nature climate change

Article

https://doi.org/10.1038/s41558-023-01679-4

Participating in a climate prediction market increases concern about global warming

Received: 8 September 2020

Accepted: 21 April 2023

Published online: 8 June 2023

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Modifying attitudes and behaviours related to climate change is difficult. Attempts to offer information, appeal to values and norms or enact policies have shown limited success. Here we examine whether participation in a climate prediction market can shift attitudes by having the market act as a non-partisan adjudicator and by prompting participants to put their 'money where their mouth is'. Across two field studies, we show that betting on climate events alters: (1) participants' concern about climate change, (2) support for remedial climate action and (3) knowledge about climate issues. While the effects were dependent on participants' betting performance in Study 1, they were independent of betting outcomes in Study 2. Overall, our findings suggest that climate prediction markets could offer a promising path to changing people's climate-related attitudes and behaviour.

The combined forces of social media and rise of populism have amplified the politicization of knowledge. What is considered true often depends on group membership rather than scientific evidence and facts[1–6]. This politicization is seen in numerous topics, including climate change. Overwhelming scientific evidence suggests that climate change is occurring[7], is caused by human activity[8] and is likely to result in dire consequences[9,10]. Nonetheless, actions of governments around the world lag behind what climate scientists say is needed. In some cases, this inaction is related to a lack of concern about climate change. For example, in the United States, surveys show that over a third of the population believes that the seriousness of global warming is exaggerated[11], and more than half the population disagrees with the claim that climate change is caused by humans[12].

Raising concern about climate change and support for remedial action at the individual and collective level is challenging for numerous reasons. First, it is difficult to attribute a specific climate-related incident to a single cause. Second, remedial actions taken by one individual or collective often do not yield visible outcomes. Third, the cost of action is immediate whereas the benefits are distributed over long time horizons[13]. Specifically, while climate change will adversely impact future generations, for most people there is no immediate cost to rejecting its occurrence on ideological grounds[14]. Compounded by the brain's challenges in thinking about temporally or spatially distant events[15–17], these factors make it difficult to change sceptics' views on the topic and garner support for corrective action.

However, acknowledging the role of erroneous beliefs that have no immediate cost offers a potential pathway to shifting people's climate change-related attitudes and behaviours: devise a mechanism to make maintaining false beliefs costly in the near term. Research shows that people often behave in ways that contradict their stated beliefs when money is on the line[18]. For example, climate sceptics publicly deny global warming but do not invest in geographic regions that will probably suffer from a rise in sea levels[19]. Building on this, we suggest using climate prediction markets to shift attitudes towards the scientific consensus by increasing the cost of maintaining false beliefs. Simply, we provide a financial reward (/penalty) for correct (/incorrect) predictions about soon-to-occur events that are impacted by global warming using a prediction market.

Traditionally, prediction markets have been implemented to crowd-source estimates about uncertain events in the future[20]. Those markets have been shown to accurately predict the outcomes of elections[21], reproducibility of scientific findings[22], spread of disease[23] or aggregation of group choices[24]. In the context of climate change, prediction markets have been suggested as a tool for aggregating views on policies[25] and as a way to provide credible signals about climate science[26–28]. However, there is no empirical evidence supporting the

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notion that betting on climate-related events can shift people's: (1) concerns about the consequences of climate change, (2) support for remedial action at the individual/collective level and (3) knowledge about climate topics.

Climate prediction markets

We introduce climate prediction markets as a novel intervention and report experimental findings on how participating in the markets influences people's concern about climate change, support for action and climate knowledge. Our market offers individuals the opportunity to bet on future outcomes (that is, 'the average temperature in the Northern Hemisphere in the coming month will be higher than that in the equivalent time window over the last decade') and earn money if their predictions are proven right.

We implemented two different prediction markets across two field studies. In both studies participants engaged in a market where they took positions on future climate events and earned money based on their prediction accuracy.

Betting topics were set by the experimenters and were released intermittently (between 1 and 3 days apart in Study 1 and daily in Study 2). The bets reflected both events that dominated the news (that is, California wildfires, extreme heat waves) and events that were less salient to the average participant (that is, Antarctic Sea ice extent, change in the Air Quality Index). All bets had a settle date/time and an unambiguous source for determining the outcome. We term a particular prediction a 'bet'. For each bet, participants could decide whether they wanted to make a bet, which position to take (Yes/No) and how much money to wager.

We surveyed participants before ('pre-survey') and after ('post-survey') the period during which they engaged in the prediction market (Fig. 1a). In both studies, we compared participants who engage in the climate prediction market to a control condition (Study 1: passive control group, Study 2: active control group that participated in a sports and entertainment prediction market). Comparisons with the control group allow us to account for changes that might occur naturally over time (for example, natural variation in the salience of climate disasters that are known to impact people's attitudes about climate change[29]).

Study 1

Participants (n = 143) were recruited online and screened for climate beliefs and US nationality. Climate belief was defined as agreement with the statement 'Global warming refers to the idea that the world's average temperature has been increasing over the past 150 years and may be increasing more. Do you think that global warming is happening?' (Supplementary Table 5 and Supplementary Fig. 4 provide demographic and climate concern breakdowns for the 70 climate believers and 73 sceptics included in the study). We screened for individuals with polarized positions by selecting only individuals who answered 'Yes'/'No', skipping those who said 'Don't know'. Participants completed two surveys, one before the beginning of the prediction period and one at its conclusion. The surveys captured participants' concerns about climate change, support for climate action, climate knowledge and variables such as demographics, political orientation and more (Methods and Supplementary Information). Participants within the groups of believers and sceptics were randomly assigned to either the control (n = 73) or treatment group (n = 70). Each participant in the treatment group received US$20 to fund bets in the prediction market. During the prediction period, participants made bets on future events (Supplementary Methods show all bets). Because of the double-auction structure of the market (if one participant bet US$0.55 that an event would occur, it only becomes a contract if another participant bets US$0.45 that the event will not occur; Supplementary Methods provide details on the betting mechanism), not all bets turned into contracts. We analysed bet offers as reflections of participants' willingness to take a position on topics. Study 1 had 4,737 interactions (stock offers, trades and so on) with an average of 9.5 contracts per day.

Concern about global warming increases, conditional on winning

We first tested whether engaging in the climate prediction market had an impact on how concerned participants were about climate change. Specifically, we ran linear regressions to predict climate concern in the post-survey from experimental condition (0 = control, 1 = treatment), controlling for participants' concern in the pre-survey. Contrary to our expectations, participating in the climate prediction market did not lead to an overall increase in climate concern compared to the control group (B = −0.005, SE(B) = 0.015, β = −0.001, t = −0.04, p = .976; Fig. 2; all results hold when using the difference between pre- and post-survey as outcome). B, Unstandardized regression coefficient. SE, Standard error. β, Standardized regression coefficient. t, statistical coefficients of test; p, statistical coefficient of significance.

