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The effect of public safety power shut-offs on climate change attitudes and behavioural intentions

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As climate change accelerates, governments will be forced to adapt to its impacts. The public could respond by increasing mitigation behaviours and support for decarbonization, creating a virtuous cycle between adaptation and mitigation. Alternatively, adaptation could generate backlash, undermining mitigation behaviours. Here we examine the relationship between adaptation and mitigation in the power sector, using the case of California's public safety power shut-offs in 2019. We use a geographically targeted survey to compare residents living within power outage zones to matched residents in similar neighbourhoods who retained their electricity. Outage exposure increased respondent intentions to purchase fossil fuel generators while it may have reduced intentions to purchase electric vehicles. However, exposure did not change climate policy preferences, including willingness to pay for either wildfire or climate-mitigating reforms. Respondents blamed outages on their utility, not local, state or federal governments. Our findings demonstrate that energy infrastructure disruptions, even when not understood as climate adaptations, can still be consequential for decarbonization trajectories.

Climate change is already exposing energy infrastructure to extreme weather and natural disasters, leading to serious disruptions[1,2]. Extreme weather has undermined grid reliability and energy provision in places such as South Australia in 2016, California in 2019 and Texas in 2021. Governments and public service providers will need to enact policies that support climate adaptation in the power sector, such as grid hardening or pre-emptive power outages. However, we still know little about how the public responds to direct experience with these climate change adaptation policies[3]. Instead, existing work has focused either on direct experiences with climate events[4], including in response to high temperatures[5–7], wildfires[8,9], hurricanes[10] and flooding[11–13]; or on direct experiences with climate mitigation policies[14–16].

In general, the public could respond to adaptation policies in ways that either reinforce or weaken decarbonization trajectories. For instance, the use of air conditioners powered by fossil fuel-generated electricity can facilitate adaptation to heat extremes but exacerbate long-term warming and local urban heat islands. Similarly, the use of fossil fuel generators to adapt to power outages caused by extreme weather could hinder mitigation goals. Moreover, when the causal chain linking climate change to the public's lived experiences is indirect, the public may not associate their experiences with climate change and, as a result, may not update their climate policy preferences[17].

Here we explore the attitudinal and behavioural effects of energy infrastructure disruptions using the case of pre-emptive power outages, also termed public safety power shut-offs (PSPSs). PSPSs are one increasingly common climate adaptation policy intended to reduce wildfire ignition risks. They are likely to become more frequent in fire-prone regions as climate change intensifies wildfire hazards[18]. PSPS events can be widespread and affect large populations[2]. They are also consequential: power supply disruptions generate substantial health, economic and social impacts for those who experience them, especially for people who already have elevated vulnerability[19,20].

PSPS events represent a category of adaptation measures that, even though they affect large populations, have received little attention in the research literature[3]. While several recent papers have examined the impacts of planned or spontaneous power outages on public attitudes and behaviours[19–22], research in this area faces barriers due to low sample sizes; there are typically few respondents in national survey samples who have recently experienced power outages. Still, large-scale disruptions of this sort may be consequential for public behaviours and attitudes. In one study in the United Kingdom and Mexico, experience with power outages was associated with elevated climate change concern but no direct effect on household energy-saving behavioural intentions[21]. Another study in California linked PSPS exposure to support for solar and storage technologies[22]. Surveys of Californians in the aftermath of power shut-offs also found that shut-off experiences were associated with negative mental and physical impacts[23].

In fall 2019, one of California's major utilities, Pacific Gas and Electric (PG&E), conducted a series of widespread PSPS outages in Northern California. During an initial shut-off from October 9 through 12, PG&E 'de-energized' over 730,000 customers across 35 counties[24]. Another 177,000 customers were de-energized during a second event between October 23 and 25 (ref. [25]), followed by two successive outage events beginning on October 26 and 29 that impacted another 941,000 customers[26].

Here, we report the results from an original, high spatial resolution, mail-to-web survey of Californians ($n=911$) fielded in the immediate aftermath of widespread outage events. We used the spatial boundaries released by PG&E to generate a sample of addresses that experienced at least one outage in October 2019 and targeted samples of non-outage addresses that were otherwise similar to outage zone addresses, including oversamples within 1 km inside or

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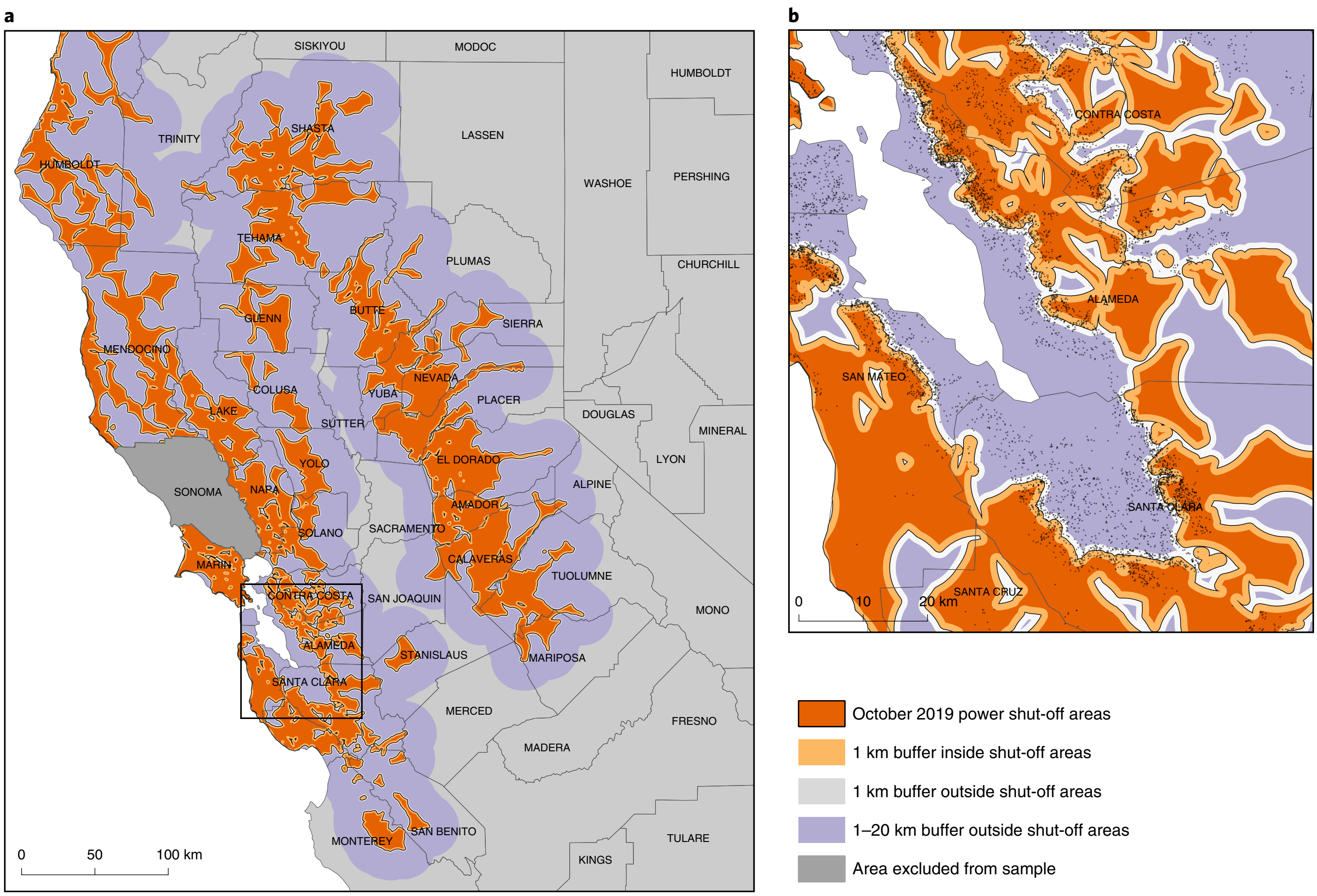

