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The pivotal role of perceived scientific consensus in acceptance of science

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Although most experts agree that CO_2 emissions are causing anthropogenic global warming (AGW), public concern has been declining. One reason for this decline is the 'manufacture of doubt' by political and vested interests, which often challenge the existence of the scientific consensus. The role of perceived consensus in shaping public opinion is therefore of considerable interest: in particular, it is unknown whether consensus determines people's beliefs causally. It is also unclear whether perception of consensus can override people's 'worldviews', which are known to foster rejection of AGW. Study 1 shows that acceptance of several scientific propositions—from HIV/AIDS to AGW—is captured by a common factor that is correlated with another factor that captures perceived scientific consensus. Study 2 reveals a causal role of perceived consensus by showing that acceptance of AGW increases when consensus is highlighted. Consensus information also neutralizes the effect of worldview.

In light of the pervasive scientific agreement[1–3] that humanity is facing a risk from climate change, and in light of indications that climate change may be outpacing projections[4], the public's decreasing acceptance of the science in at least some countries[5,6], and people's persistent under-estimation of the scientific consensus[7,8] must give rise for concern. Public support for climate legislation has been shown to depend on people's perception of a consensus among climate scientists, with nearly 60% of the variance in policy support explained by perceived scientific consensus (through mediators involving key beliefs about AGW; ref. 7). However, several questions surrounding perceived consensus remain unanswered.

First, it is unresolved how perceived consensus interacts with people's political ideology or cultural 'worldviews', which have been identified as primary obstacles to acceptance of AGW. People who endorse unregulated free markets (that is, individualistic-hierarchical libertarians[9]) lean towards rejection of AGW (refs 10, 11). The polarization of opinions on AGW is also reflected in a partisan split between Republicans and Democrats in the level of perceived consensus in climate science[8,12] as well as other polarizing risk issues such as nuclear power[12]. On this view, a scientific consensus is like any other fact that bears on a disputed question, and it may therefore not counteract ideological polarization[12]. Those findings stand in contrast to a recent detailed analysis of Republicans' opinions on climate change, which revealed perceived consensus to be the strongest predictor of acceptance of climate science[13].

Second, it is not entirely clear whether perceived scientific consensus plays a role only in politically controversial issues, such as climate science, or whether it is more generally associated with people's acceptance of science. There are suggestions that otherwise robust aspects of decision making (for example, risk aversion) may be suspended with respect to environmental or social costs[14]. Perceived consensus may thus play a different role in AGW than in other, non-environmental scientific issues.

Finally, and most important, it is unknown whether perceived consensus contributes to acceptance of science causally, whether it is a byproduct of acceptance of science, or whether both might be caused by a third variable. Perceived consensus is known to be a powerful causal agent in shaping and changing of attitudes, especially those relating to stereotypes and discrimination. Receiving information about the predominant attitudes among one's peer group—viz. their views towards minority groups—tends to shift one's attitudes in the direction of the consensus[15–17]. The effect can be long-lasting and is detectable outside the context of the initial manipulation[16]. However, there are known limits to the effectiveness of consensus in changing attitudes. In particular, a consensus-based appeal can backfire if the consensus is thought to reflect conformity with a directive from an authority rather than reflecting popular opinion[18]. It is therefore unclear whether a declared scientific consensus might alter people's attitudes. University scientists are among the most trusted information sources[19], which suggests that consensus information might facilitate public acceptance. However, scientists are also likely considered 'authorities' rather than 'peers' by the public, which might mean that consensus-information can backfire when interpreted as a directive[18].

Study 1 examined whether scientific consensus generally plays a role in acceptance of a diverse set of scientific facts. Study 2 examined whether highlighting the consensus explicitly can boost participant's acceptance of AGW in comparison to a control group in which no consensus information is presented. Study 2 also examined the interaction between people's worldview and the provision of consensus information. Both studies used a convenience sample of pedestrians; see Supplementary Information for more detail.

Perceived consensus and acceptance of science

People expressed their own belief in several scientific propositions and also estimated the prevalence of that view among scientists. People greatly underestimated the scientific consensus surrounding AGW (70% perceived versus 97% actual; see Table 2), although only 19 individuals disagreed with the AGW proposition, with a further 42 undecided and the majority ($N = 139$) accepting AGW. There were 6 and 3 participants, respectively, who disputed the link between HIV and AIDS, and between smoking and lung cancer.

The relationship between perceived consensus and acceptance of science was examined via latent variable modelling (LVM; also

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Table 1 | Questionnaire items used in Study 1 and Study 2 (indicated by '1' and '2' in the leftmost columns).

