Concern for climate change signifies apprehension about the limits and dangers of commerce and technology. This cultural meaning is congenial to egalitarian communitarians, who are morally ambivalent about such activities. It is anathema, however, to hierarchical individualists, who prize those very things. We anticipated that these resonances would be strongly evoked both by the anti-pollution condition new story, which not only reported the demand of the AAGS scientists for stricter CO<sub>2</sub>-emission controls but also featured anti-commerce and -technology images: one of smokestacks billowing clouds of (presumably) carbon-saturated emissions, and another depicting women from India who (presumably) would be adversely affected by climate change underneath a “SAVE THE CLIMATE” banner. These cultural meanings would create a psychic incentive for hierarchical individualists to dismiss, and for egalitarian communitarians to credit, the *Nature Science* study. Under the two-channel science communication model, then, we should expect subjects in the anti-pollution condition to be more polarized over the validity of the study than those in the control condition.

Assignment to the geoengineering condition, however, should have the opposite effect. Geoengineering symbolizes the ability of humans to invent technologies that modify the environment and thus overcome limits on commerce and industry. The geoengineering news story contained artist renditions of

two geoengineering technologies—carbon scrubbers, which were shown in a mountain wilderness scene; and a flying “turbine-fitted vessel” spraying clouds with a “reflective” whitener—that we expected to amplify these connotations. It makes sense to resort to geoengineering only if climate change is occurring and will cause harm if unchecked. But precisely because geoengineering is a solution that *affirms* rather than *denigrates* the values of hierarchical individualists, the geoengineering-condition news story transmits via Channel 2 meanings that offset the pressure on such persons to dismiss the information content being transmitted via Channel 1. The cultural evaluator model thus predicts that polarization over the validity of the *Nature Science* study should be mitigated in the geoengineering condition relative to the anti-pollution condition.

Unlike the irrational-weigher model, the cultural evaluator model furnishes no reason to expect either the anti-pollution or geoengineering subjects to become less concerned about climate change risks than control subjects. Because the responses of egalitarian communitarians and hierarchical individualists can be expected to offset one another, the impact of the *Nature Science* study should be close to nil in the anti-pollution condition. In the geoengineering condition, overall concern with climate change could even *increase* as a result of the willingness of hierarchical individualists to give more credence to the *Nature Science* study.

But support for the cultural evaluator model does not depend on observing a result this dramatic. Subjects of opposing cultural outlooks can be expected to come to the study with strongly held and divergent beliefs on climate change—including ones about the weight of opinion among expert scientists (Kahan, Jenkins-Smith & Braman 2011). The logic of the two-channel strategy of science communication does not entail that exposure to a single piece of additional evidence will change the position of either side to a significant degree. What it does imply, however, is that an appropriate integration of meaning and information content can ameliorate the tendency of culturally diverse citizens to form *opposing* beliefs about the validity and weight of any particular piece of evidence. In a science communication environment free of this impetus to disagreement, citizens of diverse outlooks are much more likely to converge on sound science over time—and indeed, less likely to become divided about it in the first place.

The decisive test for the two-channel strategy, then, is the hypothesis that assignment to the geoengineering condition will reduce cultural polarization over strength of the *Nature Science* study.

### *Results*

Overall, the study subjects were ambivalent. Scores on the individual items used to measure “how convincing” the subjects found the *Nature Science* study ( $M = 5.4$ ,  $SEM = 0.05$ ) and “how serious” they regarded “the risk pose[d]” by “climate change” ( $M = 6.16$ ,  $SEM = 0.06$ ) were both close to the middle of their respective ranges. Mean scores for members of the English subsample were higher on both measures than were those for members of the U.S. subsample, but by modest margins ( $\Delta M = -0.6$ ,  $t\text{-test} = -5.2$ ,  $p < 0.01$ ; and  $\Delta M = -0.6$ ,  $t\text{-test} = -5.8$ ,  $p < 0.01$ , respectively).

The experimental manipulation had no meaningful *main* effect on evaluation of the *Nature Science* study (Table SI-3, model 1).<sup>2</sup> The mean score on *study\_validity*, the scale used to measure the disposition to credit the study, was slightly higher in the geoengineering condition than in the control condition ( $\Delta M = 0.06$ ,  $SEM = 0.05$ ), but the difference was nonsignificant for the entire sample ( $p = 0.18$ ) and for both national subsamples (U.S.:  $\Delta M = 0.05$ ,  $SEM = 0.06$ ,  $p = 0.47$ ; England:  $\Delta M = 0.08$ ,  $SEM = 0.07$ ,  $p = 0.23$ ).

The experimental manipulation did have a main effect on climate-change risks, but only a small one (Table SI-4, model 1; Figure 3). The mean score on *cc\_risk*, the scale used to measure the disposition to credit climate-change risks, was slightly (and significantly) higher in the *geoengineering* condition than in the control condition ( $\Delta M = 0.13$ ,  $SEM = 0.05$ ,  $p < 0.01$ ). The impact of the experimental manipulation on *cc\_risk* did not differ to any meaningful degree for the two national subsamples.

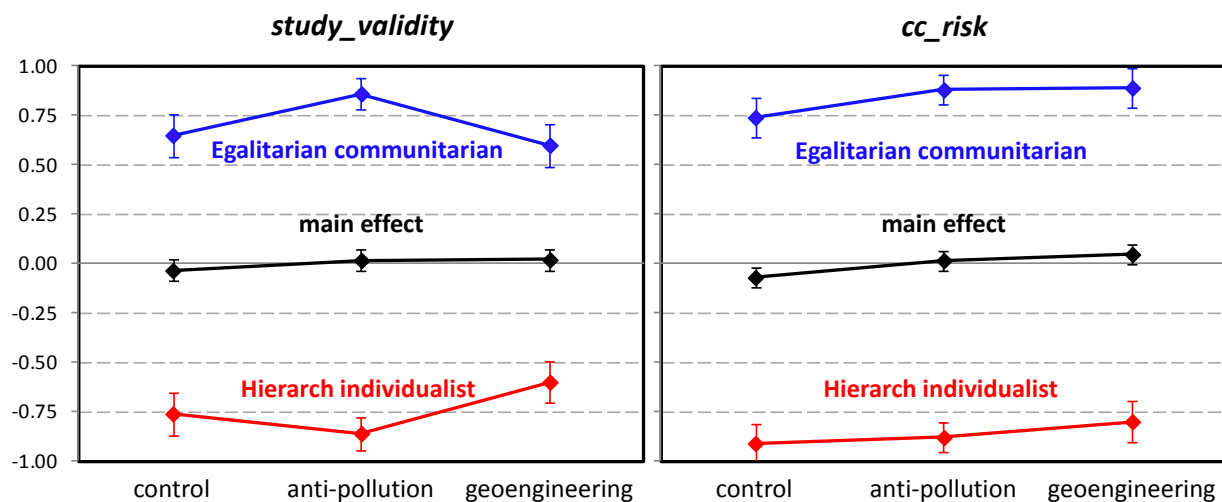
Both *study\_validity* and *cc\_risk* were of intermediate value in the anti-pollution condition. But neither differed by a meaningful or statistically significant amount from the score in the corresponding measure in either of the other two conditions.