Fig. 1 | Survey sampling zones associated with PSPS events in Northern California in fall 2019. a, Overall sample across Northern California (Methods) overlain on a county-boundary map. **b**, Inset map with dots illustrating addresses selected for sampling in the eastern San Francisco Bay Area.

outside the outage boundaries (Fig. 1 and Methods). This dataset provides the fine-grained spatial control necessary to both describe the experiences of the *average* respondent in the outage zone and to exploit spatial variation in the distribution of PG&E power outages to evaluate how the public responds to exposure to infrastructure disruptions from climate adaptation policy. Overall, we find that outage experience undermined climate mitigation by increasing respondent intentions to purchase fossil fuel generators and suggestive evidence that the outage may have decreased intentions to purchase electric vehicles (EVs). Respondents blamed outages on their utility, not the government. Outages did not directly change the public's climate policy preferences, including their willingness to pay for adaptation or mitigation actions. Broadly, our findings suggest that, in response to some climate-linked adaptation disruptions, individuals may respond in ways that simultaneously slow decarbonization efforts.

Respondent experiences with October 2019 PSPS events

Respondents in the outage zones reported serious disruptions from October 2019 PSPS events, with 44% reporting power losses for three or more days. In summary, respondents self reported that the PSPSs had both psychological and economic effects on their households (also, ref. [23]). A majority of outage-impacted respondents reported worrying about their safety and quality of life, including being able to contact people (64%), completing household tasks (55%) and caring for family (46%) (Fig. 2).

The outages also had economic effects for individuals. Most respondents in outage areas reported taking preparatory actions and spending money in advance of the PSPS events: buying additional food (64%); buying gasoline (65%); and buying flashlights, candles or rechargeable batteries (50%). Most respondents who experienced power shut-offs stayed in their own homes (78%), even if their power was shut off over night. Few stayed with friends or relatives (4%) or at a hotel or a motel (2%). Overall, 155 respondents answered an optional question asking how much money they spent on preparations. The average amount was US$327, with responses ranging from a low of US$0 to a high of US$5,000. While the outage events may have reduced wildfire risk, they also negatively impacted hundreds of thousands of people.

The effects of outage experience on climate attitudes

We then evaluated whether experiencing an outage shaped respondents' behavioural intentions and climate attitudes. Simple comparisons between individuals exposed and not exposed to outages would probably produce biased estimates; respondents 'treated' with outages may differ systematically from non-exposed respondents, including as a result of differences in neighbourhood characteristics (Table 1). While outage boundaries may be exogenous, topographical differences could still create differences between neighbourhood types, property values and other characteristics within 1 km of outage boundaries. Accordingly, we combine our spatially targeted sampling along the outage discontinuity with matching algorithms to match treated respondents with similar unexposed households. The goal is to estimate the causal effect of outage exposure (Methods).

We first checked to see if outages—despite being an indirect form of climate-linked disruption—shaped respondents' climate attitudes. Because climate change is exacerbating wildfire risks,

Table 1 | Covariate balance between treatment and control groups in overall and matched samples

	Overall sample			Matched sample		
	Treated mean	Control mean	*P* value (*t*-test)	Treated mean	Control mean	*P* value (*t*-test)
Party identification	2.249	2.346	0.377	2.243	2.313	0.610
	(0.08)	(0.076)		(0.081)	(0.111)	
Ideology	3.419	3.481	0.577	3.429	3.518	0.498
	(0.078)	(0.077)		(0.079)	(0.105)	
Educational attainment	4.562	4.444	0.092	4.559	4.554	0.947
	(0.048)	(0.052)		(0.048)	(0.063)	
Age	56.343	51.925	0.000	56.474	55.115	0.312
	(0.817)	(0.798)		(0.839)	(1.027)	
Income	2.629	2.69	0.371	2.642	2.738	0.243
	(0.045)	(0.043)		(0.045)	(0.060)	
Female	0.493	0.463	0.417	0.491	0.477	0.753
	(0.027)	(0.025)		(0.027)	(0.036)	
Married	0.682	0.626	0.109	0.686	0.667	0.641
	(0.025)	(0.024)		(0.025)	(0.034)	
Employed	0.549	0.618	0.057	0.55	0.569	0.672
	(0.022)	(0.025)		(0.027)	(0.036)	
Non English at home	0.217	0.288	0.027	0.216	0.236	0.599
	(0.022)	(0.023)		(0.022)	(0.03)	
Smoke level	2.442	2.542	0.163	2.447	2.492	0.597
	(0.054)	(0.046)		(0.055)	(0.066)	
Observations	495	395		338	195	

Notes: Ideology was measured using a standard seven-point Likert scale (1 is most conservative, 7 most liberal). Educational attainment was measured on a five-point scale (less than high school, high school diploma or GED, some college, associates degree, bachelors degree of higher). Income was measured using a four-point scale (less than US$40,000; US$40,000 to US$100,000; US$100,000 to US$250,000; over US$250,000). Smoke level is four-point measure of degree to which smoke has made air quality in respondents' community worse since the beginning of October 2019.