		(a) and (b) Scientific propositions and perceived consensus*	Reference group
1	2	Human CO_2 emissions cause climate change	Climate scientists
1	2	Smoking causes lung cancer	Medical scientists
1	2	HIV virus causes AIDS	Medical scientists
1		Obesity (excessive body weight) poses a serious health risk	Medical scientists
1		Lead in drinking water poses a serious long-term health risk	Environmental scientists
		(c) General climate trends†	
	2	Increase in atmospheric temperature observed during the past 130 years	
	2	Increase of global sea level during the past several decades	
	2	The number of weather-related natural disasters has more than doubled in the past 30 years	
		(d) Specific extreme-weather events†	
	2	The floods in Queensland last year (2010)	
	2	The floods in Pakistan last year (2010)	
	2	The Russian wild fires last year (2010)	
	2	The European heat wave in 2003 that killed 15,000 people in France alone	

*Participants' own beliefs were elicited with items of the form 'The HIV virus causes AIDS', with a 5-point scale ranging from 'Strongly disagree' (1) to 'Strongly agree' (5), with 3 representing 'Neutral' (Study 1). Consensus judgments were elicited by combining propositions and reference groups into items such as: 'Out of 100 medical scientists how many do you think believe that the HIV virus causes AIDS?' †Causal attribution to AGW in percentage terms.

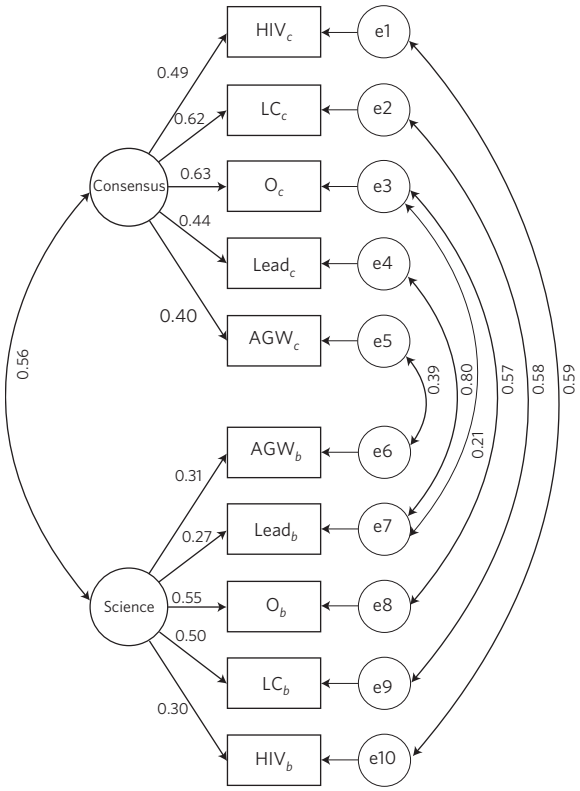

Figure 1 | Final latent variable Model 3 in Study 1 for item types (a) and (b) from Table 1. Labels for manifest variables are given in Table 2, with subscript *b* referring to acceptance of science and subscript *c* to perceived consensus, respectively. All correlations and loadings are significant. See Supplementary Information for details of model fitting.

known as structural equation modelling) of the 10 items in Table 2. LVM is essential in this case because it can estimate both general and unique effects simultaneously[20]. The Supplementary Information reports full correlation matrices.

We tested three competing models: a unique effects model containing only pairwise correlations between the respective consensus and belief items (Model 1); a correlated common factors model, in which the consensus items loaded onto a common factor (Consensus) and the belief items loaded onto another common factor (Science) (Model 2); and, finally, a combined unique effects and correlated common-factors model (Model 3).

We expected Model 3 to fit best, as it reflected the theoretical expectation that the indicators would share variance in such a way as to form factors, as well as the shared variance unique to each scientific issue. We furthermore expected the two factors to be positively correlated.