However, exploratory analyses of the treatment condition revealed an effect conditional on participants' performance in the betting market. Specifically, we used the robust MM-type estimator[30] to regress the difference in concern between post- and pre-surveys (higher values indicate a shift towards more concern about climate change) onto two indicators of performance: (1) the number of bets won and (2) total earnings. Here betting outcomes significantly and consistently predicted the change in concern (number of bets won: B = 0.007, SE(B) = 0.003, t = 2.44, p = 0.017; total earnings: B = 0.01, SE(B) = 0.005, t = 2.37, p = 0.021). That is, participants' concerns about climate change increased if they were accurate in their predictions.

Finally, we tested whether the impact of the treatment varied between believers and sceptics. Using the robust MM-type estimator to regress the difference in concern between post- and pre-surveys on the binary believer/sceptic variable, we saw a marginally significant effect (B = 0.14, SE(B) = 0.08, t = 1.71, p = 0.089) suggesting that the treatment was more effective for believers than sceptics. The moderating effects of performance on concern were found to be equally strong for both believers and sceptics (B = 0.001, SE(B) = 0.01, t = 0.11, p = 0.911).

To further explore participants' engagement with the climate prediction market, we tested for differences between believers and sceptics in betting outcomes (bets won and total earnings; Supplementary Fig. 2) and behaviour (confidence, defined as the distance from the neutral US$0.50/US$0.50 value). Despite believers being among the highest earners in our market (top 11% of earners), both groups did not significantly differ in the number of bets won (B = 0.70, SE(B) = 2.01, p = 0.728) or the total earnings (B = 1.44, SE(B) = 1.33, p = 0.282). However, the bets of believers indicated marginally higher levels of confidence (B = 0.48, SE(B) = 0.24, p = 0.053; Supplementary Fig. 6).

Altogether, Study 1 offers suggestive evidence that prediction markets can increase concern for climate change under certain conditions (that is, successful betting). Despite the promising results, Study 1 also suffers from a number of limitations. First, by virtue of its reliance on a real-world market resembling the one seen in public exchanges ('two-sided'), it was hard to isolate the treatment effects (that is, participants may have placed bets that did not turn into contracts). Second, the decision to target only individuals with polarized positions made obtaining a shift in concern challenging because believers are already at a climate concern ceiling, while sceptics are hardest to shift. Third, the size of our participant pool made it impossible to detect small effects that are common in behaviour-change research. Fourth, the fact that we opted for a passive control group that did not engage in any meaningful task during the prediction period prevented us from testing whether the effect of successful betting on concern was uniquely related to climate predictions or the result of participants experiencing positive outcomes.

Study 2 overcomes these limitations by testing the effects in a controlled experimental setting, with an active control group that

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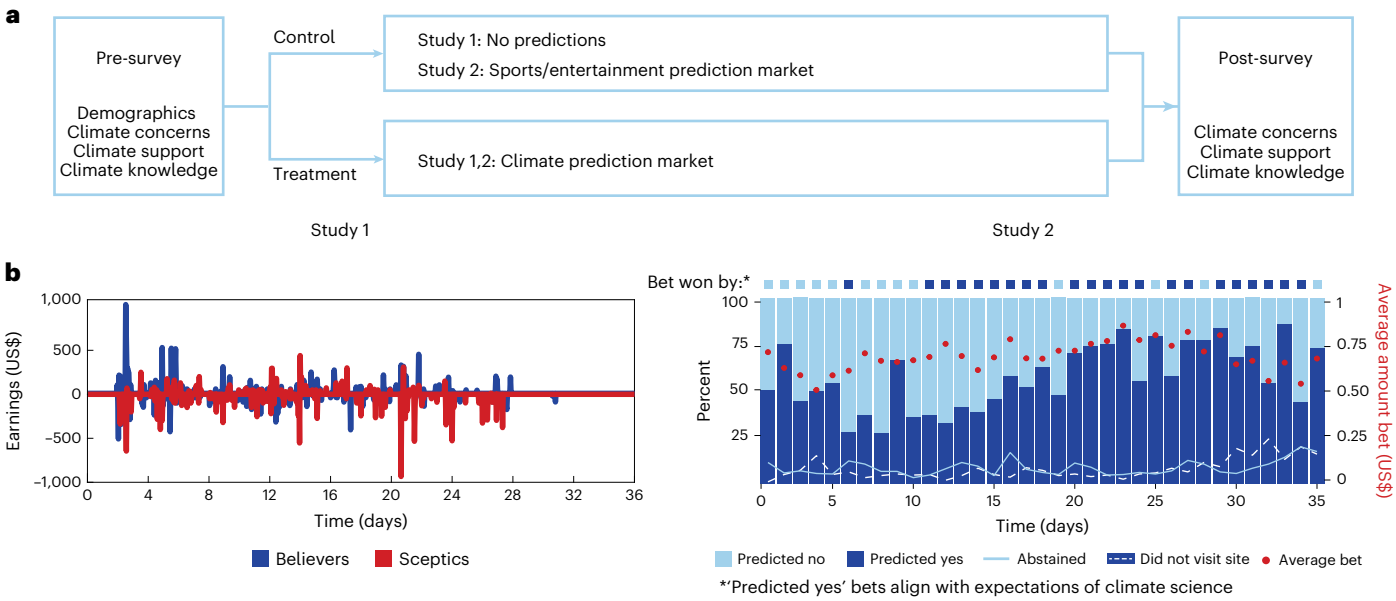

Fig. 1 | Experimental design. a, Participants first answered various questions about their views on climate issues in a pre-survey (Supplementary Tables 2, 4, 18 and 19 provide survey questions). Afterwards, participants were divided into treatment (climate prediction market) and control (Study 1: no predictions, Study 2: sports/entertainment prediction market) groups. **b**, Participants in the prediction markets made bets continuously (left: Study 1 earnings breakdown over time) or daily (right: Study 2; left *y* axis corresponds to the percent of participants taking yes/no/abstain positions on each daily bet, and the right *y* axis corresponds to the average daily bet wager). We denote above each bet the prediction that ended up being accurate (note that we attempted to ensure that 'Yes' bets would align with climate science). **c**, Visualization of the climate predictions market in Study 1 (on a dedicated website, titled C-Hedge; left) and 2 (right). The wager in Study 1 ranged from US$0.50 to US$0.99 with a position of less than US$0.50 amounting to switching (that is, US$0.40 'Yes' is US$0.60 'No'). The wager in Study 2 ranged from US$0.01–US$1. Following the prediction period, both treatment and control participants completed a post-survey addressing climate issues and assessments of their overall experience.

engaged in a non-climate prediction market, using a much larger sample size of people who are less extreme in their beliefs about climate change.