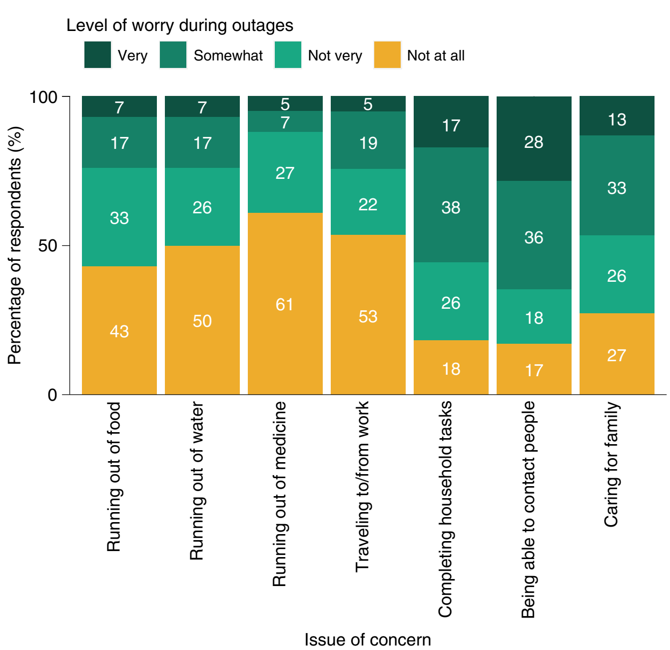

Fig. 2 | Level of concern reported by outage-impacted respondents associated with fall 2019 PSPS events in Northern California. Bar graph showing the level of concern reported by survey respondents to various issues affected by power outages. Number of respondents $n = 352$.

leading to adaptation policies such as PSPS, if respondents linked their outage experiences to climate change, they might become more concerned about climate change and more supportive of clean energy policies. However, almost no respondents mentioned climate change as a contributor to the outages. In our survey, we asked respondents why they thought the electricity was shut off, using an open-ended text field; 426 respondents offered responses (Methods provide coding details). Overall, 53% mentioned weather as a cause, generally either wind or wildfire; 28% mentioned some negligence or corruption on the part of PG&E (this included comments expressing that PG&E was only concerned with reducing their own liability); 9% referred to PG&E safety efforts; and 1% referred to government negligence or corruption. Only 4 respondents (less than 1%) mentioned climate change, emphasizing that although these shut-offs were exacerbated by a changing climate, the public did not make this connection.

Indeed, as shown in Fig. 3, outage exposure was not associated with differences in policy views on clean energy or climate policies such as achieving net zero emissions by 2035 and implementing a clean energy standard. Exposure was also not associated with increased concern about climate change.

The effects of outage experience on behavioural intentions

We next considered behavioural intentions related to climate mitigation and adaptation, even though climate attitudes and policy preferences were unchanged. Did experiencing an outage make it more likely for individuals to take action on climate mitigation or adaptation actions? We examined whether respondents planned

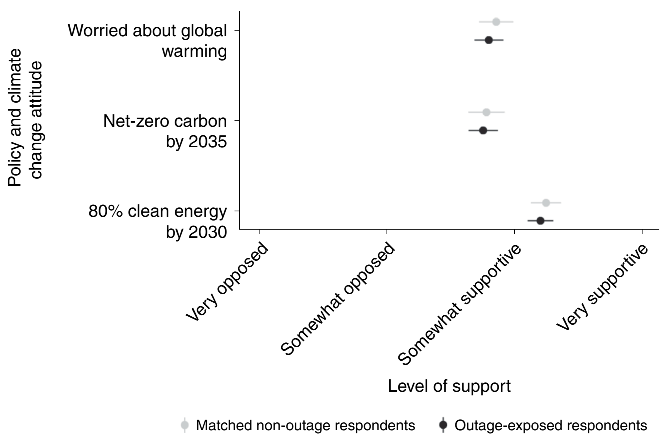

Fig. 3 | Effect of outage exposure on policy and climate change attitudes. Average policy views for matched respondents who experienced ($n = 338$) and did not experience ($n = 195$) an outage. For the global warming outcome, the opposed position corresponds to less worried. Bars show 95% confidence intervals.

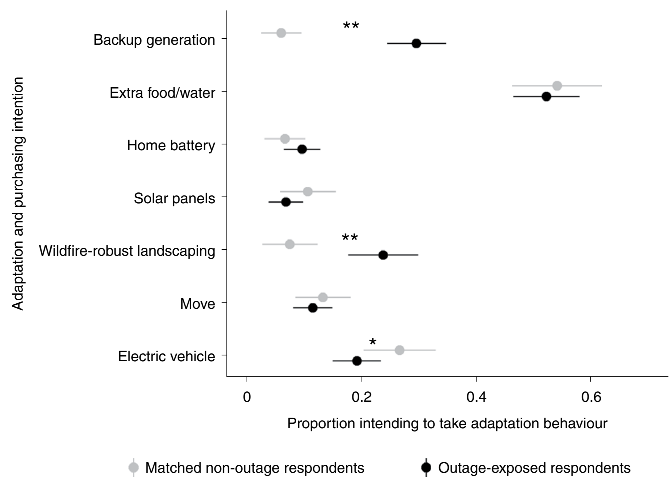

Fig. 4 | Effect of outage exposure on household-level adaptation and purchasing intentions. Proportion of outage-exposed respondents ($n = 338$) and matched non-outage-exposed respondents ($n = 195$) stating their intention to adopt a given behaviour. Figure presents the means for treatment and control groups, with estimates from a covariate-adjusted ordinary least squares (OLS) regression (Supplementary Note 3). Bars are 95% confidence intervals. Stars represent significance of difference in means between outage and non-outage sample for a given behaviour; $^{**}P < 0.05$; $^{*}P < 0.1$. We estimate a statistically significant effect of exposure to outages for the backup generation ($P = 0.000$), wildfire-robust landscaping ($P = 0.000$) and—marginally—for EV ($P = 0.053$) outcomes.