Not unexpectedly, the unique effects model (Model 1) fits poorly, $\chi^2(41) = 49.52, p < 0.001$, CFI = 0.709, RMSEA = 0.150 (90% CI: 0.131–0.170), AIC = 268.65, which suggested that modelling only the pairwise correlations between the corresponding perceived consensus and acceptance of science indicators was insufficient. The correlated common factors model (Model 2) also failed to fit well, $\chi^2(34) = 410.87$, $p < 0.001$, CFI = 0.386, RMSEA = 0.236 (90% CI: 0.216–0.257), AIC = 472.87. Finally, Model 3, which combined common factors with unique effects, yielded approximately satisfactory levels of model fit, $\chi(29) = 69.84$, $p < 0.001$, CFI = 0.933, RMSEA = 0.084 (90% CI: 0.059–0.110), AIC = 141.84. The difference in AIC values between Model 3 and the next best fitting model (Model 2) was 126.81, which is considered a substantial improvement[21]. Modification indices suggested that a further improvement in fit could be achieved with the addition of a covariance term between the error terms for obesity-consensus (O_c) and lead-acceptance ($Lead_b$). This slightly modified final Model 3 fits very well, $\chi^2(28) = 51.20$, $p = 0.005$, CFI = 0.962, RMSEA = 0.065 (90% CI: 0.035–0.092), AIC = 125.20 and is shown in Fig. 1.

All of the loadings across both latent variables were positive and statistically significant. Although the AGW_c factor loading (0.40) on the Consensus factor was numerically the smallest, constraining all five of the Consensus loadings to equality did not reduce the fit, $\chi^2(4) = 1.98$, $p > 0.10$. Likewise, constraining all five of the Science loadings to equality did not impair the fit, $\chi^2(4) = 1.47$, $p > 0.10$. Thus, there was no statistical evidence to suggest that the latent variables were defined differentially by the indicators, implying that rather than being a unique and polarizing issue, AGW is perceived, in part, according to much the same regularities as any other science.

Table 2 | Mean responses (standard errors) in Study 1.

Scientific propositions (short label)*	Perceived consensus	Belief
Human CO_2 emissions cause climate change (AGW_b)	69.68 (1.57)	3.82 (0.070)
Smoking causes lung cancer (LC_b)	88.24 (1.24)	4.42 (0.048)
HIV virus causes AIDS (HIV_b)	81.85 (1.77)	4.26 (0.057)
Obesity (excessive body weight) poses a serious health risk (O_b)	88.95 (1.20)	4.49 (0.044)
Lead in drinking water poses a serious long-term health risk ($Lead_b$)	74.80 (1.93)	3.94 (0.072)

*See Table 1 for full explanation of items. Short labels are used in Fig. 1.

The correlation between the Consensus and Science latent variables was estimated at $r = 0.56$, $Z = 6.69$, $p < 0.0001$, which implies that higher levels of perceived scientific consensus across various scientific propositions was associated with greater acceptance of those scientific propositions. In addition to the common latent variables, there were non-negligible unique effects across all five pairs of indicators (for example, AGW_b correlated with AGW_c; $r = 0.39$, $p < 0.05$). Thus, the variance shared by the scientific propositions was due to two common latent variables as well as effects that were unique to each topic.

Study 1 confirmed that perceived consensus is related to acceptance of scientific facts and showed that AGW was not unique but, instead, was considered much like other scientific issue. Study 2 examined whether the role of perceived consensus is causal by providing consensus information about AGW before evaluating people's acceptance of scientific propositions. Additionally, we examined the role of individual differences in participants' worldviews.

Raising acceptance by highlighting consensus

Participants were randomly assigned to a control condition in which no consensus information was provided, or to a consensus condition in which the consensus among climate scientists (97% agreement[2]) was highlighted using a graph and accompanying text. Participants then (a) responded to scientific propositions as in Study 1 (Table 1); (b) judged the causal contribution from human CO_2 emissions to climatic trends and specific extreme weather events (Table 3); and expressed their attitudes about the free market as a measure of worldview[10].

Control participants again greatly underestimated the AGW consensus (67%; see Table 3). This discrepancy was reduced considerably in the consensus condition (88%; $F(1, 88) = 19.12$, $p < 0.0001$, MSE = 527.2, $\eta_p^2 = 0.18$), although perceived consensus still fell 10% short of the information provided minutes earlier. The study also replicated the factors structure observed in Study 1; see Supplementary Information for LVM.

Table 3 shows that people were generally more prepared to attribute long-term global trends to human causes than specific events, mirroring the similarly graded confidence of attribution within the literature.

The consensus manipulation was tested by a one-way, between-groups multivariate analysis of variance (MANOVA) that considered responses to the AGW_b item together with responses to the causal-attribution items for general trends (Items 2–5 in Table 3). To examine whether assumptions for MANOVA were met, the natural logarithms of the group determinants were compared, which were estimated at 16.44 and 15.64 for the consensus and control groups, respectively. This confirmed that group variances and covariances were roughly equal (within 5% of each other).