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<sup>2</sup> The study hypotheses were tested by multivariate regression analyses. The results of those analyses and additional discussion of them appear in the Supplementary Material.

Breaking the subjects down by cultural worldviews, however, revealed them to be highly polarized. Consistent with previous studies (Kahan 2012), Egalitarian Communitarian subjects were substantially more concerned about climate change risks than were ones who were hierarchical and individualistic (Table SI-3, model 1). The degree of polarization was larger among U.S. subjects, but still pronounced among English ones (Figure 4).

There was also a significant interaction between the experimental manipulation and subjects' cultural worldviews. Cultural polarization over the validity of the *Nature Science* study was more pronounced in the anti-pollution condition than in the geoengineering condition (Figure 4). This effect was present in both national subsamples, but was larger in the U.S. subsample, where the level of polarization in the anti-pollution condition also exceeded the level observed in the control condition (Table SI-3, model 4).



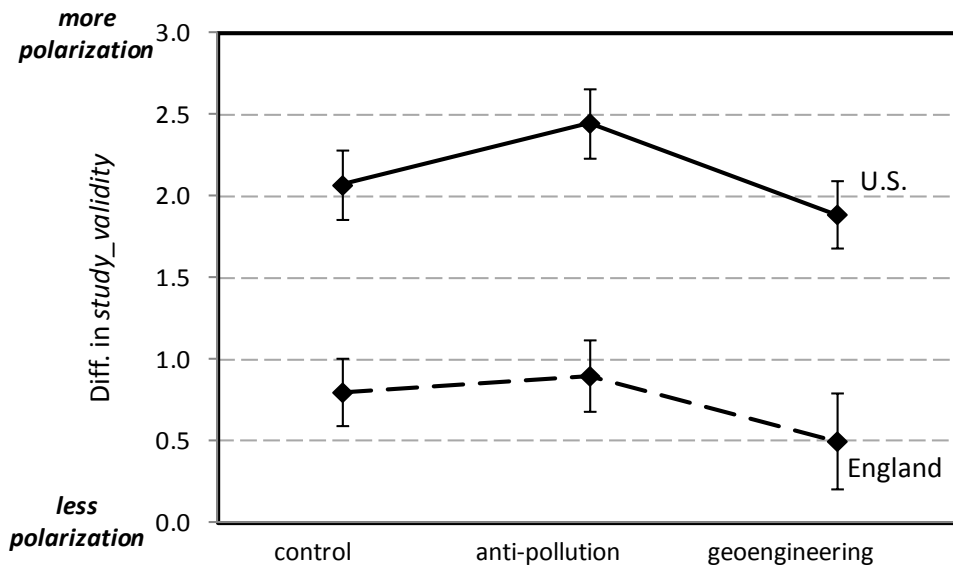
**Figure 3. Experimental manipulation, main effect and culture interactions.** Estimates derived from multivariate regression (Table SI-3, model 1; & Table SI-4, model 1, for “Main effects”; Table SI-3, model 3; & Table SI-4, model 3 for cultural worldview effects). Estimates for cultural worldview effects determined by setting scores on both Hierarchy and Individualism at +1 SD for “Hierarch individ” and -1 SD for “Egal commun.” Y-axis reflects the z-score on the respective scales. CIs denote 0.95 level of confidence.

The experimental manipulation also had a small impact on the intensity of the cultural polarization over climate-change risks (Table SI-4, model 3; Figure 3). Assignment to the anti-pollution condition as opposed to the control condition intensified the association between Hierarchy and dismissal of climate-change risks (Table SI-3, models 3). However, the gap in *cc\_risk* scores associated with being sim-

ultaneously hierarchical and individualistic as opposed to simultaneously egalitarian and communitarian did not vary significantly between the experimental conditions (Table SI-3, models 3-4).

### *Analysis and Interpretation*

This pattern of results supports the hypotheses derived from the cultural evaluator model. Although subjects in one had no more or less information relevant to assessing the validity of the study than those in the other, the two conditions conveyed different meanings. Relative to the control, the anti-pollution news story accentuated the conventional anti-commerce and anti-technology meanings that motivate Hierarchical Individualists and Egalitarian Communitarians to disagree about the evidence on climate change risks. The geoengineering news story, in contrast, linked climate-change science to cultural meanings—of human ingenuity and of overcoming natural limits on commerce and industry—that at least partially offset the threat that crediting such information would normally pose to the identity of Hierarchical Individualists. Consistent with the two-channel science communication strategy, cultural polarization over the *Nature Science* study was reduced in the geoengineering condition.



**Figure 4. Impact of experimental manipulation on cultural polarization relating to *study\_validity*.** Estimates derived from multivariate regression (Table SI-3, model 4). Point estimates reflect the difference between the estimated score of a prototypical egalitarian communitarian (-1 SD on both Hierarchy and Individualism scales) and that of a prototypical hierarchical individualist (+1 SD on both scales). Y-axis reflects the difference measured in z-score increments. CIs denote 0.95 level of confidence.



The results of the study do not support the hypotheses derived from either of the other two models of risk perception and science communication. One irrational-weighter hypothesis was that the anxiety aroused by the reaction of the scientists in the anti-pollution news story would likely generate more resistance to the *Nature Science* study in the anti-pollution condition than in the control. Another hypothesis associated with that model suggested that “false hope” stimulated by the geoengineering news story would generate a disposition to discount climate change risks generally. The rational-weighter model, in contrast, predicted that the subjects in both the anti-pollution and geoengineering conditions would have reason to give the *Nature Science* study more credence than ones in the control condition, and possibly, as a result, revise upward their assessment of the seriousness of climate-change risks.

These effects were not observed. In aggregate, evaluations of the validity of the study did not vary in any meaningful way between the conditions. Consistent with the cultural evaluator model, this effect reflects the offsetting impact of the judgments of subjects of diverse worldviews.

Contrary to the “moral hazard” effect posited by the irrational-weighter model, subjects in the geoengineering condition did not become sanguine about climate change risks. Indeed, on the whole, they displayed *more* concern over climate change than ones in the control condition (Figure 3).

The effect, however, was quite small. Moreover, if this was the increased concern with climate change predicted by the rational-weighter theory, then this effect apparently depended on the power of the geoengineering news story to mitigate cultural polarization over the validity of the *Nature Science* study.

Two additional points about the results are worth noting. First, the geoengineering condition diminished polarization over the validity of the *Nature Science* study relative to the anti-pollution condition only. The degree of polarization that persisted in the geoengineering condition, in other words, was comparable to that which existed in the control.

Second, the impact of the geoengineering treatment appeared to be *symmetric*. Whereas Hierarchical Individualists (subjects who scored in the top 50% on both Hierarchy and Individualism) assigned to the geoengineering condition had a higher mean score on *study\_validity* than their counterparts in the anti-pollution condition ( $\Delta M = 0.17$ ,  $SEM = 0.08$ ,  $p = 0.03$ ), Egalitarian Communitarians (those who

scored in the bottom 50% on both Hierarchy and Individualism) gave it a comparably *lower* one ( $\Delta M = -0.20$ ,  $SEM = 0.08$ ,  $p = 0.01$ ). Depolarization occurred, then, because both moved toward the mean, and not merely because Hierarchical Individualists became less dismissive.