Study 2

Participants (n = 1,005) were recruited online similar to Study 1. Of the total participants, those (n = 664) who wagered at least US$10 and placed at least 15 bets were included in the analyses. As in Study 1, pre- and post-surveys measured participants' climate concern, support and knowledge (Methods). Between surveys, participants were randomly assigned to either a climate prediction market (n = 356, treatment) or a sports and entertainment prediction market (n = 308, control; Methods and Supplementary Information provide evidence that the randomization was successful). Both prediction markets ran for a period of 35 days during which one new bet was posted daily. Upon logging into the prediction market, participants saw an overview of their betting profile (amount won thus far, number of bets placed) and were informed about the outcomes of previous bets. Participants then saw the daily bet (Fig. 1c). Participants were asked to decide whether to bet, which position to take and how much money to wager. Each participant received US$20 at the beginning of the study. Overall, participants placed 10,384 bets (15.6 bets per person).

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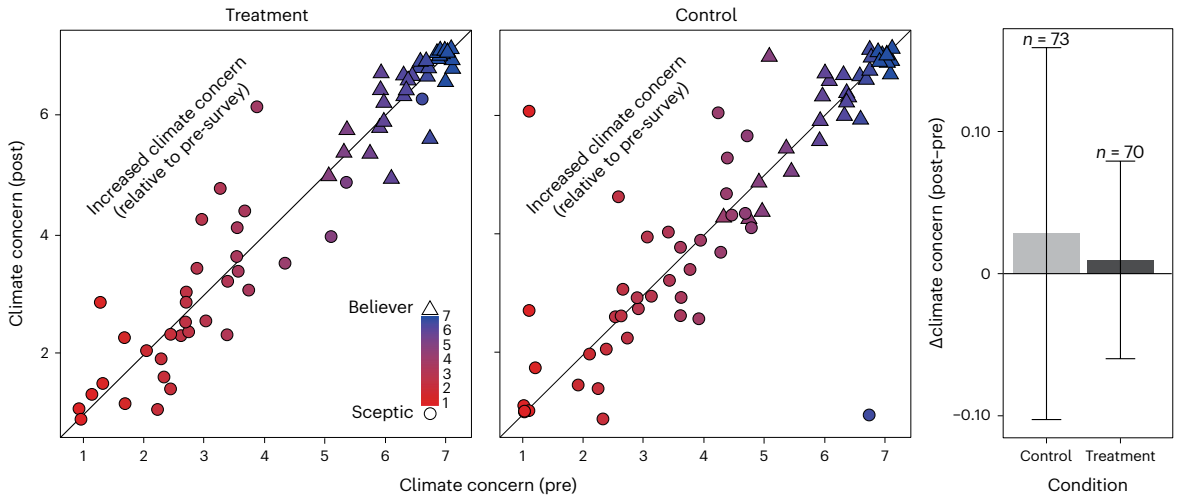

Fig. 2 | Distributions of climate beliefs before and after participating in the climate market. Taking the average of the three climate concern questions (Supplementary Fig. 4), we see that among the treatment ($t(68) = 0.14$, $p = 0.890$, two-tailed paired t test; left) and control ($t(70) = 0.22$, $p = 0.830$, two-tailed paired t test; centre) groups, there is no significant change in concerns following a month of waiting/betting (markers above the diagonal). Self-described believers and sceptics are marked by different symbols. Participants' group designation aligns with the reported answer to the survey questions with the majority of believers scattered at the top-right of the panels (Supplementary Fig. 5). Right panel depicts the average difference concern score among treatment and control conditions between the pre- and post-surveys. Error bars depict standard errors ($t(106) = 0.12$, $p = 0.901$, two-tailed independent t test).

Increase in concern about global warming

We tested whether engaging in the climate prediction market had an impact on how concerned participants were about climate change, how supportive they were of remedial action and how much they knew about climate change. Specifically, we ran a series of linear regressions to predict climate concern, support and knowledge in the post-survey from category of experimental condition (0 = control, 1 = treatment) controlling for the respective concern, support and knowledge in the pre-survey and including the socio-demographic variables to increase the precision of the estimates (Supplementary Information 'Robustness checks'). The treatment group showed significantly higher levels of concern ($B = 0.12$, SE(B) = 0.045, $\beta = 0.08$, $t = 2.69$, $p = 0.007$; Fig. 3a), support for remedial action ($B = 0.13$, SE(B) = 0.058, $\beta = 0.09$, $t = 2.19$, $p = 0.029$; Fig. 3b), and knowledge ($B = 1.58$, SE(B) = 0.22, $\beta = 0.52$, $t = 7.15$, $p < 0.001$; Fig. 4) in the post-survey compared to the control group.

Given that we asked the same question regarding concern and support in the pre- and post-survey, we could compare participants' scores to understand the underlying mechanisms of the effects. Participants in the treatment condition showed significantly higher levels of concern in the post-survey than the pre-survey ($t(355) = 2.23$, $p = 0.026$; Fig. 3) while controls did not ($t(307) = -0.93$, $p = 0.353$; paired t tests). Similarly, participants in the treatment condition increased their support for remedial action ($t(355) = 2.89$, $p = 0.004$) while controls did not ($t(307) = 0.37$, $p = 0.712$; paired t tests).

In addition to testing our main hypotheses, we conducted a series of exploratory analyses. First, we tested whether the treatment effect was stronger in certain conditions (that is, as in Study 1, when participants were successful in their bets). While we did not observe significant interaction effects between the experimental condition and the bet winnings for climate concern ($B = 0.009$, SE(B) = 0.011, $\beta = 0.04$, $t = 0.75$, $p = 0.455$) or support ($B = 0.007$, SE(B) = 0.014, $\beta = 0.04$, $t = 0.55$, $p = 0.583$), we found a significant moderation for climate knowledge ($B = 0.182$, SE(B) = 0.053, $\beta = 0.41$, $t = 3.44$, $p < 0.001$). Notably, we observed a significant interaction between the treatment and political ideology. The treatment was more effective at increasing support for remedial action among more conservative participants ($B = 0.077$, SE(B) = 0.036, $\beta = 0.13$, $t = 2.14$, $p = 0.033$). All treatment effects were independent of initial climate concerns, suggesting that participants at all levels of climate concern were equally affected by their involvement in the climate prediction market.

In line with findings on motivated reasoning[1,6,31], we observed a marginally significant relationship between political ideology and the percentage of bets that superficially align with climate change ($r = -0.10$, $t = -1.90$, $p = 0.058$). Testing for correlations between political ideology and outcomes (number of bets won, $r = -0.02$, $p = 0.526$; and total amount earned, $r = -0.004$, $p = 0.921$) or betting behaviours (total bets placed, $r = -0.01$, $p = 0.828$; and total amount spent, $r = 0.05$, $p = 0.192$) did not show any significant correlations (Supplementary Fig. 8). Accordingly, political ideology did not influence participants' engagement with the markets, confidence in their bets or prediction accuracy.

Implications of climate prediction markets

In line with existing theoretical arguments about the power of climate prediction markets[32], our findings from two field studies suggest that participating in such markets can influence people's attitudes towards climate change. Specifically, we show that participants who bet on climate-related events reported higher levels of concern about climate change, showed higher levels of support for remedial climate action and had higher levels of knowledge on climate issues. While the positive impact of our intervention on attitudes was conditional on betting success in Study 1, it was unrelated to earnings in Study 2. This discrepancy might, in part, be explained by the fact that the participants in Study 1 were recruited to be highly polarized in their views on climate change.