The MANOVA tested the hypothesis that group centroid means would not be equal between conditions, which was supported by Pillais' Trace = 0.11, $F(4, 84) = 2.63$, $p < 0.05$. Using the raw canonical variate coefficients, the centroid means and standard deviations for the consensus and control groups were estimated at $M = 4.62$ (s.d. = 0.83) and $M = 3.92$ (s.d. = 1.14), respectively, which corresponds to a Cohen's $d = 0.71$. This effect size is considered (nearly) large[22].

Table 3 | Mean responses (standard errors) across conditions in Study 2.

Item	Condition	
	Control	Consensus
(a) Acceptance of scientific propositions*		
CO_2 emissions cause climate change	3.96 (0.081)	4.35 (0.146)
Smoking causes lung cancer	4.63 (0.069)	4.72 (0.109)
HIV virus causes AIDS	4.24 (0.106)	4.61 (0.146)
(b) Perceived consensus among scientists		
Emissions and climate change	67.28 (3.11)	88.47 (3.66)
Smoking and lung cancer	91.81 (1.90)	92.79 (2.62)
HIV and AIDS	84.83 (2.79)	91.21 (3.16)
(c) General climate trends†		
Increase in atmospheric temperature	60.53 (2.42)	71.86 (3.05)
Increase of global sea level	61.52 (2.94)	66.28 (3.15)
Doubling of weather-related natural disasters	53.26 (3.38)	57.56 (3.52)
(d) Specific extreme-weather events†		
The floods in Queensland	42.17 (3.48)	47.14 (4.57)
The floods in Pakistan	43.80 (3.41)	48.21 (4.59)
The Russian wild fires	45.00 (4.15)	47.98 (4.45)
The European heat wave	53.26 (3.61)	57.44 (4.27)

*5-point scale ranging from 'Absolutely False' (1) to 'Absolutely True' (5), with 3 representing 'Unsure'. †For these items participants placed a tick mark along a horizontal line with endpoints 0% and 100% to express the 'contribution from human CO_2 emissions to cause each event'.

The MANOVA-derived canonical variate can be interpreted by considering its correlation with each dependent variable. The largest correlations were $r = 0.83$ and $r = 0.70$ for increase in atmospheric temperature and AGW_b, respectively. The correlations involving global sea level, $r = 0.33$, and doubling of natural disasters, $r = 0.27$, were comparatively lower. Thus, the differences between the two groups primarily reflected the temperature and acceptance items.

Finally, we examined the role of worldview on acceptance of AGW (that is, AGW_b) using the summed responses to the five free-market items (reported in Supplementary Information; Cronbach's $\alpha = 0.68$). Items were reverse-scored where necessary, and missing values ($N = 5$; 1.1%) were estimated using the expectation maximization procedure. AGW_b scores were first regressed onto the free-market scores and the experimental condition variable (coded as control = 0; consensus = 1), which yielded a multiple $R^2 = 0.138$. The centred free-market and condition product term was then added to the model, which yielded $R^2 = 0.188$. The increase in R^2 (0.051) was statistically significant, $F(1, 85) = 5.30$, $p < 0.05$,

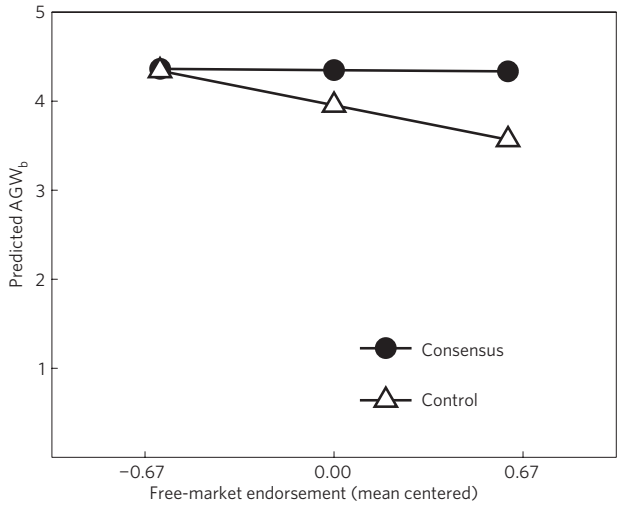

Figure 2 | The interaction effect of experimental conditions on the association between mean-centred free-market endorsement and acceptance of AGW in Study 2 (AGW$_b$ predicted from the regression model). See text for details.

revealing that the role of free-market ideology in acceptance of AGW$_b$ interacted with condition. The unstandardized regression weights were: free market, $\beta = -0.34$ ($p = 0.016$); experimental condition, $\beta = 0.39$ ($p = 0.016$); interaction of condition and free market, $\beta = 0.61$ ($p = 0.027$).