to take any of the following actions over the subsequent year: (1) change home landscaping to reduce wildfire risk; (2) upgrade home building materials to reduce wildfire risk; (3) install a home battery system; (4) install fossil fuel backup generation; (5) move; (6) purchase additional food and water supplies to prepare for future shut-offs; (7) install solar panels and (8) purchase an EV. Overall, in the outage-exposed area, 52% of respondents reported plans to purchase additional food and water, 30% reported plans to install backup fossil fuel generation and another 24% reported plans to change home landscaping. On the other hand, just 6% reported plans to upgrade home building materials to reduce wildfire risk, 10% reported plans to install a home battery system and 7% reported plans to install solar panels. In this analysis, we exclude respondents who had already taken the activities before outage onset. We do not find differences in previously adopting these behaviours between treatment (experienced an outage) and control (did not experience an outage) groups (Supplementary Note 1).

Looking at the matched sample, there were some differences in the behavioural intentions in the areas that experienced outages. As shown in Fig. 4, exposure to an outage had the strongest effect on respondents' plans to install a backup fossil fuel generator—individuals exposed to outages were 24 percentage points (standard error (SE) = 0.03, $P = 0.000$) more likely to plan generator installation. In addition, outage-exposed respondents were 16 percentage points more likely to report that they planned to change their home landscaping to reduce wildfire risk (SE = 0.04, $P = 0.000$). Finally, in a suggestive effect that is only marginally significant, outage-exposed respondents were 7 percentage points less likely to report that they planned to purchase an EV as their next car (SE = 0.04, $P = 0.053$). This may be a function of shifting perceptions of EV benefits in the context of less reliable electricity service. We do not find statistically significant effects for other household-level behavioural intentions, including building upgrades, rooftop solar installations, moving or preparing for future outages by buying additional food and water. We might expect a household's ability to undertake these actions depends on home ownership. However, because the great majority of our sample owned their homes (86%), we were unable to estimate heterogeneous effects by home ownership. We do not find statistically significant differences in adaptation behaviours by income (Supplementary Note 2).

Figure 5 presents estimates of the effect of the outages on these behavioural intentions, splitting the sample by whether respondents accept that global warming is caused mostly by human activities. We generally do not find major differences in the effects of outages conditional on whether respondents accept or deny that human activities are causing global warming. We also find no significant differences in adaptive responses to outages by partisan identification (Supplementary Note 2).

In addition to evaluating the degree to which outage exposure affected behaviours and attitudes, we also evaluated respondents' willingness to pay (both financially and in terms of days without power) to reduce fire risk and make the electricity system more stable in California (Methods). Respondents, on average, were willing to live without electricity for 9.21 days to reduce fire risk. We also estimate that the average respondent would be willing to pay a surcharge of just US$21.87 per month to avoid future planned power shut-offs. This contrasted with a higher estimated willingness to pay, US$58.60 per month, to bury power lines underground to improve overall system stability and resilience.

Overall, we find that outage-exposed respondents were more likely to report intentions to engage in certain household-level adaptation and mitigation behaviours. Unfortunately, some of these responses are counterproductive in terms of climate mitigation, such as an increase in fossil fuel generator purchases and a possible decrease in EV purchases.

The effects of outages on utility and government trust

Our final set of outcomes concern respondents' attitudes with respect to electric utilities and government officials. To what degree does experience with this climate adaptation policy reshape the public's approval of government and private sector actors and how might that shift incentives to reform electricity systems? Because outage decisions were made by electric utilities (in this case, PG&E), being exposed to outages might shape respondents' attitudes towards their electricity providers. We measured respondents' trust in their electric utility, the degree to which respondents held their utility responsible for power shut-offs, whether they held PG&E liable for damages from their equipment and whether they thought PG&E's

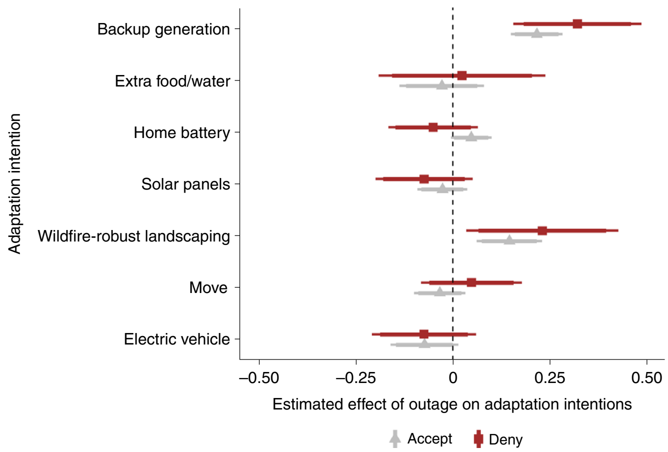

Fig. 5 | Heterogeneous effects of outage exposure on adaptation by respondent acceptance that global warming is caused mostly by human activities. Estimated effect of outage exposure on adaptation intentions among respondents who accept that global warming is caused mostly by human activities ($n=421$) and those who do not ($n=110$), all within the matched sample. The vertical dashed line gives the point estimate for no effect. Bars provide 90% (thick) and 95% (thin) confidence intervals.

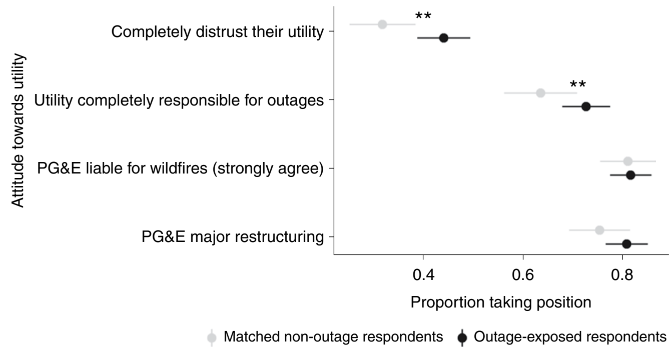

Fig. 6 | Effect of outage exposure on attitudes towards utilities. Proportion of outage-exposed respondents ($n=338$) and matched non-outage-exposed respondents ($n=195$) who take stated position, with estimates from covariate-adjusted OLS regression in Supplementary Note 3. Bars are 95% confidence intervals. Stars represent significance of difference in means between outage and non-outage sample; $^{**}P<0.05$. We estimate statistically significant effects for distrust ($P=0.004$) and holding-utility-responsible outcomes ($P=0.040$).

corporate governance should be restructured as part of its bankruptcy proceeding. Overall, respondents held negative attitudes towards their utility. In the sample, more than half of respondents felt that PG&E was 'completely' responsible for the shut-offs, and 80% agreed that PG&E is liable for wildfire damage caused by their equipment. Respondents were also in favour of reform: just 23% felt that PG&E should continue to operate as a privately owned utility.

These attitudes were amplified by outage exposure. As Fig. 6 shows, outage-exposed individuals reported lower levels of trust towards their utility: 44% of outage-exposed respondents reported they completely distrusted their utility, compared with 32% in the control group (SE = 0.04, $P=0.004$). They were also more likely, by nearly half a standard deviation, to hold their electric utility responsible for causing the planned power shut-offs: 73% of outage-exposed respondents reported that the utility was completely responsible, compared with 64% in the control group (SE = 0.04, $P=0.040$]. However, we do not find that outage exposure was causally associated with respondents agreeing that utilities should be liable for the damage from wildfires caused by their equipment, nor with respondents advocating for a major restructuring in PG&E's corporate governance. These latter results may stem from limited variation in the outcome measure; even in the control group, 81% of respondents reported holding PG&E liable and 75% supported a major restructuring.

While the shut-offs reduced support for the utility, they did not reshape public perceptions of government leaders, including the president, governor and local politicians. As the outages were happening, President Donald Trump's Republican administration was in the process of rolling back climate policies while Governor Gavin Newsom's Democratic administration in California sought to further the state's position as a climate leader.

Exposure to outages caused by wildfire risk—which is worsened by climate change—might lead respondents to be more supportive of Democratic (more environmentally progressive) politicians. On the other hand, respondents might also blame their largely Democratic state and local politicians for contributing to the wildfire risk and outages. Overall, as demonstrated by Fig. 7, we do not find evidence that exposure affected overall attitudes towards former President Trump, Governor Newsom or local politicians.

We also estimated the effect of outage exposure on politician approval, splitting the sample by partisan identification. Given extreme partisan polarization in the United States, it is plausible that experiencing a negative event such as an outage would affect politician approval only among political independents, who are more willing to draw on their experiences to update political attitudes[27]. Indeed, when we split the sample by partisan identification, we find some suggestive evidence (though not statistically significant) that Independents exposed to outages had a lower approval of Governor Newsom.

Discussion

PSPSs are an increasingly common climate adaptation policy used in California. As climate change worsens, so too will energy system disruptions. How will the public respond to adaptation policies, such as PSPSs? These disruptions are distinct from direct experiences with natural disasters and extreme weather, which have been the primary focus of studies to date. Instead, the disruptions are indirect and the result of adaptation policies aiming to reduce climate risks. Our work suggests that the public may not view these policies as a response to climate change. At the same time, the outages still shifted behavioural intentions in consequential ways for climate mitigation and adaptation policy by changing energy and climate-related behavioural intentions. Our findings are thus consistent with a separate cross-sectional survey of Californians following the 2019 power outages[22]. Broadly, public responses to these power outages reflected households' short-term and proximate needs—maintaining power and reducing fire risk—rather than efforts to mitigate climate change, a systemic but indirect driver of this energy system disruption. In this way, direct experiences with a climate adaptation policy in the power sector may have somewhat undermined climate mitigation. Moreover, outage-exposed respondents tended to blame their utility, who made the proximate decision to implement the outages, rather than the politicians, who could potentially be held accountable for the systemic policies that shape climate change risk.

Our results are largely robust to a number of alternative specifications that we present in our supplementary materials. These include: adjusting by a set of covariates (Supplementary Note 3); checks where treatment assignment is determined purely by their location, versus self reports (Supplementary Note 4); and using a two-stage least squares analysis where location-based treatment

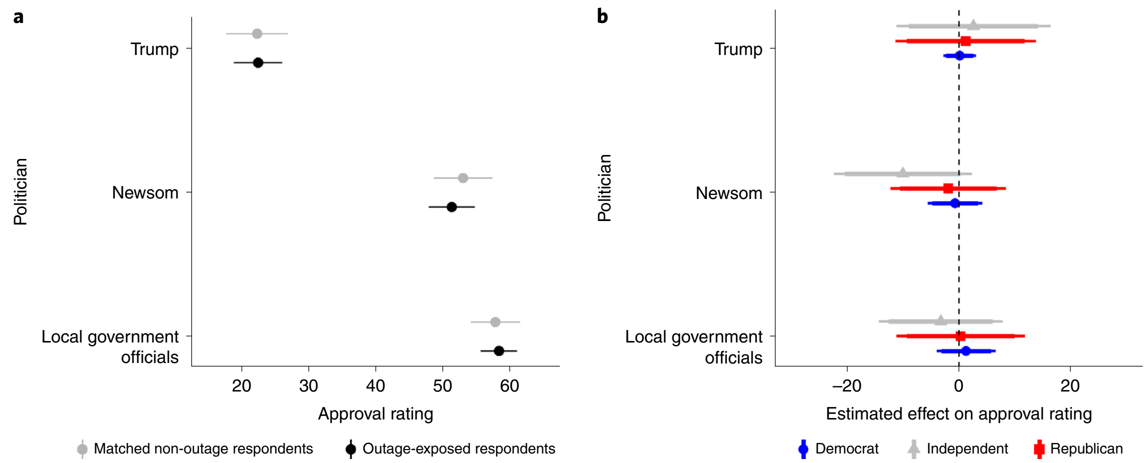

Fig. 7 | Effect of outage exposure on politician approval ratings. a, Average politician approval rating (on a scale of 0–100) for matched outage-exposed ($n=338$) and non-outage-exposed respondents ($n=195$). **b**, Estimated effect of outage exposure on approval ratings in matched sample by partisan identity. Bars in **a** are 95% confidence intervals. Bars in **b** provide 90% (thick) and 95% (thin) confidence intervals.

assignment is used as an instrument for for self-reported outage exposure (Supplementary Note 4).

Overall, our findings question assumptions that individuals will change their attitude and behaviours if simply informed about the ways that climate change will personally affect them or if they experience a climate-related hazard event, particularly when—as was the case with the 2019 Californian outages—climate change was not portrayed as a major event driver. Efforts to decarbonize our energy systems cannot assume that as climate change accelerates, dramatic power sector disruptions and adaptation policies will mobilize the public behind climate mitigation policies. Instead, public attitudes and behavioural intentions will reflect a complex and sometimes counterproductive interplay of climate and non-climate concerns.

Methods

Sampling approach. Our data collection protocol began with creating a spatially disaggregated sampling frame that allowed us to target individuals who experienced at least one PSPS and groups of otherwise similar residents. In general, the boundaries of PSPSs are a function of local transmission networks that remain opaque to most residents. Because transmission networks play a negligible role in structuring where people choose to live, we can estimate the causal effect of outage exposure on public attitudes by matching respondents within outage zones with otherwise similar respondents just outside outage zones.

Specifically, during the fall 2019 PSPS events, we collected spatial polygon files publicly shared online by PG&E for each successive shut-off event. We intersected all outage polygons to define the spatial extent of Californians who were projected to experience one or more PSPS events in the PG&E service area during October and November 2019. We also recorded the number of overlapping projected outages experienced in each part of the service area.

We then defined a series of additional spatial zones using buffering methods. First, we defined a spatial zone containing all areas within California located between 0 km and 1 km *inside* the projected outage zone boundaries. Second, we defined a spatial zone containing all areas located between 0 km and 1 km *outside* the outage zone boundaries. Third, we defined a spatial zone containing all areas located between 1 km and 20 km *outside* the outage zone boundaries. For all zones, we excluded Sonoma County because active wildfires and evacuations associated with the 2019 Kincade Fire remained in effect there during our survey period. Figure 1 illustrates these different spatial zones that structure our survey sampling frame.

Using the WorldPop gridded 100 m population dataset as a probability surface, we generated 1 million points within Northern California county boundaries, weighted by population distribution. This point dataset simulated a random sample of the population within our target counties. For every point, we extracted its CalFire fire threat zone from CalFire gridded data (https://frap.fire.ca.gov/mapping/gis-data/) and its census tract identification. We then subset this Northern California point sample layer by clipping to each of our four spatial zones: (1) 0–1 km buffer outside outage boundaries; (2) 0–1 km buffer inside outage boundaries; (3) 1–20 km buffer outside outage boundaries; (4) actual outage boundaries. This created four-point sample layers for geocoding. Within each layer, we randomly sampled 6,000 points. Then, using the Google reverse geocoding API (via the 'ggmap' package[28]), we reverse geocoded the coordinates of each sample point in all four layers. Reverse geocoding produced a street address (if available) for each point and a label indicating whether the address was a 'premise' (Google's label for a dwelling unit). We then subset reverse geocoded points to only those with street addresses identified as premises and removed duplicates. Finally, we randomly subset 3,000 addresses in each zone, except for the full outage zone, where we selected 6,000 addresses to sample. In Fig. 1 we also visualize address-level sampling points in the eastern San Francisco Bay Area. As an exploratory effort, we also generated a list of control addresses in Southern California. This sampling process is described in Supplementary Note 5.

Overall, this sampling process resulted in a list of 15,000 addresses: a representative sample of 6,000 addresses from within the PSPS outage zone, a representative sample of 3,000 addresses from 0 km to 1 km inside the outage boundary, a representative sample of 3,000 addresses from 0 km to 1 km outside the outage boundary and a representative sample of 3,000 addresses from 1 km to 20 km outside the outage boundary. We visualize this sampling frame as Fig. 1.

On 14 November 2019, we mailed a customized letter to each of these 15,000 addresses, inviting one resident from each household to participate in an online survey on California's electricity system (Supplementary Note 6 provides example recruitment letter). Each letter contained a customized URL so that we could identify the spatial location for every survey response. Respondents who completed our survey received a US$5 digital gift card by email that they could redeem at dozens of different online retailers or that they could donate to a charity of their choice. As a result of our initial letter, we received 565 complete survey responses. On 3 December 2019, we sent a follow-up letter to all individuals who had not completed the survey, again inviting them to participate. This generated an additional 325 survey responses. In total, we received 911 complete responses, a 4.94% response rate. We recorded a response rate of 5.73% across all outage areas ($n=495$), 5.03% in the buffer between 0 km and 1 km from the outage boundary ($n=151$), 4.97% in the buffer 0 km to 1 km outside the boundary ($n=149$) and 3.87% in the larger buffer 1 km to 20 km outside the boundary ($n=116$). Supplementary Note 7 provides a map of respondents' addresses. We provide the full text of our survey instrument as Supplementary Note 8. Respondents provided research consent on the first page of the survey.

Among our sample of respondents located within the outage zones released by PG&E, 85% reported experiencing at least one recent power outage. Of those respondents, the majority (57%) reported experiencing more than one outage. Among respondents who experienced an outage, a majority were without power for three or more days.

Respondents who self reported experiencing a planned outage differed systematically from respondents who were not exposed to outages, as demonstrated by Table 1. This may be a function of topography, where distances of 1 km from the outage boundary in Northern California include stark differences in urban (low-lying) versus suburban and periurban neighbourhoods (hillside) across the Bay Area. In particular, those exposed to outages had higher educational attainment, were older, were less likely to be employed and were less likely to speak English at home. As a result, we should still be concerned about underlying differences in attitudes and behaviours when making naive, direct comparisons between these groups.

Analytical strategy. To address these possible underlying variations between these treated and untreated groups, we used a matching algorithm to construct a plausible control group and estimate the effect of exposure to outages. Specifically, we leveraged genetic matching[29] via the 'Matchit' package in R to identify a set of individuals that were not exposed to outages that were otherwise comparable to the individuals exposed to outages. An alternative approach is to compare individuals on either side of the boundary between outage-exposed and non-outage areas through a geographic regression discontinuity design[30]. If the boundary is randomly placed, we would expect, within a small geographic window around the boundary, no systematic differences between treatment and control groups. The problem with this approach in our case is imprecision in the spatial data specifying the outage-exposed areas. Only 25% of respondents living between 0 m and 1,000 m on the inside of an outage zone (as reported in the data provided by PG&E) reported exposure to planned outages, while 12% of respondents living between 0 m and 1,000 m on the outside of an outage zone reported exposure. Given this imprecision, the matching design provides much greater leverage for estimating the effect of outages exposure. In this way, our spatially resolved sampling helps us to identify high quality likely matches for treated respondents; likewise, the quasi-arbitrary nature of outage boundaries reduces somewhat the risk of persistent unobserved confounders.

The matching algorithm identified 533 respondents (of 739 in the Northern California sample) for whom we were able to achieve balance on key covariates: 338 reported that they experienced a planned outage (treatment group) and 195 did not (control group). Table 1 also presents summary statistics on the individuals in the full sample and the matched sample.

In the main text, we measure outage exposure by respondent self reports, as measured in our survey instrument. In Supplementary Note 4, we show that all results are replicated if we instead measure outage exposure based on whether an individual resides within the spatial boundaries of the planned outage as released by PG&E during the PSPS events.

In the paper's main analysis, we estimate the effect of outage exposure by calculating the difference in means between the treatment and control groups in the matched sample. By contrast, in the robustness tests presented in Supplementary Note 3, we estimate a linear model among respondents in the matched sample:

$$y_i = \beta_1 T_i + \beta_2 X_i + \alpha + \varepsilon_i \tag{1}$$

Respondents are indexed by i. T_i denotes outage exposure and X_i is a matrix of demographic covariates measured at the respondent level. α is an intercept, and ε_i represents standard errors. We exclude income from the covariates in regression adjustment because high missingness reduces sample size considerably. Table 1 indicates balance on income. Discussion of covariates included and estimates from covariate-adjusted models are provided in Supplementary Note 3. Throughout, all statistical tests are two sided.

In addition to using the survey for causal inference, we also leveraged the survey to gain insights about the public's understanding of reasons for the planned electricity outages. For respondents who had reported experiencing a shut-off, we asked, "In a few words, why do you think your electricity was shut off?" For respondents who did not report that their own electricity was shut off, but that electricity of other homes in their communities was shut off, we asked: "In a few words, why do you think the electricity of other homes in your community was shut off?" Overall, 426 respondents answered the open-ended question. We first conducted an analysis of the most common words used. The five most common words were 'fire' (177 times), 'wind' (129), 'PG&E' (125), 'power' (91) and 'high' (91). From this preliminary analysis, and from inspecting the first 100 responses, we generated five non-unique (for example, a single response can fall into multiple) keys for responses: weather and fire risk, PG&E taking action to protect public safety, negligence or corruption on the part of PG&E, government negligence or corruption and uncertainty as to what caused the shut-offs. We discuss the proportion of responses that fell into each category in the main text.

In the main text, we also report median respondent willingness to pay (both financially and in terms of days without power) to reduce fire risk and make the electricity system more stable. To estimate willingness to live without electricity to reduce fire risk, we asked respondents, "Would you be willing to live without electricity for X days each year to reduce the risk of wildfires in California?" We randomly assigned X from among 1, 2, 3, 4, 5, 7, 10, 14 and 21, and used the function 'sbchoice' from the package 'DCchoice' in R to compute median willingness to pay. We conducted similar analysis for the other willingness-to-pay items. To estimate willingness to pay a surcharge to reduce future planned power shut-offs, we asked, "Would you be willing to pay a surcharge of $X every month on your electricity bill to avoid future planned power shut-offs?" We randomly assigned X from among US$1, US$2, US$5, US$7.50, US$10, US$15, US$20, US$30, US$40, US$50, US$75, US$100, US$150 and US$250. To estimate willingness to pay to bury power lines underground, we asked, "How much would you support burying power lines in California if it cost you $X more per month on your utility bill for the next 10 years?" We provided more detail in a prior vignette: "A number of different policy ideas are being discussed to try to make the electricity system in California more stable. One idea is to bury power lines underground. This would likely cost $3 million per mile. Currently, California has over 175,000 miles of overhead power lines. This means that burying all California power lines would cost over $525 billion dollars, more than twice the state's total annual budget for all government spending." For this question, we randomly assigned X from among US$1, US$2, US$5, US$10, US$25, US$50, US$75, US$100 and US$110.

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

Data availability
The underlying data used in this article has been deposited in a Harvard Dataverse repository to accompany publication of this article, available at https://doi.org/10.7910/DVN/UUYMNG.

Code availability
The code and replication scripts necessary to generate the figures, tables and analysis reported here have also been been deposited in the Harvard Dataverse repository at https://doi.org/10.7910/DVN/UUYMNG.

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Author contributions

M.M. and P.D.H. jointly participated in all stages of this study, including design, data collection, analysis and writing. S.T. participated in analysis and writing. L.C.S. and M.L. participated in design, data collection and writing.

Competing interests

The authors declare no competing interests.

Ethics statement

This study was reviewed and approved by the University of California Office of Research as Protocol 22-19-0808. Respondent participation in our survey was voluntary, and respondents provided informed consent before taking the survey.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s41560-022-01071-0.