The effects of our intervention are small, with our experimental condition explaining between 1% and 7% of the variance in the post-survey responses regarding concern, support and knowledge. However, we argue that our intervention offers a meaningful tool for behaviour change. Prior work has suggested that when considered at scale, small effects can turn into highly impactful outcomes[33]. Further, our intervention results in positive attitude shifts across the entire political spectrum. Neither political ideology nor people's prior views on climate change moderated the effect. The only exception to this lack of moderation by political ideology was the shift in climate support in Study 2, where the intervention was stronger among more conservative participants. The success of the intervention is promising given that prior works have reported adverse reactive behaviour among climate sceptics targeted with attempts to shift their climate views[12,34–37].

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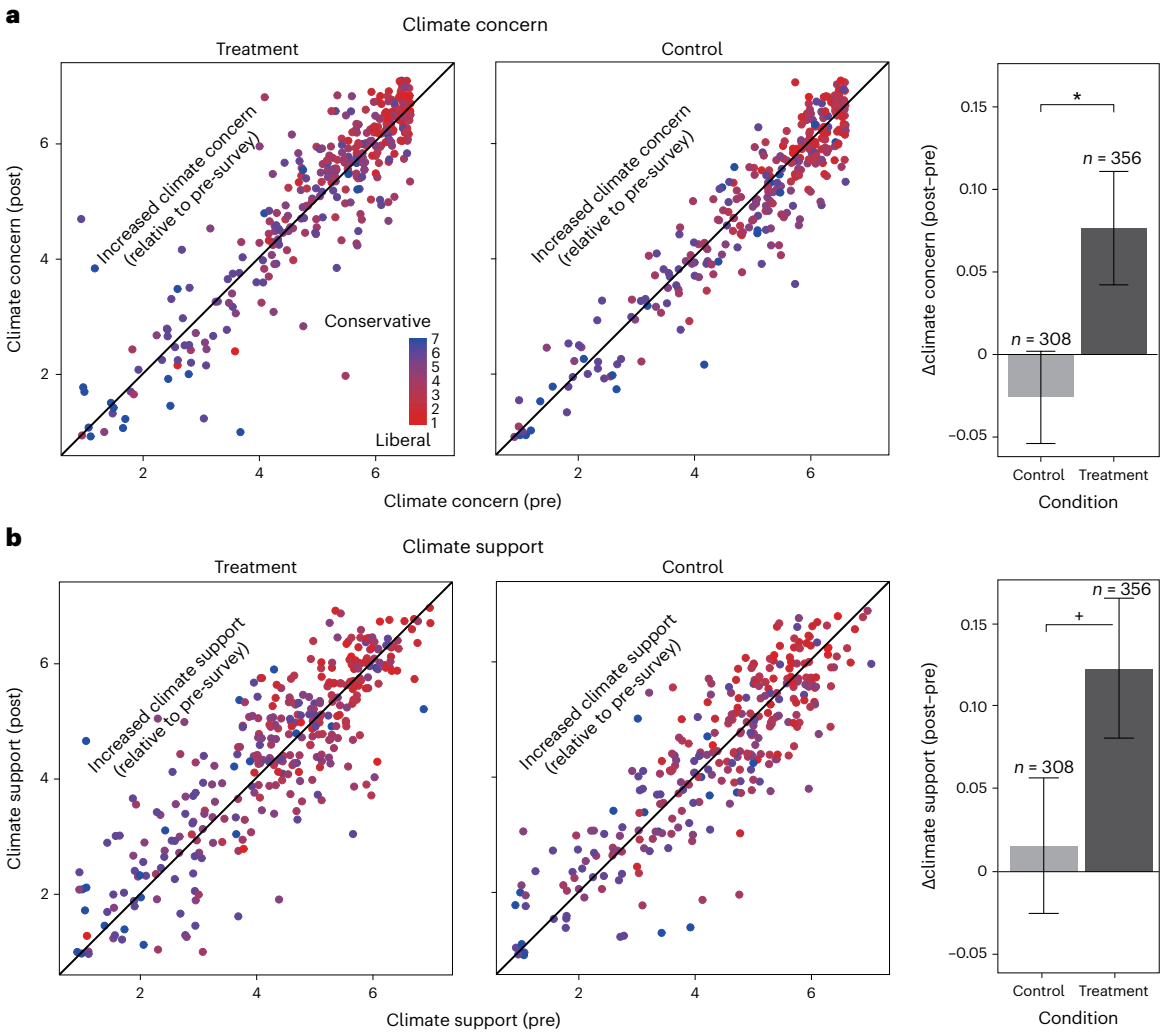

Fig. 3 | Effects of condition on climate concern and support. a,**b**, Participants concern (**a**) and support (**b**) before (*x* axis) and after (*y* axis) the prediction market. Right column depicts the shifts in concern across control and treatment conditions, calculated as the average difference scores across conditions between the post- and pre-surveys. Error bars depict standard errors (*ΔConcern: (651) = 2.27, $p = 0.024$, two-sided independent *t* test, +ΔSupport: $t(661) = 1.82$, $p = 0.069$, two-sided independent *t* test).

We propose that even if the participation in a climate prediction market is limited, the media accounts about market valuations, the prediction outcomes and the dissemination of knowledge that is derived from the markets may yield an increased shift in concerns in the larger population.

While it is difficult to translate the effects in field studies to population-level outcomes, there are some metrics that could be impacted by interventions such as ours. For example, if the prediction market in Study 1 was scaled to 1,000,000 climate believers and sceptics, and all believers decided to invest their annual earnings from, say, US$500 in market money (US$25, on average, if applied to our results) into countering climate change, this would result in an estimated US$25,000,000 of additional funding for climate solutions. Note that this amount could quickly increase when considering highly motivated players that might have far greater yields than the 5% earnings observed for the average believer in Study 1. Similarly, given that participation in climate markets such as the one in Study 2 yields an increase in climate concern, support and knowledge, such an intervention among a representative subset of the population could yield a shift in attitudes among millions[12] of individuals (Box 1 provides implementation details).

The majority of previous attempts at getting people to update their existing position on climate change focused on highlighting scientific consensus[37–41], neutralizing partisan conflicts[34–37] or appealing to norms[31,42–45]. The success of a number of those efforts was driven primarily by increasing knowledge and providing information, which, in turn, helped shift perspectives. Some of the challenges in previous studies have been attributed to: (1) motivated reasoning (that is, rejection of new information that contradicts standing beliefs[6]), (2) desire to signal social identity within a group by clinging to information that fosters collective homogeneity[46], (3) active efforts to foster uncertainty about climate science[47]. Our intervention offers a solution to all three of these challenges by: (1) making motivated reasoning costly, (2) anonymizing people's decisions (thereby protecting their position within a group of climate sceptics, for example) while conveying aggregated public opinion and (3) creating higher levels of certainty by having people actively engage with scientific sources. Additionally, because the change in attitudes is intrinsically driven, it has the potential to be less threatening to one's identity and hence more sustainable. Together, these features might allow people to engage with climate-related topics in a way that is less polarizing and less prone to partisan interpretation[4,34–37].