The interaction is visualized in Fig. 2, which shows predicted AGW$_b$ scores for the two conditions as a function of the centred free-market scores specified at three points; viz. low (one s.d. below the mean), medium (mean), and high (one s.d. above the mean)[23]. The figure clarifies that the association between free-market endorsement and AGW$_b$ was effectively non-existent in the consensus condition, $\beta = -0.02$, $p > 0.10$. By contrast, there was a clear negative effect in the control condition, $\beta = -0.63$, $p = 0.003$, such that a one unit increase in free-market endorsement was associated with a 0.63 unit decrease in acceptance of AGW. The latter effect replicates much previous work on the importance of worldview in the rejection of climate science[9,10], whereas the former represents the novel finding that the role of ideology was drastically attenuated when participants were provided with information about the scientific consensus.

A parallel analysis using perceived consensus (AGW$_c$) found significant effects of condition and free market, but no interaction between the two: free market, $\beta = -12.51$ ($p = 0.0006$); experimental condition, $\beta = 21.14$ ($p < 0.0001$); interaction of condition and free market, $\beta = -4.96$ ($t = -0.65$; $p > 0.10$). This analysis confirms that the consensus manipulation was equally effective across all levels of free-market endorsement.

Discussion

The studies answer the questions posed at the outset: Is perceived scientific consensus associated with acceptance of science? Do the processes governing acceptance of AGW differ from those underlying other scientific issues? Does highlighting a scientific consensus increase acceptance? What is the impact of worldview or ideology on processing of consensus information?

The LVM in Fig. 1 answers the first two questions: Acceptance of all scientific propositions was, in part, captured by a single common factor, which was in turn correlated with another factor that captured the perceived consensus among scientists themselves. This illustrates the—hitherto imperfectly understood—association between perceived scientific consensus and people's attitudes. There are two reasons to suggest that people's knowledge and acceptance of science represents at least in part a unitary construct. First, the pairwise correlations between consensus-belief dyads were insufficient to capture the relationship among the manifest variables, and two correlated factors were required to account for people's belief structure (viz., superior fit of Model 3 over Model 1). Second, all propositions, ranging from AGW to medical facts with varying strengths of association between the proposed cause and the outcome (for example, HIV–AIDS versus obesity–ill health), could be constrained to load equally onto their corresponding factor without loss of fit in both studies. The general factor structure seems quite general as it has also recently been obtained with a sample of visitors to climate blogs[24].

The fact that climate science is not unique is particularly notable in light of the divisive nature of the public discussion surrounding climate change, which at first glance suggests it might differ from other scientific issues such as the link between lung cancer and smoking. However, HIV-AIDS, like climate change, has its own history of denial[25,26], and the perception of a debate among scientists about HIV is a known contributor to AIDS denial[27].

The shared importance of consensus across multiple scientific issues is also consonant with previous findings that people's perception of risks relating to issues as diverse as nanotechnology[28] and HPV vaccinations[29] are often uniformly governed by their worldviews—and people's worldview, or personal 'ideology', is also a prime candidate for a variable that can explain the remaining true-score variance that is unaccounted for by perceived consensus. In support, we replicated the known effect of worldview in Study 2 in the condition in which people were not given information about the scientific consensus.

Turning to our manipulation in Study 2, highlighting the consensus within the relevant scientific community increased people's acceptance of science: People were more willing to attribute long-term climatic trends to human causes when they had been informed of the scientific AGW consensus, and they were more likely to accept as true the statement that human CO_2 emissions cause climate change. Notably this manipulation attenuated the effect of free-market worldview on acceptance of AGW, because its role—which was strongly negative in the control condition—was eliminated on provision of the consensus information. This meshes well with previous research which likewise found that even among Republicans, perceived scientific consensus was by far the strongest predictor (from among a set of 24 variables) of acceptance of climate change[13]. At first glance, our results challenge the results of Kahan and colleagues, that perceived consensus operates like any other fact that is equally subject to dismissal as other evidence surrounding AGW (ref. 12). However, on closer inspection, the study by Kahan did not provide socially-normative information about a consensus (that is, '97 out of 100') but instead presented participants with an informational vignette, attributed to a fictional expert, that either described the risk from climate change or downplayed it. Because this manipulation provided anecdotal rather than social-norming information, it is not surprising that participants rated the source as less trustworthy if the message was worldview dissonant. Normative information, by contrast, is widely assumed to be more resilient to ideologically-motivated dismissal[30,31], a fact confirmed by the present studies and related results[13]. Techniques for the delivery of normative information to the public have been developed in the context of AIDS-education. Delivery of peer-normative information has been shown to reduce the incidence of high-risk sexual behaviour[32,33].