These results also lend support the more basic premises of two-channel model of science communication. In the real world, there is no “control condition”: people get scientific information about climate change in the course of practical deliberations about what to do. The two-channel model implies only that the relative salience of different proposals can make a difference in the acceptance of such information when those proposals bear contrasting cultural meanings. The relative effects of the anti-pollution and geoengineering conditions on evaluations of the *Nature Science* study corroborate this conclusion.

In addition, the cultural cognition thesis does not imply that only one side in the debate over climate change or other issues is reacting with identity-defensive bias (Kahan 2013). The culturally symmetric effect of the geoengineering condition—while at odds with theories positing that politically motivated reasoning is associated with political conservatism (Jost, Hennes, Lavine 2013)—is thus not contrary to the basic conjecture that the advent of geoengineering can be used to convey meanings along Channel 2 that conduce to open-minded consideration of climate change science by citizens of diverse outlooks.

As we understand it, the goal of democracy-promoting science communication is not to stifle citizens’ critical engagement with scientific information but rather to remove from their deliberative environment antagonistic cultural meanings and other influences that predictably distort the quality of such engagement. The proper measure of success for a two-channel strategy, then, is not its impact on making any group of citizens more or less disposed to credit a particular form of scientific evidence—much less to impel them into a state of agreement with any particular conclusion—but rather its success in abating antagonisms in meaning that drive citizens of diverse worldviews apart when they consider such evidence in common.

That is exactly the effect that the geoengineering treatment had (Figure 5). On the whole, subjects in that condition were neither more accepting nor more skeptical toward the scientific evidence presented. But insofar as the geoengineering treatment reduced cultural polarization over the study relative to the

anti-pollution treatment, the geoengineering subjects' reactions displayed a more open-minded quality of common engagement, one that could be expected to move them progressively toward convergence if it could be amplified and maintained over time.

### **Implications for science communication**

The results of the study furnished support for the cultural evaluator model relative to rival models of risk perception and science communication. The cultural cognition thesis implies that ordinary citizens, as cultural evaluators of risk, process scientific information via two channels: one that relates to the content of that information; and another that assesses the compatibility of assent to it with expression of their defining group commitments. The effect that making emission-controls salient had in accentuating identity-protective reactions to climate-change information, and the effect that making *geoengineering* salient had in reducing such reactions, supports this position. Rival models that emphasize rational and irrational weighing of scientific information are not consistent with this result.

The study finding has two important practical implications. The first concerns the significance of geoengineering in public deliberations over climate change. The second has to do with the significance of meaning in science communication more generally.

#### *What geoengineering might do to/for the deliberation environment*

Just as scientists have started to investigate the feasibility of geoengineering as one response to climate change, so science communication scholars have started to examine how information about geoengineering should be transmitted to the public (Pidgeon, Corner, Parkhill, Spence, Butler & Poortinga 2012; Corner, Pidgeon & Parkhill 2012). Some commentators view public debate over geoengineering as an opportunity to renew efforts to educate the public on the science of climate change and the need to contain human CO<sub>2</sub> emissions (Bloss, Bouzarovski, Cai, Chapman, Clark, Dessai, Du, der Horst, Kendall, Kidd & Randalls 2010). But others advocated that information about geoengineering be downplayed lest it interfere with efforts to focus public attention on the dangers that climate change poses and thus erode political motivation to do anything to counteract it (Hamilton 2013).

The cultural cognition thesis furnishes reason to be skeptical of both of these responses, which can be seen as reflecting an amalgam of sensibilities associated with the rational- and irrational-weighter models of risk perception. Contrary to the rational-weighter view, the *reason* that many people dismiss evidence of the seriousness of climate change is not that they have been exposed to insufficient information about its potential negative consequences for society, but rather than such information has been suffused with meanings that threaten their cultural outlooks. Instead of worrying, then, that the public might over-estimate the efficacy of potential responses to climate change—an irrational-weighter anxiety—science communicators should be looking for ways to dissipate the meanings that make large, politically consequential segments of the population dismissive of the evidence that there is anything to worry about.

The study results suggest that geoengineering might be able to play a role in doing that. Geoengineering is consonant with a narrative that depicts human technological ingenuity as the principal means by which our species has succeeded in overcoming environmental constraints on its flourishing. Geoengineering permits climate change to be assimilated into this story and thus turns climate change from an indictment of hierarchical individualists' values into an occasion in which the forms of human excellence that such citizens prize can again be deployed for the advance of human welfare (Pidgeon et al. 2012).

From this point of view, the anxiety that geoengineering might “let the air out” of efforts to arouse political concern with climate change has things exactly backwards. In order to overcome cultural resistance to sound scientific evidence that a problem exists, the two-channel communication strategy associated with the cultural evaluator model says that people of diverse values must all be shown *solutions* that they find culturally congenial.

None of this is to say, of course, that geoengineering of any particular form is necessarily an appropriate response to climate change. The feasibility and risks of geoengineering are open issues that demand intensive scientific study, as both the National Academy of Sciences (National Research Council 2010, 2011) and the Royal Society (2009) have stressed.

That geoengineering *will* and *should be* investigated is the only assumption that the argument for harnessing its contribution to public discourse depends on. Open-minded public engagement with scientific information requires a deliberation environment in which no group of citizens is forced to see dissent to sound evidence as hostile to its defining commitments. In cultivating such an environment for deliberations over the problem of climate change, the diverse cultural resonances associated with the *full range* of potential responses is a resource to be exploited in science communication.

### *Cultural cognition and meaningful science communication*

According to the cultural cognition thesis, group values pervade the psychological mechanisms by which individuals form perceptions of risk. Individuals behave not like rational- or irrational-weighers but like cultural evaluators, adopting toward risks stances that affirm their commitment to their preferred view of how society should be organized (Jenkins-Smith & Herron 2009; Kahan 2013). The experimental results we've reported in this paper support this understanding.

But more so than previous studies of cultural cognition, this one demonstrates how a deeper understanding of this dynamic can be used to *improve* science communication. Whereas most such studies have furnished evidence of how identity-threatening meanings can provoke resistance to sound science (e.g., Kahan 2013; Kahan, Jenkins-Smith & Braman 2011; Jenkins-Smith 2001), this one confirms that framing climate-change science with identity-*affirming* meanings can mitigate such resistance.

Moreover, the particular framing technique featured in this study is likely only one of many that can be expected to achieve this effect (Nisbet 2009). Indeed, previous studies suggest that attention to assuring the cultural diversity of science communicators can likewise dissipate cultural polarization (Kahan, Braman, Cohen, Gastil & Slovic 2010). So, too, there is reason to believe, can communication cognizant of the heterogeneous narrative structures that citizens of diverse outlooks use to process information (Jones & McBeth 2010). Likely there are still other devices (e.g., LaMarre 2009; Cohen, Bastardi, Sherman, Hsu, McGoey & Ross 2007) that can arrest the identity-protective anxiety that makes cultural cognition a barrier to engaged and instructive deliberation over policy-relevant science.

Recognizing that there are two channels of science communication—a *meaning* channel as well as a content channel—is a one of the many insights associated with an emerging *science* of science communication. The perfection of that science is the key not just to diagnosing the pathologies that constrain science communication in democracy but to effectively treating them as well.