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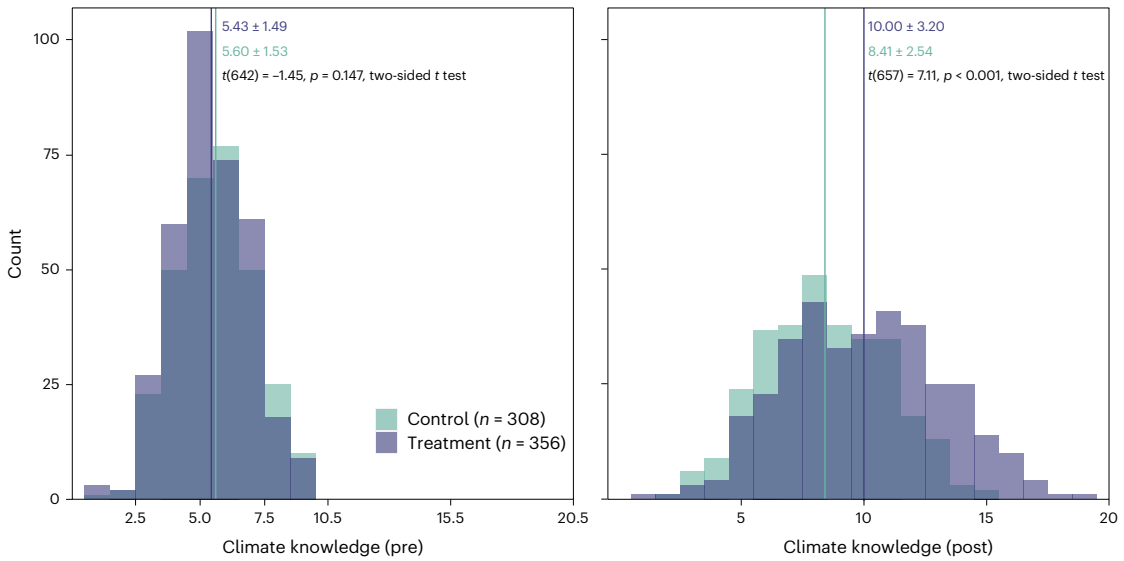

Fig. 4 | Climate knowledge increases after participating in a climate prediction market. Participants' knowledge was evaluated by comparing the treatment and control groups' knowledge in the pre-survey (left; n.s.) and post-survey (right). Vertical lines are the mean of the corresponding color distribution. n.s., not significant.

Our findings contribute to the existing knowledge on behaviour change, both inside and outside of the climate domain. First, they align with existing empirical results on how betting can serve as a tool for boosting engagement and behaviour change. For example, participating in sports prediction markets was shown to drive engagement with athletics[48], and trading stocks of companies increases people's consumption of news related to those companies[49]. Second, the findings speak to a growing body of work suggesting that reducing the 'distance' (psychologically, temporally or spatially) to a problem can lead to shifts in attitudes and behaviours[37,50,51]. For example, people who live closer to coastlines, where the effect of climate change is more concrete, express greater concern about climate change and higher support for regulating carbon emissions[52], although unlike our intervention, this may not hold for sceptics[53]. While our intervention does not change the physical setting of participants, continuous engagement with tangible climate-related events may reduce the psychological distance to climate change and make its impact appear more imminent. Third, our findings align with simulations suggesting that participation in climate prediction markets should foster alignment with scientific climate consensus[32].

Limitations

Our studies had a number of limitations. First, given that these were field experiments involving real-time responses, the results are impacted by ongoing events (that is, actions taken by other participants, news cycle or saliency of climate-related events). In Study 2, for example, climate events dominated the news during our pre-survey period (including a 50-year record high heatwave in Europe), which probably has impacted our baseline climate concern and support levels. This might have made it harder to see bigger increases in concern in the post-survey. By virtue of their realistic nature, our studies produce findings of high ecological validity and the results might vary depending on when the studies are conducted. Future climate prediction market studies should replicate our findings across multiple time windows to corroborate the outcomes' generalizability.

Second, given that the participants were recruited based on location and climate beliefs, our results reflect the behaviour of US participants and not necessarily the world population. Indeed, the polarization of US citizens with respect to climate change is larger than in other countries[54]. This polarization might have made it more difficult to shift concerns with our prediction markets, suggesting that our results could be a conservative estimate of the effect size elsewhere.

Third, we cannot speak to the exact mechanisms of our effects. Betting behaviour is the reflection of a complex combination of factors, including: (1) participants' view/knowledge on topics, (2) their confidence, (3) their risk tolerance, (4) their understanding of the market forces, (5) the amount of time participants have to do research and place bets, (6) the availability of funds, (7) the likelihood that others would take the opposite position of a prediction (in Study 1) and (8) the available information on the outcomes (that is, more data were available as the settle dates approached, in Study 1) and other psychological mechanisms. Future research could investigate these mechanisms individually.

Fourth, our limited study duration imposed a stringent cap on the temporal horizon of predictions. This cap aligns poorly with the longer timescale of climate change. We could not, for example, look into notable changes in Earth's temperature within the time limit. This limitation forced us to generate climate predictions with large spatial domains (that is, multiple cities) or comparison to historical events. The uncertain relationship between near-term events and outcomes causally related to global warming inevitably caused some of our markets to reflect weather events rather than climate events. An implementation of climate prediction markets on a longer period (that is, years) would allow for long-term predictions and understanding of the effect of new information on these predictions, irrespective of the temporal horizon (that is, predictions about the year 2100 can be updated far ahead of their settle date if new information in, for example, 2025 suggests a need for change of bet values). In fact, when Study 2 concluded, we asked participants to make predictions that span years into the future (Supplementary Table 19), which could be analysed when they settle (data available along with our Supplementary Information).

Fifth, our studies were limited to a financial allotment of US$20 per participant, capping motivation and outcomes. Participants were limited to using their allotted amount and, correspondingly, participants who lost much of their income early were effectively excluded from further activity (and presumably less engaged with the study). The fact that participants did not invest their own money may have changed their overall motivation compared to prediction markets in

BOX 1

Applications

Climate prediction markets can be a useful tool for financial policy estimation[27], for evaluation of public opinion[25] and for aggregation of views and signals about the future[26–28]. Importantly, by making false beliefs regarding the future impacts of climate change costly, climate prediction markets are likely to present a more accurate reflection of expectations about climate change. As such, they might help overcome politically motivated scepticism and gradually shift attitudes by highlighting that concern about climate change is more widespread than surveys suggest. Our finding that in various conditions the shift in concern was stronger among conservatives is particularly notable in this regard. As one key attribute of any prediction market is its reliance on an independent adjudicator, the power of prediction markets is that participants, upon entry, agree on the source they will use to determine the outcome.