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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	Survey data was collected using the online Qualtrics survey platform.
Data analysis	All data was analyzed using the R (version 4.2.1) statistical computing platform, including the Matchit package (version 4.3.4), the ggmap package (version 3.0.0) and the DCchoice package (version 0.1.0). Replication scripts are available as part of a Harvard Dataverse repository at https://doi.org/10.7910/DVN/UUYMNG.

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All data necessary to replicate and support the study's empirical findings have been deposited as part of a Harvard Dataverse repository at https://doi.org/10.7910/DVN/UUYMNG. The sampling frame for this study also used publicly available WorldPop gridded 100 meter population data and shapefiles of planned outages that were publicly released by Pacific Gas & Electric during the study period. These outage shapefiles have been archived as part of the same project Harvard Dataverse repository.

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Behavioural & social sciences study design

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

Study description

This study reports on the results from a new public opinion survey of California residents. Survey data is analyzed using quantitative statistical analysis.

Research sample

Our sample was all Californian households residing in specific spatial zones, with zones defined in relation to the distribution of power outages in Fall 2019. The construction of zone boundaries is described below in the "Sampling Strategy" section. This sample provided a direct way of measuring the experiences and attitudes of Californians exposed to power outages in Fall 2019.

Invitations to participate in our study were provided to representative samples of households in each of the spatial zones defined below. The representativeness of respondents who volunteered to participate in the study could depart from being fully representative to the degree that particular types of households were more or less likely to accept our invitation. Additionally, we should not expect that a random individual in a given household will reply to the sample; instead, older household members who are more likely to be responsible for managing household mail are more likely to receive and reply to the invitation. Overall, our sample was 49% female with an average age of 56. Respondents had an average education level of 4.5 on a 5 point scale and an income level of 2.6 on a 4 point scale. 68% married of respondents were married, 55% were employed and 22% spoke a language other than English at home. Our analytic strategy reflects the structure and characteristics of this sample.

Sampling strategy

During planned safety power shut-off (PSPS) events in Fall 2019 in California, we collected spatial polygon files publicly shared online by the electric utility PG&E for each successive shut-off event. We intersected all outage polygons to define the spatial extent of Californians who were projected to experience one or more PSPS events in the PG&E service area during October and November 2019. We also recorded the number of overlapping projected outages experienced in each part of the service area. We then defined a series of additional spatial zones using buffering methods. First, we defined a spatial zone containing all areas within California located between 0 and 1 km inside the projected outage zone boundaries. Second, we defined a spatial zone containing all areas located between 0 and 1 km outside the outage zone boundaries. Third, we defined a spatial zone containing all areas located between 1 and 20 km outside the outage zone boundaries. For all zones, we excluded Sonoma county because active wildfires and evacuations associated with 2019 Kincade fire remained in effect there during our survey period.

Then, using the WorldPop gridded 100 meter population dataset as a probability surface, we generated 1 million points within Northern California county boundaries, weighted by population distribution. This point dataset simulated a random sample of the population within our target counties. We then subset this Northern California point sample layer by clipping to each of our four spatial zones: 1) 0-1 km buffer outside outage boundaries; 2) 0-1 km buffer inside outage boundaries; 3) 1-20 km buffer outside outage boundaries; 4) actual outage boundaries. This created four point sample layers for geocoding. Within each layer, we randomly sampled 6000 points. Then, using the Google reverse geocoding API (via the ggmap package in R), we reverse geocoded the coordinates of each sample point in all four layers. Reverse geocoding produced a street address (if available) for each point and a label indicating whether the address was a ``premise'' (Google's label for a dwelling unit). We then subset reverse geocoded points to only those with street addresses identified as premises and removed duplicates. Finally, we randomly subset 3000 addresses in each zone, except for the full outage zone, where we selected 6000 addresses to sample.

Overall, this sampling process resulted in a list of 15000 addresses: a representative sample of 6000 addresses from within the PSPS outage zone, a representative sample of 3000 addresses from 0 to 1 km inside the outage boundary, a representative sample of 3000 addresses from 0 to 1km outside the outage boundary, and a representative sample of 3000 addresses from 1 to 20 km outside the outage boundary.

We ultimately received responses from 890 respondents (for a 4.94% response rate).Our sampling strategy maximized sample size given available resources, rather than reflecting statistical simulations.

Data collection

Respondents were contacted by mail inviting their participation in our study. Respondents who decided to participate were directed to a web-based survey that was hosted on the Qualtrics survey platform. Respondents were compensated with a $5 online digital gift card for their time. This was provided by email upon survey completion.

Where survey content was randomized, this was automated so that the research team was blind to which respondent received which experimental condition. Respondents were blind to experimental conditions and the study's theoretical hypotheses. Respondents were invited to the survey with the prompt: "We want to ask you a series of questions about your community and the recent power shut-offs in many parts of California."

Timing

We mailed a survey invitation to respondents on November 14 2019. On December 3 we sent a follow-up postcard to individuals who had not yet responded to our initial invitation. All respondents completed the survey before the end of December 2019.

Data exclusions

No data was excluded from the analysis. In our manuscript some of our findings report subgroups, all clearly specified and explained

Non-participation	Our survey had a 4.94% response rate. Participation was voluntary.
Randomization	Some components of the survey were randomized. Participants were randomly allocated (without researcher control) to these survey components through automatic randomization features built into the Qualtrics online survey platform.

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.

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Methods

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

Human research participants

Policy information about studies involving human research participants

Population characteristics	See above
Recruitment	Our sampling procedure generated a list of 15,000 Californian addresses that met our spatial sampling criteria (see Methods section in our manuscript, and research section above). We mailed invitation letters to all of these addresses. Respondent participation in our survey as a response to this survey was voluntary and included informed consent before completing the survey. As with all surveys, it is possible that certain types of respondents differentially responded to the survey invitation, though our use of financial compensation can partially mitigate some of these selection pressures. Our analytic strategy is not premised on particular response dynamics. However, patterns of survey invitation response could still condition the generalizability of the findings to types of individuals who systematically refused to reply to the survey invitation.
Ethics oversight	The University of California Santa Barbara Office of Research, Protocol 22-19-0808

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