## **Conclusion**

Cultural commitments are intrinsic to human rationality. It is only through access to networks of trust and authority that human beings (experts as well as lay people) are able to form reliable assessments of whom to trust on what, and thus to accumulate and share collective knowledge. The distinct networks that various groups of citizens rely on usually lead them to converge on the best available information. Nevertheless, the sheer number and diversity of cultural communities that inhabit pluralistic democracies assures—almost with mathematical certainty—that risks and other policy-consequential facts will on occasion become suffused with antagonistic meanings, generating conflict that persists even in the face of ample and widely distributed scientific evidence. Although small in proportion to the number of complex scientific issues on which diverse citizens unremarkably (almost invisibly) reach agreement, these cultural meaning conflicts can pose a disproportionately large threat to the health, safety, and prosperity—and even to the deliberative capacity—of self-governing societies. Identifying how to protect the deliberation environment from this distinctive toxin, we submit, is the central mission of the science of science communication in a democratic society.

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## Supplemental Information

### 1. Information on sample

The study was administered on-line to a broadly representative sample of 1,500 U.S. adults and 1,500 English adults between July 27 and August 2, 2011. Subjects were recruited by Polimetrix/YOUGOV, Inc., a public opinion research firm that conducts on-line surveys and experiments on behalf of academic and governmental researchers and commercial customers (including political campaigns). Polimetrix used stratification methods designed to generate a sample demographically comparable to the national adult populations in the U.S. and England (Rivers 2007).

	<i>n</i>	Female	Avg. Age	White	Black	Avg. Education	Median Annual Income
US	1,500	54%	51 yrs.	71%	12%	some college	\$40,000-\$49,000
UK	1,500	52%	45 yrs.	94%	1%	GCSE/ O' levels	£25,000-£29,000

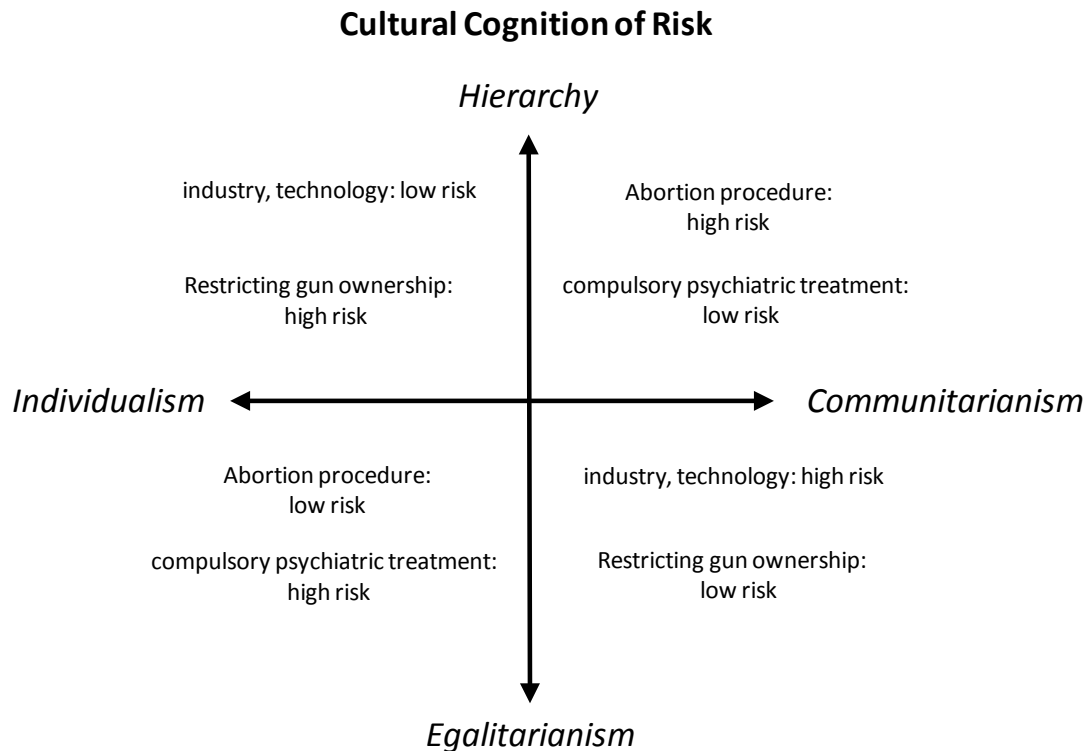
**Table SI-1. Subsample demographics.** Characteristics of study subjects selected via demographic matching.

Because the study was lengthy and cognitively demanding, completion times were checked to confirm the persistence of subjects' good-faith effort to perform the necessary reading and assessments. Sixty-nine U.S. subjects and 102 English ones who completed the study in an unrealistically short time period (less than six minutes) were removed, resulting in a final total sample of 2,829 (U.S.,  $n = 1,431$ ; England,  $n = 1,398$ ).

### 2. Cultural worldviews

Subjects' cultural values or "worldviews" were measured with items used in previous studies of cultural cognition. These items characterize worldviews along two cross-cutting dimensions: Hierarchy-Egalitarianism ("Hierarchy") and Individualism-Communitarianism ("Individualism") (Figure SI-1). The former set of items indicate attitudes toward social orderings that connect authority to stratified social roles based on highly conspicuous and largely fixed characteristics such as gender, race, and class. The latter indicate attitudes toward social orderings that reflect an expectation that individuals will secure their own well-being without assistance or interference from society versus those that assign society the obliga-

tion to secure collective welfare and the power to override competing individual interests. For all items, subjects indicated agreement or disagreement on a six-point scale (Kahan 2012).



**Figure SI-1. Cultural cognition of risk.** Using attitudinal scales, cultural cognition measures cultural worldviews, or preferences for how society and other collective undertakings should be organized, along two dimensions: “Hierarchy-Egalitarianism” and “Individualism-Communitarianism.” The theory on which it is based posits that perceptions of environmental and technological risks should be expected to diminish as worldviews become simultaneously more hierarchical and individualistic, and increase as worldviews become simultaneously more egalitarian and communitarian. Other types of risks, including ones relating to public health and social deviance, can be expected to vary more dramatically as worldviews become progressively more hierarchical and communitarian or progressively more egalitarian and individualistic. Survey and experimental studies have found support for these predictions (Wil-davsky & Dake 1990; Jenkins-Smith 2001; Kahan, Braman, Monahan, Callahan & Peters 2010; Kahan, Braman, Slovic, Gastil & Cohen 2009; Kahan, Braman, Gastil, Slovic & Mertz 2007).

For this study, we used short-form versions of Hierarchy and Individualism, each of which consisted of six items (Table SI-2). Minor variations were made in wording for certain items administered to the English subsample in order to assure conformity to English usage. In factor analyses performed separately on each subsample, the worldview items loaded appropriately on two discrete factors corresponding to Hierarchy and Individualism; in addition, the two six-item sets, which formed reliable scales in each subsample considered separately (U.S.: Hierarchy,  $\alpha = 0.88$ ; Individualism,  $\alpha = 0.84$ ; England, Hierarchy,  $\alpha = 0.76$ ; Individualism,  $\alpha = 0.73$ ), remained reliable when the two subsamples were combined (Hierar-

chy,  $\alpha = 0.84$ ; Individualism,  $\alpha = 0.80$ ). This comparability in the covariance structures of the scales for the two national subsamples implies their equivalence as measures of variance in the specified dispositions across the sample as a whole (Tran 2009).

The factor scores generated separately within each subsample were retained in the aggregated data. This form of standardization assures that nation-specific differences in response-style do not alter the covariance between the worldview measures, on the one hand, and the study outcome measures, on the other, when the subsamples are merged into one sample for analysis (Fischer 2004).

<b>Individualism-Communitarianism (Individualism)</b>	
IINTRSTS.	The government interferes far too much in our everyday lives.
CHARM.	Sometimes government needs to make laws that keep people from hurting themselves.
IPROTECT.	It's not the government's business to try to protect people from themselves.
IPRIVACY.	The government should stop telling people how to live their lives.
CPROTECT.	The government should do more to advance society's goals, even if that means limiting the freedom and choices of individuals.
CLIMCHOI.	Government should put limits on the choices individuals can make so they don't [get in the way of/interfere with] what's good for society.
<b>Hierarchy-Egalitarianism (Hierarchy)</b>	
HEQUAL.	We have gone too far in pushing equal rights in this country.
EWEALTH.	Our society would be better off if the distribution of wealth was more equal.
ERADEQ.	We need to dramatically reduce inequalities between the rich and the poor, whites and [people of color/ethnic minorities], and men and women.
EDISCRIM.	Discrimination against minorities is still a very serious problem in our society.
HREVDIS2.	It seems like [blacks/ethnic minorities], women, homosexuals and other groups don't want equal rights, they want special rights just for them.
HFEMININ.	Society as a whole has become too soft and feminine.

**Table SI-2 Cultural worldview items.** Bracketed material indicates wordings that were varied for the national subsamples. In each bracket, the wording before the slash (“/”) was included in the version of the item administered to the U.S. subjects, and the wording after in the version administered to English subjects.

### 3. Study instrument

*a. Stimulus materials.* The experimental stimulus used for the study consisted of two components. The first was a set of fictional newspaper articles: one, supplied to subjects in the “control” condition, which described a municipalities adoption of a provision requiring developers to post a “surety bond” to cover the installation of new traffic signals (Figure SI-2); another, supplied to subjects in the “anti-pollution” condition, which described a call by the “American Academy of Geophysical Scientists” for “even stricter” CO<sub>2</sub> emission controls “than ones proposed by the United Nations” (Figure SI-3); and a third, supplied to subjects in the “geoengineering” condition, which described a call by the same (fictional) group of scientists for increased research into “new technologies aimed at counteracting the effects of climate change” as opposed to stricter controls on CO<sub>2</sub> emissions (Figure SI-4).

The second component of the stimulus was a document represented to be an excerpt from an article entitled “Irreversible climate change due to CO<sub>2</sub> emissions,” and published in the journal “*Nature Science*” (Figure SI-1). The document, which described findings that suggested a dissipation rate for atmospheric CO<sub>2</sub> slower than the one that had been estimated in previous studies, was in fact a composite of material appearing in two scientific journals (Allen, Frame, Huntingford, Jones, Lowe, Meinshausen & Meinshausen 2009; Solomon, Plattner, Knutti & Friedlingstein 2009).

Subjects read the newspaper story associated with their respective experimental conditions before reading the *Nature Science* article. In the anti-pollution and geoengineering condition newspaper stories, members of the American Academy of Geophysical Scientists were described as basing their respective proposals on their assessment of the *Nature Science* study. However, the *Nature Science* article itself did not propose or refer to any policy solutions, and both the anti-pollution condition and geoengineering condition newspaper stories explicitly stated that the *Nature Science* “study was done by researchers from the Massachusetts Institute of Technology who were unaffiliated with AAGS.”

## Traffic Signal Funds Required Developers Must Put up Surety Bond

by Jeffrey Cohen

Broomfield County Star June 15, 2011

A new Broomfield County policy will ensure that the next time a community needs a new traffic light to handle traffic associated with a commercial development, it will have the funds necessary to pay for it.

Developers who want to begin work on a new subdivision will be required to put up a surety bond, probably as much as \$300,000, said Dorothy Doyle, the county's traffic division director. Traffic signals range in price from \$60,000 for those strung on wires to \$300,000 for a sturdier mast arm signal.

The impetus for the requirement comes from six recent cases in which traffic signals ended up being needed at communities where the developer had finished building, or in which the county had not initially heard concerns about a light, Doyle said.

The county will be able to hold the surety well after the subdivision is built, Doyle said, adding that the developer will be required to notify the county as it nears

completion.

"We've always required developers to defray costs associated with the impact of their projects on local traffic, so this is nothing out of the ordinary," Doyle said.

Kevin Bain, President of GL Homes, Inc., the largest developer in the county, said many of his company's developments qualify for a signal anyway, adding that it's an appropriate issue for the county to address.

"It's a safety issue for our residents," Bain said. "We don't have an issue whatsoever with posting the surety."

Harry Halman, chairman of the Broomfield Chamber of Commerce, said the new surety policy makes sense.

"I think that the new requirements of anticipating the need for a traffic light are very valid, because inadequate traffic control is likely to discourage shopping downtown," said Halman.



**Traffic signal bond policy adopted.** Kevin Bain, President of GL Homes, Inc., (left) makes statement at Broomfield County Safety Commission meeting on surety bond proposal. The Commission approved a policy that would require developers to post a bond to cover the cost of installing traffic lights (right) at development sites after construction is concluded. (Credit: Harry Stevens.)

**Figure SI-2. Control condition newspaper story.**

# Scientists: Even Stricter Anti-Pollution Regulations Needed to Fight Climate Change

## New study finds proposed CO<sub>2</sub>-emission targets will be ineffective

by Andrew Taylor

April 21, 2011

WASHINGTON, D.C. Staving off the catastrophic effects of global warming will require industrialized countries to enact anti-pollution limits even stricter than ones proposed by the United Nations, a group of expert scientists announced today.

The group, the American Academy of Geophysical Scientists, based this conclusion on a new study finding the environmental impact of human carbon dioxide (CO<sub>2</sub>) emissions is likely to be significantly more severe than previously estimated.

The study was done by researchers from the Massachusetts Institute of Technology who were unaffiliated with AAGS and who published their findings earlier this year in the journal *Nature Science*.

"Before this study," said AAGS spokesman Dr. Alan M. Williams of Harvard University, "the scientific community assumed it would be enough to gradually slow down and then stabilize CO<sub>2</sub> emissions at 450-600 parts per million," a target approved by the United Nations in 2006. "But the data and computer simulations published by this research team in *Nature Science* show that this strategy will be completely ineffective," Dr. Williams said.

"Even if we somehow stopped emitting CO<sub>2</sub> into the atmosphere today," Dr. Williams told reporters, "the *Nature Science* study shows there would be irreversible and devastating effects to the earth's climate."

The AAGS report states that the *Nature Science* study "supports only one conclusion: cutbacks on carbon emissions will have to be much more drastic than anyone previously believed." As a result, "it will be necessary for industrialized societies to enact much more drastic anti-pollution controls," the AAGS report concludes.

"World governments have a wide range of pollution-cutting tools at their command — 'cap and trade,' fuel taxes, restrictions on the production and use of electricity, subsidies for solar power," said Dr. Williams. "It's time to use them," he said.

Industrialized nations such as the United States and Great Britain have so far balked at adopting policies deemed essential to meeting the U.N.'s 450-600 ppm target because of concerns over the burdens such measures would inflict on businesses and consumers. The even lower CO<sub>2</sub> ceiling by the AAGS — 175 ppm — would impose even larger costs, the report acknowledged.

"Yes, we will all need to make sacrifices," stated Williams in a press conference announcing the AAGS report. "It's precisely because the residents of industrialized countries have for decades insisted on a standard of living that exceeds the capacities of the natural environment that we are in this mess," Williams told an assembly of reporters in Washington, D.C.



**CO<sub>2</sub> emissions and climate change.** Recent study suggests that CO<sub>2</sub> emissions from power plants and other sources will cause "irreversible" damage to the environment even at levels proposed by the U.N. On this basis, AAGS has called for even stricter anti-pollution regulations. (Credit: AAGS Report, "Climate Change: The Urgent Need to Cut Back.")

Figure SI-3. Anti-pollution condition newspaper story.



# Scientists: More Technology, Not More Limits, Needed to Fight Climate Change

## New study finds proposed CO<sub>2</sub>-emission limits will be ineffective

by Andrew Taylor

April 21, 2011

WASHINGTON, D.C. Staving off the catastrophic effects of global warming will require industrialized countries to shift emphasis from anti-pollution regulations to new technologies aimed at counteracting the effects of climate change, a group of expert scientists announced today.

The group, the American Academy of Geophysical Scientists, based this conclusion on a new study finding the environmental impact of human carbon dioxide (CO<sub>2</sub>) emissions is likely to be significantly more severe than previously estimated.

The study was done by researchers from the Massachusetts Institute of Technology who were unaffiliated with AAGS and who published their findings earlier this year in the journal *Nature Science*.

"Before this study," said AAGS spokesman Dr. Alan M. Williams of Harvard University, "the scientific community assumed it would be enough to gradually slow down and then stabilize CO<sub>2</sub> emissions at 450-600 parts per million," a target approved by the United Nations in 2006. "But the data and computer models published by this research team in *Nature Science* show that this strategy will be completely ineffective," Dr. Williams said.

"Even if we somehow stopped emitting CO<sub>2</sub> into the atmosphere today," Dr. Williams told reporters, "the *Nature Science* study shows there would be irreversible

and devastating effects to the earth's climate."

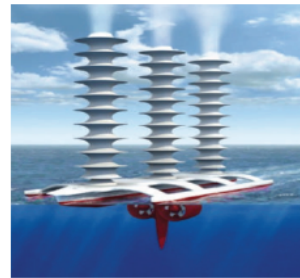
The AAGS report states that the *Nature Science* study "supports only one conclusion: limiting emissions is a wasteful and futile strategy." Instead the report urges removal of restrictions on research into technologies for controlled climate cooling.

"There are scores of such technologies on drawing boards around the globe," said Dr. Alan Williams. "Land-based filters could remove excess CO<sub>2</sub> from the air; high-altitude reflectors could be turned on and off to reduce solar heating; organic materials could be added to the ocean to speed up natural CO<sub>2</sub> absorption."

Developing these so-called "geoengineering" technologies, the AAGS report concludes, would not only be more effective than enactment of emission restrictions, but also spare consumers and businesses from the heavy economic costs associated with the regulations necessary to reduce atmospheric CO<sub>2</sub> concentrations to 450 ppm or lower.

"Human beings have faced challenges from nature throughout history," Williams told reporters at a press conference. "We've never succumbed to those challenges – we've always overcome them with ingenuity."

"Consider today's high-yield agricultural techniques, the miracles of modern medicine, and the breathtaking feats of urban engineering," Williams stated. "Well, it's time for us to innovate our way out of another jam."



**Geoengineering response to climate change.** AAGS report proposes "geoengineering" after study finds that without "measures to remove gases already in the atmosphere or induce atmospheric cooling, existing CO<sub>2</sub> concentrations will cause irreversible environmental damage." Filters (left) could be placed in wilderness areas and that would soak up billions of tons of CO<sub>2</sub> from the atmosphere. Turbine-fitted vessels (right) could spray a mist to whiten clouds and make them more reflective of incoming sun light. (Credit: AAGS Report, "Beating Climate Change: Creating New Technologies, Not Restricting Old Ones.")

Figure SI-4. Geoengineering condition newspaper story.



Excerpt from: “Irreversible climate change due to CO<sub>2</sub> emissions,” *Nature Science*, Vol. 73, pp. 516-32 (2011):

Even if we could halt human carbon emissions today, the world would face risks of climate change for well over 1,000 years. The impact of CO<sub>2</sub> carbon emissions persists longer than that of nuclear waste, the archetypically long-lived waste product. However, an immediate emissions halt is essentially impossible. Moreover, simple projections suggest that even with strenuous efforts to limit emissions, atmospheric CO<sub>2</sub> concentrations will rise beyond 450 ppm, the level commonly thought to be the maximum safe upper limit.

If CO<sub>2</sub> is allowed to peak at 450-600 ppm, the results would include persistent decreases in dry-season rainfall comparable to the 1930s North American Dust Bowl in zones including southern Europe, northern Africa, southwestern North America, southern Africa and western Australia.

Such concentrations can also be expected to generate irreversible changes in the geography of the Earth because many coastal and island features would ultimately become submerged.

Attribution studies suggest that such a drying pattern is already occurring, particularly in the southwestern United States and Mediterranean basin. For the same reason, the physical climate changes that are due to CO<sub>2</sub> already in the atmosphere today are expected to be largely irreversible.

It is sometimes imagined that a choice can be made to quickly reduce emissions and thereby reverse any harm from climate change within a few years or decades. We have shown that this assumption is incorrect, because of the longevity of the atmospheric CO<sub>2</sub> perturbation and ocean warming. Irreversible climate changes due to CO<sub>2</sub> emissions have already taken place, and future carbon dioxide emissions would imply further irreversible effects on the planet.

Advances in modeling have led not only to improvements in complex Atmosphere–Ocean General Circulation Models (AOGCMs) for projecting 21st century climate, but also to the implementation of Earth System Models of Intermediate Complexity (EMICs) for millennial time scales. These two types of models have been used in this paper to show how peak carbon dioxide concentrations that can be expected in the 21st century are likely to lead to substantial and irreversible damage to the environment.

**Figure SI-5. “Nature Science” article.**

*b. Response measures.* After reading the *Nature Science* article, subjects responded to four items designed to measure their assessment of the soundness and credibility of the article. The first, labeled *convincing*, stated:

We would like to know what you think of the *Nature Science* study, excerpts of which you just read. In your view, how convincing was the study on a scale of 0-10 with 0 meaning “completely unconvincing” to 10 meaning “completely convincing”?