An additional advantage of climate prediction markets is that they make it possible to quantify probabilities about future events long before the outcomes are manifested. In Study 1, for example, participants traded positions with different values far before the contracts' settle date. This indicates that the additional information about the future manifested itself in people's present behaviour regardless of the ultimate outcome. As an example, outcomes of electoral bets (say, the winner of a presidential election in Brazil) may not be determined for several months. However, new information about current events and policies might change the bet's value in ways that capture the crowd's changing estimate of the probability of the outcome.

Taken together, these prediction markets' properties make their application at scale (that is, under a federally regulated authority) a promising instrument in the arsenal of climate policymakers[56]. As current direct financial incentives—for example, tax credits or government subsidies—produce limited results with respect to shifting concerns on climate[58], prediction markets could act as a complementary tool for climate policy. The introduction of large-scale prediction markets for climate change could create a new sector of the financial information industry where climate attribution and prediction modelling would grow from a small academic enterprise to one that can help numerous governmental and private sector entities plan for the manifold effects of climate change and prioritize mitigation efforts.

Implementing multiple climate prediction markets over the course of this work has highlighted the importance of market makers (that is, the individuals generating the bets) in the process. For example, the selection of market topics or market launch times may influence market activity by nudging participants towards engagement with a specific topic. Similarly, setting markets that are realistic and fair requires effort and knowledge on the topic. Bets that are too extreme in any direction make all participants act in unison irrespective of their personal opinions. For example, the thresholds we chose for settling the first set of markets in Study 2 led to almost all bets resolving in favour of predictions that aligned with climate scepticism (Fig. 1b). Although we do not find evidence that this alignment with climate scepticism affected our main outcomes (shift in climate concern and support), it resulted in a general shift among participants towards more conservative bets in subsequent markets (Supplementary Information 'Mid-study survey' examines this effect). The impact that such choice of markets can have on the outcomes (and associated attitude change) raises concerns about potential market manipulation. While prior work has explicitly suggested market manipulation as a means to subsidize certain positions, encourage informed traders and reward accuracy[25], our experience suggests that this is not necessary for shifting attitudes. Put simply, engaging in climate prediction markets without any manipulation yields increase in concern about climate change and support for climate action. The unfortunate reality of climate change means that any randomly chosen period of time we may have selected for our studies would have had an abundance of salient climate anomalies that yielded an increase in concern about climate change. Given trends in global warming and its causal role in extreme weather events, this will be even more true in the future.

public exchanges. However, prior work has suggested that using virtual money may be as effective as real money[55]. We argue that this limitation may indicate that a real-world prediction market could in fact amplify the outcomes identified.

Taken together, these limitations suggest that while our work provides an initial feasibility test for climate prediction markets, further research should examine the markets' ability to shift attitudes persistently across a more diverse set of samples. Specifically, future work should investigate whether changes in concern, support and knowledge are sustained long term and whether continuous participation in climate markets solidifies those changes. Additionally, further analyses of the bets could focus on the positions taken by individuals as dependent observations to test whether certain outcomes affect future attitudes or bets (that is, losing multiple bets in sequence leading to less extreme bets).

Finally, we strongly advocate for replication of our results using large-scale prediction markets, implemented over a longer period in an open, non-experimental setting[56]. This would allow market forces to strengthen the effects and could lead to widespread attitude change.

Conclusion

This study offers empirical evidence for the ability of prediction markets to change people's attitudes about climate change. The engagement with climate prediction markets in a domain that is uniformly quantitative and less polarizing than politics could not only support existing methods to change climate concerns[4,13,51,57] but also act as an ultimate polling tool to help scientists, activists and politicians aggregate public opinion about trends, policy preferences and future scientific predictions. It has not escaped our notice that the powerful financial instrument proposed here could be used in other topics of controversy where an agreed-upon arbiter of truth could allow individuals to reflect their views through market economics rather than publicly stated opinions.

Online content

Any methods, additional references, Nature Portfolio reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at https://doi.org/10.1038/s41558-023-01679-4.

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Methods

Study 1

Participants. A total of 160 participants were recruited for the study. Participants were recruited online using Prolific Academic and through the Reddit 'Climate Change sceptics' group. Participants were screened on Prolific using two questions: (1) 'What is your nationality?' (only participants who answered 'United States' to this question were eligible to participate) and (2) 'Do you believe in climate change?' (people could answer: 'Yes', 'No', 'Don't know' or 'Not applicable/rather not say'; an equal number of people saying 'Yes' or 'No' were recruited). Participants' location within the United States varied and spanned areas that are deemed high and low for their support for climate change science[59] (Supplementary Fig. 1). To ensure that participants beliefs about climate change were consistent with the earlier Prolific screening, we added an additional filter question ('Global warming refers to the idea that the world's average temperature has been increasing over the past 150 years and may be increasing more. Do you think that global warming is happening?'; Answers: 'Yes', 'No' and 'Don't know'). Only people who responded 'Yes' or 'No' were included in the study.

Seventeen participants were excluded from the analysis, broken down as follows: three were excluded because they did not complete the required surveys, five because they failed an attention check question in either the pre-/post-survey and nine because they did not fulfil the requirement to use the entirety of the allotted US$20. Of the 143 remaining participants, 73 were used as controls (35 believers, 38 sceptics) and the remaining 70 were used as the treatment group (35 believers, 35 sceptics). Supplementary Table 5 provides a breakdown of all participants' demographics.

Participants in the control group received US$5 for completing the pre-survey and an additional US$5 for completing the post-survey. Participants in the treatment group received the same renumeration for these surveys, along with additional US$20 to spend in the climate prediction market (Supplementary Fig. 3 provides bet topics distribution). Participants were instructed to use the full amount for climate predictions. At the end of the study, participants received their earnings in the climate prediction market. Participants who lost all their US$20 allotment during the betting period received only a US$10 participation fee. In total, participants in the treatment group could earn anything from US$10 (participation fee) to a maximum of US$650 (participation fee and their earning from bet wins).

Experimental procedure. On the day of the study initiation, participants received a message instructing them to complete a pre-survey. At the end of the survey, they were given a personalized link to a web-based online climate betting site. Upon logging in to the site, they were presented with a number of climate betting markets and could take a position on any number of them (Fig. 1). In addition, participants could choose to trade a position with other participants. The number of available markets changed daily based on old markets closing and new markets opening. Participants could place multiple bets on the same market and could trade continuously before the bet's settle date and time.