Critics might argue that the results of Study 2 reflect demand characteristics, with people simply satisfying the experimenter's expectations after being told about the consensus. We find this unlikely, given that people did not adjust their causal attributions for specific extreme-weather events, despite the same demand characteristics being present. Moreover, we conducted

a companion study ($N = 297$) which also used a consensus manipulation and asked people to express their agreement with 4 items pertaining to AGW. Unlike in Study 2, people in the companion study first stated how they would have responded before reading the consensus information. Such retrospective judgments circumvent demand characteristics and can reveal hidden attitude changes[34,35]. A factor-means comparison of those retrospective judgments found a significant effect of the consensus manipulation, $\Delta\chi^2(1) = 4.453, p < 0.05$, suggesting that the effect persisted even when people were explicitly instructed to ignore the information they had just received.

We therefore propose that the effect of our manipulation in Study 2 underscores the vital role of highlighting a scientific consensus when communicating scientific facts. Appealing to a consensus is known to be particularly effective in situations in which social norms are ambiguous[17]. It follows that people may be particularly susceptible to perceived consensus among domain experts when forming their own beliefs about scientific issues that—like climate change—are difficult to grasp or are hotly debated or challenge people's world views[9,28].

Methods

Study 1

Participants. Pedestrians ($N = 200$; mean age 37.8; $s = 19$; range 13–87) were approached during business hours in downtown Perth, Western Australia, in February 2010 and voluntarily completed the five minute task without remuneration. Maximum daily temperatures during testing ranged from 24.6 to 34.3 °C ($M = 31.5$), nearly coinciding with the long-term average for February (31.8 °C).

Procedure and materials. Participants first performed a brief graphical extrapolation task (reported in ref. 36) before completing a questionnaire (two orders of items, $N = 100$ each) that queried (a) the perceived consensus among scientists on five scientific propositions (see Table 1 for details) and (b) participants' own belief in those propositions.

Both studies reported in this article were approved by the University of Western Australia's Human Research Ethics Committee. Completion of the questionnaires after viewing an information sheet that explained the study was taken to constitute informed consent.

Study 2

Participants. There were 100 participants (mean age 30.03; $s = 15$; range 15–75; 53 female and 42 male, 6 gender unspecified), who were tested in December 2011 in the same manner as in Study 1 (maximum temperature was 29.60 °C; long-term average 29.31 °C). There were 51 participants in the consensus group and 49 in the control group (no consensus information provided).

Procedure and materials. After providing an initial estimate of how many climate scientists out of 100 would support the basic principles of AGW, participants in the control condition were shown a neutral statement about climate change. Participants in the consensus condition were instead informed, via a text passage and a graphic, that 97 out of 100 climate experts agree that global warming is a consequence of the burning of fossil fuels. This information was immediately followed by recall of the consensus information to verify comprehension. This manipulation check was failed by eight participants, who were eliminated from analysis. (A further two participants responded only to the first one or four items, respectively, and thus also had to be removed. Analysis was thus based on 47 and 43 participants in the control and consensus condition, respectively.)

Participants in both conditions then judged the presumed causal contribution from human CO_2 emissions to three global climate trends (item (c) in Table 1) and the presumed causal contribution to four specific extreme-weather events (item (d) in Table 1). Two of the extreme events have been explicitly linked to AGW in the literature; viz. the European heat wave of 2003 (ref. 37) and the Russian heat extremes of 2010 (ref. 38). The two flood events, by contrast, have so far not been attributed to human emissions. Participants also responded to a subset of the items used in Study 1 (types (a) and (b) in Table 1) before completing a 5-point scale that queried their attitudes towards the free market[10].

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Author contributions

S.L. designed and supervised the studies and wrote the paper. G.E.G. and S.L. jointly conducted the analyses and G.E.G. contributed to writing of the article, and S.V. was involved in design and execution of Study 2.

Additional information

Supplementary information is available in the online version of the paper. Reprints and permissions information is available online at www.nature.com/reprints. Correspondence and requests for materials should be addressed to S.L.

Competing financial interests

The authors declare no competing financial interests.

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