The next three directed the subjects to indicate on a six-point scale (“strongly disagree, moderately disagree, slightly disagree, slightly agree, moderately agree, [or] strongly agree”) their disagreement or agreement with a set of statements relating to the *Nature Science* study:

*Biased.* The scientists who did the study were biased.

*Computers.* Computer models like those relied on in the study are not a reliable basis for predicting the impact of CO<sub>2</sub> on the climate.

*Moredata.* More studies must be done before policymakers rely on the findings of the Nature Science study.

The four items (after reverse coding of *convincing* and *z*-score normalization of all variables) were combined into a composite Likert scale ( $\alpha = 0.84$ ), which was transformed into a *z*-score and labeled *study\_validity* (Smith 2000, p. 31).

Finally, subjects responded to a set of items designed to measure their perceptions of climate change risks. They first indicated a six-point scale (“strongly disagree, moderately disagree, slightly disagree, slightly agree, moderately agree, [or] strongly agree”) their level of disagreement or agreement with a set of factual statements relating to climate-change:

*Happening.* Average global temperatures are increasing.

*Human.* Human activity is causing global temperatures to rise.

*Effect.* Unless steps are taken to counteract global warming, there will be bad consequences for human beings.

They then responded to an item (*gwrisk*) that measured their overall assessment of the seriousness of climate change as a societal risk:

We would like to know what you think of the *Nature Science* study, excerpts of which you just read. In your view, how convincing was the study on a scale of 0-10 with 0 meaning “completely unconvincing” to 10 meaning “completely convincing”?

The four items (after *z*-score normalization of all variables) were combined into a composite Likert scale (a *z*-score transformation of the sum of the normalized responses to the items). The scale, labeled *cc\_risk*, was highly reliable ( $\alpha = 0.93$ ).

#### 4. Multivariate regression analysis

The study hypotheses were tested by ordinary-least-squares multivariate regression analyses. Two analyses were performed: one for *study\_validity*, the continuous Likert scale (centered at 0 and measured in increments of standard deviations from the mean) that measured the disposition to credit the *Nature Science* article; and another for *cc\_risk*, the continuous Likert scale (also centered at 0 and measured in increments of standard deviations from the mean), that measured the disposition to be concerned about climate-change risks.

Model predictors were selected to assess both the main effects of the experimental manipulation and the interaction of the manipulation with subject worldviews. The predictors included dummy variables for the experimental conditions (“control,” “antipol,” “geoengineering,”); a dummy variable to indicate national subsample membership (“US”: 0 = English subsample, 1 = U.S. subsample); the two continuous worldview scales (“Hierarchy,” and “Individualism”); and cross-product interaction terms to measure the effects of both the experimental manipulation conditional on subsample membership (“US x control,” “US x antipol,” “US x Geo”) and worldviews conditional on subsample membership and experimental condition (“Hier x U.S.”; “Individ x U.S.”; “Hier x control,” “Hier x antipol,” “Hier x geo,” “Individ x control,” “Individ x antipol,” “Individ x geo”; “U.S. x hier x control,” “U.S. x hier x antipol,” “U.S. x hier x geo,” “U.S. x individ x control,” “U.S. x individ x antipol,” “U.S. x individ x geo”) (Cohen, Cohen, West & Aiken 2003, pp. 555-56).

For expositional convenience, we vary the excluded or reference-group dummy variable associated with the experimental conditions (Cohen, Cohen, West & Aiken 2003, pp. 303-04). In the analysis of *study\_validity*, we exclude *antipol*, in order to highlight how being assigned either to the control or to the geoengineering condition affected subject assessments of the *Nature Science* study relative to assignment to the anti-pollution condition. In the analysis of *cc\_risk*, we exclude *control*, in order to highlight how

being assigned either to the antipollution and geoengineering conditions affected subject's climate-change risk perceptions relative to being assigned to the control condition.

We report the analysis for each outcome variable separately. Predictors are entered in sets to facilitate ease of interpretation.

### *Assessments of the validity of the Nature Science study*

Model 1 in Table SI-3 reflects the main effect of the experimental manipulation. Considered independently of subject worldviews, the impact of assignment to either the control or to the geoengineering condition rather than the anti-pollution condition was essentially nil.

Considered independently of which experimental condition subjects were assigned, the impact of subject worldviews, in contrast, was substantial. As reflected in model 2, Hierarchy ( $b = -0.44, p < 0.01$ ) and Individualism ( $b = -0.27, p < 0.01$ ) independently predicted a disposition to dismiss the *Nature Science* study. These effects signify the impact of worldviews for the sample considered as a whole.

Model 3 illustrates the interaction of the cultural worldview predictors and the experimental assignment. The coefficients for Hierarchy ( $b = 0.54, p < 0.01$ ) and Individualism ( $b = -0.32, p < 0.01$ ) (the impact of those respective predictors when both *geo* and *control*, and hence the cross-product interaction terms, are set to zero) indicate the impact of the worldviews in the anti-pollution condition; their negative signs indicate that in that condition both are associated with negative assessments of the validity of the *Nature Science* study. The coefficients for *Hier x geo* ( $b = 0.17, p < 0.01$ ) and *Individ x geo* ( $b = 0.09, p = 0.02$ ) represent the impact of the worldviews in the geoengineering condition relative to the anti-pollution condition: their positive signs indicate that the geoengineering condition both worldviews are associated with *less* dismissiveness. The coefficient for *Hier x control* ( $b = 0.11, p < 0.01$ ) is likewise positive, indicating that Hierarchy is associated with less dismissiveness toward the study in the control condition than in the anti-pollution condition as well. Individualism is also associated with less dismissiveness in the control condition but the effect is nonsignificant ( $b = 0.05, p = 0.23$ ). These effects, too, measure the impact of the predictors for the sample considered as a whole.

	<i>study_validity</i>							
	model 1		model 2		model 3		model 4	
control	-0.03	(-0.60)	-0.05	(-1.21)	-0.05	(-1.29)	-0.04	(-0.70)
geo	0.03	(0.73)	0.00	(0.10)	0.00	(0.08)	0.04	(0.83)
Hierarchy			<b>-0.44</b>	(-27.09)	<b>-0.54</b>	(-18.64)	<b>-0.22</b>	(-5.38)
Individualism			<b>-0.27</b>	(-16.83)	<b>-0.32</b>	(-11.49)	<b>-0.23</b>	(-6.13)
Hier x control					<b>0.11</b>	(2.73)	-0.01	(-0.26)
Hier x geo					<b>0.17</b>	(4.36)	<b>0.12</b>	(2.17)
Individ x control					0.05	(1.21)	0.06	(1.16)
Individ x geo					<b>0.09</b>	(2.27)	0.08	(1.51)
US							-0.05	(-0.86)
US x control							-0.03	(-0.35)
US x geo							-0.10	(-1.32)
US x hier							<b>-0.60</b>	(-10.91)
US x individ							<b>-0.18</b>	(-3.35)
US x hier x control							<b>0.19</b>	(2.46)
US x hier x geo							0.06	(0.75)
US x ind x control							-0.04	(-0.57)
US x individ x geo							0.03	(0.38)
Constant	0.00	(-0.07)	0.01	(0.48)	0.02	(0.59)	0.04	(1.09)
$R^2$	0.00		<b>0.27</b>		<b>0.28</b>		<b>0.35</b>	
$F$ -test	(2, 2826)	0.91	(4, 2824)	<b>255.54</b>	(8, 2820)	<b>132.58</b>	(17, 2811)	<b>89.57</b>
$\Delta F$ -test			(2, 2824)	<b>507.61</b>	(4, 2820)	<b>6.09</b>	(9, 2820)	<b>37.44</b>

**Table SI-3. Multivariate regression analysis for *study\_validity*.**  $N = 2829$ . The dependent variable is *study\_validity*. Regression weights are unstandardized OLS coefficients, with corresponding  $t$ -statistic indicated parenthetically. **Bold** typeface denotes that the indicated coefficient, model  $R^2$ , model  $F$ -statistic, or change in  $F$ -statistic associated with the introduction of additional predictors is statistically significant at  $p < 0.05$ . Multiple imputation was used for observations with missing data (Little & Rubin 2002).

Finally, model 4 adds the predictors necessary to compare responses of subjects in the English and U.S. subsamples. Controlling for worldview, English subjects formed essentially the same view of the validity of the study in the control ( $b = -0.04$ ,  $p = 0.48$ ) and geoengineering ( $b = 0.04$ ,  $p = 0.41$ ) conditions as they did in the anti-pollution condition; for English subjects, being assigned the geoengineering as opposed to the control condition ( $\Delta b = 0.08$ ,  $p = 0.13$ ) was associated with a small but nonsignificant disposition to credit the study. U.S. subjects in the control ( $b = -0.03$ ,  $p = 0.72$ ) and geoengineering ( $US \times geo$   $b = -0.10$ ,  $p < 0.19$ ) conditions were slightly but nonsignificantly more dismissive than U.S. subjects assigned to the anti-pollution condition, again controlling for worldview. The impact of being a U.S. as

opposed to an English subject controlling for worldview and experimental assignment was close to nil ( $\Delta EM = -0.03$ ,  $SEM = 0.03$ ,  $p = 0.39$ ).

The negative coefficients for Hierarchy ( $b = -0.22$ ,  $p < 0.01$ ) and Individualism ( $b = -0.23$ ,  $p < 0.01$ ) signify that for members of the English subsample in the anti-pollution condition both worldviews were associated with a disposition to dismiss the study. The negative (and statistically significant) coefficients associated with *US x hier* ( $b = -0.60$ ,  $p < 0.01$ ) and *US x individ* ( $b = -0.18$ ,  $p < 0.01$ ), indicate that the disposition to dismiss associated with both worldviews was even stronger for members of the U.S. subsample assigned the anti-pollution condition. The positive coefficient associated with *US x hier x control* ( $b = 0.19$ ,  $p = 0.01$ ) indicates that the tendency of Hierarchy to generate dismissiveness in the anti-pollution condition relative to the control was greater for members of the U.S. subsample than for members of the English one.

The coefficients for both *Individ x geo* ( $b = 0.08$ ,  $p = 0.13$ ) and *US x individ x geo* ( $b = 0.03$ ,  $p = 0.70$ ) were both positive but nonsignificant. Thus, Individualism did not generate an effect for either subsample that differed significantly from its effect in generating dismissiveness for the sample as a whole in the anti-pollution condition (Table SI-3, Model 3, *Individualism*:  $b = 0.09$ ,  $p < 0.01$ ).

#### *Climate change risk perceptions*

Model 1 in Table SI-4 indicates that the experimental manipulation had a mild effect independently of subjects' worldviews and subsample membership. The positive coefficient for *geo* ( $b = 0.13$ ,  $p < 0.01$ ) indicates that being assigned to the geoengineering condition as opposed the control condition increased concern. The negative effect for the constant indicates that the average level of concern in the geoengineering and anti-pollution condition exceeded the level of concern in the control.

Model 2 indicates that both worldviews were associated with less concern (*Hierarchy*:  $b = -0.53$ ,  $p < 0.01$ ; *Individ*:  $b = -0.31$ ,  $p < 0.01$ ). These effects reflect the sample-wide impact of the cultural worldview predictors controlling for experimental assignment.

	<i>cc_risk</i>							
	model 1		model 2		model 3		model 4	
antipol	0.06	(1.33)	<b>0.08</b>	(2.30)	<b>0.08</b>	(2.32)	0.08	(1.65)
geo	<b>0.13</b>	(2.79)	<b>0.12</b>	(3.19)	<b>0.12</b>	(3.21)	<b>0.16</b>	(3.38)
Hierarchy			<b>-0.53</b>	(-36.09)	<b>-0.51</b>	(-19.76)	<b>-0.31</b>	(-9.16)
Individualism			<b>-0.31</b>	(-20.88)	<b>-0.32</b>	(-12.25)	<b>-0.18</b>	(-5.28)
Hier x antipol					<b>-0.07</b>	(-2.01)	0.00	(-0.05)
Hier x geo					-0.01	(-0.30)	0.01	(0.18)
Individ x antipol					0.01	(0.24)	0.03	(0.59)
Individ x geo					0.01	(0.18)	0.02	(0.48)
US							<b>-0.18</b>	(-3.71)
US x antipol							0.02	(0.24)
US x geo							-0.10	(-1.48)
US x hier							<b>-0.41</b>	(-8.65)
US x individ							<b>-0.29</b>	(-5.94)
Hier x US x antipol							-0.09	(-1.31)
Hier x US x geo							-0.03	(-0.52)
US x individ x antipol							-0.02	(-0.31)
Individ x US x geo							0.00	(-0.04)
Constant	<b>-0.06</b>	(-1.96)	<b>-0.07</b>	(-2.64)	<b>-0.07</b>	(-2.66)	0.02	(0.65)
$R^2$	0.00		<b>0.38</b>		<b>0.38</b>		<b>0.47</b>	
$F$ -test	(2, 2826)	<b>3.89</b>	(4, 2824)	<b>436.80</b>	(8, 2820)		(17, 2811)	<b>145.15</b>
$\Delta F$ -test			(2, 2824)	<b>219.16</b>	(4, 2820)		(9, 2820)	<b>49.18</b>

**Table SI-4. Multivariate analysis for *cc\_risk*.**  $N = 2829$ . The dependent variable is *cc\_risk*. Regression weights are unstandardized OLS coefficients, with corresponding  $t$ -statistic indicated parenthetically. **Bold** typeface denotes that the indicated coefficient, model  $R^2$ , model  $F$ -statistic, or change in  $F$ -statistic associated with the introduction of additional predictors is statistically significant at  $p < 0.05$ . Multiple imputation was used for observations with missing data (Little & Rubin 2002).

Taking experimental assignment into account, Hierarchy ( $b = -0.07$ ,  $p = 0.05$ ) predicts even greater skepticism about climate change in the anti-pollution condition than in the control condition (Table SI-4, Model 3). Hierarchy predicts a slightly greater negative effect in the anti-pollution condition (relative to the control) for U.S. subjects than for English ( $US \times hier \times antipol$ :  $b = -0.09$ ,  $p = 0.19$  in Table SI-4, Model 4) but the effect is nonsignificant. There are no other meaningful or significant sample-wide interactions between the worldviews and the experimental assignments. The impact of the experimental assignments for the sample as a whole are estimated and plotted in Figure 4.

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