During the betting period, participants could log in to the prediction market site whenever they wished, monitor their currently available funds, view the available markets, make bets or trade positions. The market mechanism was 'double auction' (Supplementary Information), which required two participants to take opposite bets such that the sum of two bets was US$1 (that is, if one participant chose to wager US$0.60 that a 'Yes' bet will occur, only when another participant wagered US$0.40 that a 'No' on the outcome would a contract be initiated). If no participant was willing to take the opposite wager, the offer remained pending until the participant making the offer chose to revoke it. The manifested value of each market at any given moment was that of the last 'Yes' transaction to occur. That is, if a participant made a bet for US$0.82 that the average methane level in October 2018 will be the highest on record and another participant took the opposite position at US$0.12, then all participants saw the current market value as US$0.82. Accordingly, the values of markets represented the aggregated stable amount of money people were agreeing to wager on each topic. Naturally, as the settlement date of markets approached, the bets were likely to converge to the probability (0…100) of the correct outcome (that is, if the market asked whether the number of disasters in a certain location be more than 10 by a certain date, and a few days before the closing time, a number of disasters already reached 9, the likelihood of a 'Yes' bet was higher). The betting period was initiated on 9 September 9 2018, and lasted until 11 November 11 2018. When the betting period was complete, participants were instructed to complete a post-survey. Once participants completed the post-survey, they were paid for their participation in the entire study. The pre- and post-surveys included a variety of questions (Supplementary Information provide all questions), but the main focus of the study was the subset of questions pertaining to the concern about climate change.

To ensure the site's robustness to large-scale use and to reduce the risk of technical issues jeopardizing the real-time experiment, we ran a pilot test of the site for two months before the experiment on a smaller group of participants.

Study 2 was similar to Study 1 in its design, with the following deviations: (1) the criteria for exclusion in Study 1 was stricter (that is, participants were asked to use the full amount of money allotted to them), (2) the betting period in Study 1 was longer and bets were not released daily but rather intermittently, (3) the participant population for Study 1 was selected such that the pool was more polarized, (4) the control group for Study 1 did not participate in an alternative prediction market, (5) the treatment group's bets in Study 1 occurred in a double auction, which pitted the believers and sceptics against each other with predictions occurring only when two participants claimed opposite sides of a bet such that the sum of the positions was US$1 (Supplementary Information provides an explanation of the double-auction fulfilment method), (6) participants in Study 1 could trade their bets in the market as the settle date was approaching based on the value of the trade at the time, (7) participants in Study 1 did not have to take a position on a bet as soon as it appeared on the portal but could choose to make a decision to enter as more information became available (the option price presumably reflected the information availability and outcome certainty), (8) participants in Study 1 could take contrary positions on the same bet or hedge their bets with a variety of positions.

Study 2

Participants. Participants were recruited through an online panel, Prolific Academic. Our target sample for the start of the study was 1,000 participants with anticipated attrition rates of approximately 30–40% over the course of the entire assessment period. To obtain this initial sample, we recruited 1,754 participants whose native language was English and who currently resided within the United States. We used Prolific's representative sample criteria to ensure that the sample was generalisable. We excluded participants who took less than two minutes to complete the survey and who failed an attention check embedded in the survey ($n = 134$).

All participants were asked a series of questions about their concerns pertaining to climate change, their support for climate action and their knowledge on basic climate-related topics (Measures). We further excluded participants whose answers were at ceiling (by calculating the sum across four 'Concern' questions with a score of 1–7 each and excluding participants with a score of 27 or 28, out of 28; $n = 615$; Supplementary Information).

A total of 1,005 participants met all inclusion criteria. Participants were randomly assigned to a treatment ($n = 524$) or control condition ($n = 481$; Supplementary Table 6). Participants in the treatment condition were told that they would participate in a four-week-long climate prediction market, while participants in the control condition were told about their participation in a sports and entertainment prediction

market (Supplementary Table 6 provides evidence that the treatment and control groups randomization assignments did not significantly differ from one another).

Each participant was allotted US$20 to use for bets throughout the study. We considered participants' study records complete if they: (1) placed at least 15 bets and spent at least US$10 from their allocated wages during the prediction period, (2) completed the post-survey at the end of the study, which included the same climate-related measures (that is, concern, support and knowledge) as the pre-survey. After excluding participants who did not meet these criteria, we were left with an analysis sample consisting of 664 participants (34% overall attrition rate; 32% in the treatment group, 36% in the control; $x^2(2) = 1.71$, $p = 0.191$, n.s.). Participants were compensated with a fixed sum of US$11 for completing the pre- and post-surveys and a variable additional amount depending on their earnings in the prediction period.

Experimental procedure. The study consisted of three main building blocks: (1) the pre-survey that measured participants' concern about climate change (climate concern), their support for possible solutions (climate support) and their knowledge on climate issues (climate knowledge) before the intervention, (2) a five-week-long prediction market and (3) a post-survey that captured climate concern, support and knowledge following the intervention. Participants were recruited between 17 July and 21 July 2022 and completed the pre-survey as part of the initial screening procedure. After exclusion, participants were randomly assigned to the five-week climate (treatment) or sports/entertainment (control) prediction markets. The betting period started on 1 August 2022 and concluded on 4 September 2022. The final bet was settled on 6 September 2022. The post-survey was sent to participants on 8 September 2022 and was closed on 14 September 2022, at which point all participants were paid (Fig. 1).

Each participant received a unique login identifier that allowed them to use a personalized version of study surveys. Every day at 10:00 all participants received an email through the study messaging system indicating that a new bet was available on the prediction portal. The message included a link to the prediction portal.

Upon receipt of the daily reminder, participants had 20 hours to enter the portal (Fig. 1), look at that day's bet and decide whether to make a prediction. Once participants logged in to the portal, they were greeted with their personal identification and a summary of their personal study metrics. The metrics were: how many bets they had already placed, how much money they currently held in their wallet, how much money they had in bets escrow (that is, bets awaiting resolution) and their total earnings up to that point. Below the metrics, participants saw a summary of the bets that already materialized and their outcome. Below this information, participants saw the day's new bet (that is, 'Will the number of wildfires in California exceed 5,500 by August 8, 2022?') alongside the bet's settle date/time (that is, 'August 8, 2022, 23:59 EDT'), the source for determining the outcome (that is, 'https://www.fire.ca.gov/incidents/2022') and (where possible) a graph of the history of the variable being bet on, showing the settle date of the current bet with respect to that graph.

Participants were then asked to indicate whether they wanted to abstain from betting, predict 'Yes' or predict 'No'. If participants elected to make a Yes/No prediction, they advanced to the next screen where they were asked to select the bet amount. Depending on their level of confidence, participants could bet any amount between US$0.01 and US$1. After participants determined their position and bet wager, they were asked to confirm their decision or restart their decision. Once the participants confirmed their decision, the bet was locked for the day and they were not able to alter their bet.

Measures

Climate concern. We measured people's concern about climate change in both the Pre- and Post-survey using the following four items: 1) 'Do you think that global warming/climate change is happening?' (Definitely not—Definitely yes, 2) 'Do you think global warming/climate change is the result of human activities?' (Definitely not—Definitely yes), 3) 'How much risk do you believe global warming/climate change poses to humanity's health, safety and prosperity?' (None at all—Extremely high), and 4) 'Some people say that global warming/climate change is simply a scam. What do you think about this?' (Strongly disagree—strongly agree; reverse coded). The measure was adopted from work by Weber and colleagues[54]. Responses were recorded on a 7-point scale. With a Cronbach's alpha of 0.93 in both the Pre- and Post-surveys, the internal consistency of our measure was found to be excellent.

Support for climate change solutions. We measured people's support for climate change solutions in both the pre- and post-survey using the following three items: (1) 'Addressing global warming/climate change should be a priority of the government' (strongly disagree—strongly agree), (2) 'I feel personally responsible to help slow down global warming/climate change' (for example, by making changes to my lifestyle or paying higher taxes) (strongly disagree—strongly agree) and (3) 'Some people say that climate change is real, but that the cost of fixing it today might not be worth the investment (that is, that the cost of fixing it today is higher than the cost of the damages caused by it)' (strongly disagree—strongly agree). Responses were recorded on a seven-point scale. With a Cronbach's alpha of 0.84 in the pre- and 0.87 in the post-survey, the internal consistency of our measure was found to be good.

Climate knowledge. The questions for climate knowledge differed between pre- and post-survey. The pre-survey asked ten relatively generic multiple-choice questions (that is, 'How many major layers does Earth's atmosphere have?' Or 'What is the primary effect of greenhouse gasses?'. The post-survey, on the other hand, asked a more comprehensive set of questions that were directly related to knowledge about climate change (that is, 'When does a tropical disturbance become a tropical storm and gains a name?' or 'What percentage of heat from global warming has the ocean absorbed in the past 40 years?'; Supplementary Tables 2, 4, 18 and 19 provide all questions).

Socio-demographic control variables. We collected information about a wide range of participants' socio-demographic characteristics. These included: age, gender, ethnicity, education, employment status, income, religious beliefs, political ideology and number of children (Supplementary Tables 18 and 19).

Ethics statement

All participants in Study 1 and Study 2 signed an online consent form upon initial engagement with the pre-survey. Study 1 protocols were approved by Northwestern University's Institutional Review Board (STU00206273). Study 2 protocols were approved by Columbia University's Institutional Review Board (AAAU2501).

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

The data generated during the work are available at https://doi.org/10.17605/OSF.IO/PH72Y.

Code availability

The codes used for the analyses are available at https://doi.org/10.17605/OSF.IO/PH72Y.

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Acknowledgements
We thank M. Kim and A. Yu for assistance with managing the prediction market and maintaining the study throughout the betting periods; A. Mishra and I. Katz for designing and coding an initial version of the online prediction markets; J. McCoy for discussion on prediction market utility; B. B. McShane, S. Franconeri, J. N. Druckman and A. Coughlan for comments on the manuscript; E. Weber for support with climate concern assessment; G. Schmidt, K. Hayhoe, D. Horton, E. Berlow and K. Marvel for help with identifying climate markets; and R. Behnam and members of the US Commodities and Futures Trading Commission for discussions on federal implementation of climate prediction markets. This work was funded by the Columbia University Tamer Center for Social Enterprise (M.C. and S.C.M.) and by the Northwestern Institute on Complex Systems (M.C. and M.A.M.).

Author contributions
All authors equally designed the research, performed the research, analysed the data and wrote the paper.

Competing interests
The authors declare no competing interests.

Additional information
Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s41558-023-01679-4.

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Peer review information *Nature Climate Change* thanks Paul Stern, Michael Vandenbergh and the other, anonymous, reviewer(s) for their contribution to the peer review of this work.

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Last updated by author(s): April 21, 2023

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Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	Data were collected online using a dedicated server (www.c-hedge.com), Qualtrics, and Prolific.
Data analysis	Data were analyzed using Matlab and R.

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio guidelines for submitting code & software for further information.

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Research involving human participants, their data, or biological material

Policy information about studies with human participants or human data. See also policy information about sex, gender (identity/presentation), and sexual orientation and race, ethnicity and racism.

Reporting on sex and gender	Findings apply to all sexes and genders. Demographic characteristics were collected based on self-reporting through the participant recruiting platform ("Prolific"). These attributes were not relevant to the study design. Study 1 included 72 women and 71 men. Study 2 included 318 women and 346 men.
Reporting on race, ethnicity, or other socially relevant groupings	Findings apply to all races and ethnicities. Demographic characteristics were collected based on self-reporting through the participant recruiting platform ("Prolific"). These attributes were not relevant to the study design. Other socially relevant data collected included age, education level, income, political ideology, and number of children. Only political ideology was relevant for the results.
Population characteristics	Complete population characteristics appear in the Supplementary Information ("Descriptive Information") for both Study 1 and Study 2.
Recruitment	Participants for Study 1 were recruited online using "Prolific" and through the Reddit "Climate Change skeptics" group. Participants for Study 2 were recruited online using "Prolific".
Ethics oversight	Study protocols were authorized by Columbia University's Institutional Review Board and Northwestern University's Institutional Review Board.

Note that full information on the approval of the study protocol must also be provided in the manuscript.

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Behavioural & social sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	Participants completed surveys before and after engaging in a prediction market. The surveys measured their climate concerns, support for climate action, and climate knowledge. Between the surveys, participants were randomly assigned to either engage in a climate prediction market (treatment), or a control group. In Study 1 (n=143) the control group sat idle, while in Study 2 (n=664) the control group engaged in a sports/entertainment prediction market. During the prediction period, participants in the climate prediction market made bets about future climate outcomes (i.e., "Will the number of wildfires in California exceed 5,500 by August 8, 2022?").
Research sample	Participants in Study 1 (n=143; average age: 35.9 years old; 50.5% female) were recruited online using "Prolific Academic" and Reddit. The sample was intentionally skewed towards extreme and polarized views regarding climate change. Participants in Study 2 (n=664; average age: 42.6; 47.9% female) were recruited online using "Prolific Academic". The participants pool constituted a representative sample.
Sampling strategy	Sample sizes were determined to ensure statistical significance.
Data collection	Data were collected online using Qualtrics and a dedicated experiment website (www.c-hedge.com).
Timing	Data for Study 1 were collected between September 1, 2018, and November 15, 2018. Data for Study 2 were collected between July 17, 2022, and September 14, 2022.
Data exclusions	Study 1: 17 participants were excluded from the analysis. Three were excluded because they did not complete the required surveys, five because they failed an attention check question in either the Pre-/Post-survey, and nine because they did not fulfill the requirement to use the entirety of the allotted $20. Study 2: 749 participants were excluded from the analysis. Those included participants who took less than two minutes to complete the Pre-Survey, or failed an attention check embedded in the survey (n=134), as well as participants who were at ceiling (27 or 28, on a 4-28 scale) in their answers to the Pre-Survey questions about climate concern (n=615).
Non-participation	Participants that were dropped did so because they did not manage to use their entire allotted budget. These were notified in advance that they do not qualify for the Post-Survey and elected to drop.
Randomization	Participants were randomly assigned to "treatment" and "control" conditions.

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology and archaeology
☒	☐ Animals and other organisms
☒	☐ Clinical data
☒	☐ Dual use research of concern
☒	☐ Plants

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging