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POPULAR IMPACT: PUBLIC OPINION AND PLANETARY DEFENSE PLANNING

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Introduction

In February 2023, NASA began tracking a near-earth object (NEO, in this case an asteroid) in space that they designated as having a non-zero probability of hitting the Earth. The European Space Agency added the asteroid, 2023 DW, to its Risk List. NASA's capacity to track these objects has received a boost in recent years as budgets for planetary defense have grown 4,000% in a decade (Drier 2019). With this rise, new initiatives and proposals increasingly explore new approaches for asteroid deflection, including the use of nuclear explosives. In this environment, technical feasibility is a necessary but not sufficient condition for policy success. Within democratic societies, public acceptance is a necessary ingredient in legitimating a policy and shaping its contours. Almost entirely ignored in debates about planetary defense, however, are questions of public support for these policies.

Previous research primarily views the public as reactive, framed within disaster-response perspectives that attempt to organize the disclosure of information (Billings 2015). Only a rare subsection of research here has explored the public's role prior to any active threat scenario, and even most of this work relies on generalized notions of education and outreach (Friedman 1996, France 2000, Haddaji 2021, Billings 2021). This leaves planners with limited information on how the public engages with ongoing and future policies.

What little information we do have paints a mixed picture with respect to the public's risk assessment and corresponding policy preferences. Surveys investigating the public's projection of hypothetical threats places asteroid impacts as nearly last, indicating a widespread expectation that we are highly unlikely to face any asteroid impact threat (Friedman 2019). And yet, other survey research has seen the public rank planetary defense as their second-highest priority, almost on-par with demands for deploying space assets to track climate change, and far above currently better-funded projects like human space exploration (Funk and Strauss 2018). Although the public considers impact threats as highly unlikely, they do appear to believe that planetary defense is important. What explains public support for a low-likelihood, high-consequence threat, including variation in the modality of planetary defense policies?

In this research, we explore several factors that may inform public preferences for low-probability, high-consequence risk mitigation. We argue that the public's preferences can be modeled as an expected utility function, where the expected probabilities, costs, and benefits of planetary defense policies shape individual considerations. Opinion sensitivity is therefore predicated on information that shapes beliefs about the probabilistic risk of facing a given hazard; the characteristics of risk mitigation methods; and the

side-benefits of investment into these methods. First, we observe that individuals will condition their assessment of risk probability–the danger ascribed to hazards like asteroid impacts–on the credibility of informational sources. Variable perceived credibility across different authorities can greatly modify the context and the interpretation of identical information (Druckman 2001, Wachinger et al. 2012, Kreps and Wallace 2016). In turn, the salience of threat ascribed by informational authorities shapes the public's support for prioritizing risk mitigation.

Second, the public may hold preexisting preferences for the format of a mitigation policy, and thus increase their confidence in a mission that includes desired policy components. Engaging with policy options currently under consideration allows the public to identify a "correct" combination of policy components that provide sufficient confidence in investments (Drews and Van dem Bergh 2016, Stadelmann-Steffen and Eder 2021). Third, we expect that the public will engage in issue linkage and tie support for particular risk mitigation to the prospect of parallel distributional benefits, such as economic development (Halsnæs and Verhagen 2007, Lockwood 2011, Rouillard et al. 2015), international status (Musgrave and Nexon 2018, Grydehøj and Kelman 2017), or military power (Khong 2019, Peldszus 2021, Wolfe 2022). Despite the rarity of some threats, the guarantee of side-benefits from policy implementation, regardless of whether the primary threat ever appears, reframes benefits of risk mitigation from a lottery to a source of public goods, in which case mitigation policies provide other benefits even if not narrowly for planetary defense.

We test these three factors through a survey experiment fielded in the United States and United Kingdom and United States in 2023 that assesses the plausibility of each mechanism. We select these two countries because they are both English speaking but spend considerably different amounts and have different roles in space exploration, which could produce a range of views about planetary defense or indicate whether these views are unrelated to individual country's capacity for planetary defense. First, we evaluate the relationship between individuals' perceived credibility of information sources and their expected likelihood of asteroid impact to in turn establish the potential effectiveness of specific policy elites to more credibly establish the need to commit more resources for planetary defense. Second, we employ a conjoint experiment that varies technical, political, and temporal components of hypothetical planetary defense missions to isolate the features of planetary defense that the public would support. Third, we include a vignette about space that experimentally varies supplemental economic, political, and security side-benefits or opportunity costs of investment into planetary defense to test which justifications augment or detract from policy proposals.

We find support for all three considerations. Trust in scientists and researchers as an informational authority is very high and correlates with the most accurate understanding of asteroid impact threat probability. In parallel, inaccurate and exaggerated threat perceptions correlate with greater support for increasing investment into planetary defense. However, broader informational engagement still clearly outweighs any "costs" of accurate perceptions. Nearly all survey respondents support a major allotment of disaster management resources to planetary defense, approximately 10.5% of an abstracted disaster management budget, and allocate an average of 3% more at the end of the survey, even though they recognize that near-earth object impacts are "black swan"-type events. Despite findings that accurate perceptions of probability predict a lower baseline for support, the receptiveness to information gleaned over the course of the survey strongly supports the value of public outreach and education efforts for justifying current and future expenses and activities.

Next, respondents show statistically significant and robust preferences for missions that are multilateral, deploy kinetic impactors, and launch early (closer to the discovery of a potential hazard, rather than later in its approach towards the Earth). In addition, not only do these components increase support for a hypothetical mission, but excluding them in favor of any alternative methods (acting unilaterally, utilizing nuclear explosives, or launching later in the threat's approach towards the Earth) are all associated with lower levels of support. Lastly, economic development and dual-use security applications are associated with modest increases in support for greater investment into planetary defense.

Beyond the primary mechanisms we tested, we also uncovered several other findings. We find that support for increased funding for planetary defense is associated with a preference for prioritizing space activities at the national level, suggesting that specific judgements on planetary defense tie into generalized views on the value of the broader space program. Further, the public generally reports a moral obligation to protect all countries from asteroid impact threats, including states politically unaligned

with their own, and even geopolitical rivals. Although the strength of these perceived obligations varies, these results bode well for those concerned with potential for opportunistic behavior by mutually antagonistic states during an actual crisis.

This research makes several important contributions. It adds to the literature on the psychology of risk and security, and especially for current planetary defense policy. Identifying the respective weight the public places on sources of support for risk-mitigation lends to a generalizable framework for analysis and policy design of other risk-management programs. Specifically, this project tests in synthesis certain explanations that previous risk studies have primarily studied separately (Balog-Way et al. 2020, Renn 2020, Rickard 2021), allowing for a more holistic understanding of simultaneous heuristic processes. Further, it contributes to policy-relevant questions about planetary defense. Our findings suggest that simply because something *can* be done does not mean that the public will support the technical solution and leaders should not take their freedom of action for granted, recognizing what paths may serve as potential tripwires for the public, nor should they miss effective solutions for fear of opposition. Despite arguments in favor of specific mission parameters based on efficiency, particularly the use of nuclear explosives (Green 2019, Osberg et al. 2020, Doboš et al. 2022), policymakers cannot assume the availability of such methods without first shifting public opinion. The survey results highlight the opportunity for further outreach that might shift public perceptions of planetary defense and provide policymakers with policy flexibility.

Transnational Challenges to Planetary Defense

Robert Dahl, a scholar of American democracy, wrote prophetically in 1994 that “the boundaries of a country, even one as large as the United States, have become much smaller than the boundaries of the decisions that significantly affect the fundamental interests of its citizens” (Dahl 1994). His observation built on the unexpected opposition that the citizens of European countries had expressed toward the Maastricht Treaty that would create a common currency in Europe, but the observation carries much further today. Since the early 1990s, the political science literature has increasingly focused on transnational institutions and, correspondingly, challenges or risks that transcend traditional boundaries and challenge conceptions of national sovereignty. Many such risks are difficult for states to address alone, due to their scale, dispersion, and complexity, but are unavoidable due to the interconnectedness of risk-prone material and social infrastructures (Centeno et al. 2015, Galaz et al. 2017, Schweizer and Renn 2019). But the presence of an international concern hardly guarantees that those afflicted will devote sufficient attention to its solution, at home or abroad. As issues like climate change, nuclear proliferation, or global pandemics imply major costs, free-riding incentives inevitably emerge and a collective action problem obstructs support for solutions (Kaul et al. 2003, Barrett 2007, Buchholz and Sandler 2021).

Any investment or international cooperation is complicated by the inherent political nature of transnational challenges. International politics can have major domestic impacts, empowering interests and interacting with domestic institutions (Gourevitch 1978). Thus, policy solutions to transnational challenges are inherently high stakes for invested actors. Considering such interests, some scholars model the decision to cooperate across borders as a two-level game, highlighting the need to convince both foreign partners and domestic constituencies to act (Putnam 1988), including for international public goods (Kroll and Shogren 2008). Furthermore, knowledge of distributional interests makes actors hesitant to act, as the omnipresent incentives for parochialism may leave them too suspicious for even mutually beneficial collaboration.

Any solution must therefore overcome relative cost concerns, where two considerations predominate. Preferences of the actors most directly affected by policy implementation shape their reaction to any proposals, particularly if they would derive rents or public goods from the status quo that could be undermined by new policy (Genovese 2019). In conjunction, catalysts or obstructions to consensus are sometimes endogenous to the issue area itself, mediating mobilization by political entrepreneurs (Kapstein and Busby 2016). Policies only reach implementation when they achieve a favorable coalition of interests, accommodate underlying conditions of the policy area and policymaking environment (Kingdon and Stano 1984, Petridou and Mintrom 2021). Such a coalition is only possible by adjusting policy to match the perceptions of key players, such as policymakers or the public, to achieve “transcendent solutions” that maximize policy acceptability until a viable coalition becomes possible

(Farnham 2004). If perceptions of vital supporters form heuristically, entrepreneurial efforts to shape the perceptions will make or break the consensus necessary to address a transnational challenge, particularly multilaterally (De Vries et al. 2021).

Public Attitudes on Planetary Defense

Planetary defense is a collective action problem (Avnet 2012) in that one state's investment inevitably protects other actors in non-excludable ways, therefore reducing the incentives for individual solutions yet creating challenges for international cooperation by raising questions about where the investment costs should be concentrated. Planetary defense consists of observation, characterization, threat-mitigation, and disaster response to deal with threats from near-earth objects. Nearly 30,000 near-earth asteroids have been discovered since 1980, the vast majority of which are not expected to threaten Earth for at least the next few centuries (Space Studies Board 2010). However, this survey has yet to capture many additional existing NEO and cannot account for many comets, whose elliptical orbits carry them far beyond visual range, which obscures the risk of their relatively swift approach on reentering the inner solar system (Gehrels 2021). Although an NEO has yet to cause a single confirmed casualty, their ability to cause great damage is well-documented, even for smaller objects (Perna et al. 2013, Yeomans and Chodas 2013).

To address this potential threat, governments worldwide have increased their research, development, and testing. Funding for NASA's Planetary Defense Coordination Office increased by over 4,000% in 10 years (Dreier 2019) and the agency recently launched an experimental test of kinetic deflection of an asteroid (Rivkin et al. 2021). Other space programs have likewise rapidly escalated their ambitions, with China raising the policy to a near-term priority (Goswami 2018) and the European Space Agency scheduling its own interception experiment for 2024 (Michel et al. 2021). Against the backdrop of large increases in spending on planetary defense, studies of public attitudes toward the policy have been comparatively sparse. Public support may not be determinate but leaders in democratic countries have electoral incentives to heed public opinion (Tomz et al. 2020). Further, democratic countries like the United States have a long history in which public concerns about risk perception or indeed misperception drive policy and regulation (Morgan 1993). Understanding the public's sense of risk and investment on planetary defense is warranted by way of gleaning the potential bottom-up effects of the public on either more or less aggressive prophylactic measures toward planetary defense (Kertzer and Zeitoff 2017).

Although there have been cursory investigations of public opinion on planetary defense, data is extremely sparse and suggests some puzzling, but not entirely incompatible, findings. First, a Pew Research poll conducted in the United States suggests that the public is generally supportive of planetary defense, with two-thirds of respondents ranking it as "top priority" and as the second highest overall preferred priority for the American space program (Funk and Strauss 2018). These results, while limited to a single question on one survey, in which planetary defense was not even a major focus, stand in stark contrast to the actual distribution of the American space program. Despite ranking near the top of all options in popularity, planetary defense today still occupies a relatively small portion of the budget for the space program, with the fiscal year 2023 request for $138 million consuming little of the $25.4 billion total NASA allocation. In juxtaposition, manned spaceflight missions to the Moon and Mars, which NASA currently lists as its main priorities and whose own funding is over 130 times greater than planetary defense (Dreier 2021), ranked last and second to last, respectively. This survey initially seems encouraging for planetary defense planners, as their program appears quite popular across many demographics. However, a separate survey conducted in the same year found that, from a selection of 100 potential concerns, respondents ranked an asteroid impact as second-most statistically unlikely (Freidman 2019). This suggests the possibility that the public is highly supportive of planetary defense, despite perceiving the threat it addresses as extremely rare.

These previous studies are revealing in some ways but also have major limitations. First, neither survey tested public support for planetary defense directly or independently from other activities, making it difficult to distinguish their specific views from the process of considering parallel policies and hazards simultaneously. Second, both surveys used restrictive measures of public support that complicate application of their findings. The Pew Research survey used a semi-approval voting approach, where respondents were able to state their support for planetary defense but with no quantified specification of degree or relation to allocation for non-space policies, while Freidman's survey reduces support for

mitigation to a binary. Third, both served as purely descriptive examinations, with no consideration of how heuristics actively shape public preferences. Because the public is unlikely to eventually encounter planetary defense in the vacuum of an experiment, these survey results may not have held if their respondents were exposed to more specific information about planetary defense. As such, further examination is warranted to understand the reasons for why the public could be so supportive of prioritizing planetary defense in national policy despite being aware of the rarity of its necessity.

Behavioral Measurements and Risk

A behavioral study of public attitudes provides the ideal analytical tool for assessing public attitudes toward the NEO threat and appropriate levels and type of investment in planetary defense. As Hafner-Burton et al. (2017) suggest, behavioral studies sidestep strict rationality assumptions or objective material versions of "risk" but rather probe individuals' views about personally and socially constructed phenomena emerging as the product of cognitive biases (Taleb 2007, Royal 2017) and framing effects (McDermott 1998, Kahneman and Tversky 2013). Likewise, the ambiguity of variables involved when multiple risks are bundled together (Halevy 2007) complicate any examination of planetary defense. Low-probability concerns increase uncertainty, and therefore can magnify the effect of parallel or heuristic considerations. In such an environment, individuals could calculate radically different expected utilities from potential solutions to transnational challenges, and low probability alone may no longer preclude support for risk mitigation. The public may resist deviation from the status quo when the solution is complex (Ho and Imai 2008) or jump to heuristic shortcuts for what deviations they would tolerate, such as ideology (Kertzer and McGraw 2012).

A particularly challenging subset consists of "black swan" events, which are not only rare and consequential, but may also fall outside the range of most recorded experience. This lack of precedent data complicates the Bayesian inferences individuals often implicitly rely upon to evaluate their vulnerability to low-probability risks (Royal 2017). Black swan threats have three main characteristics (Taleb 2007). First, they are extraordinarily rare, which induces a cognitive bias against preparation. Second, they have significant consequences, such that their occurrence is both disruptive and damaging. Third, they are rationalized as realistic threats primarily in retrospection, often leading to questions of why such a major risk went unaddressed. Evidence from historical impacts and expanded surveillance increasingly imply that traditional average damage-over-time assessments for near-earth object threats are perhaps imperfect representations of risk. These analyses might warn against investing to prevent a hazard with an impact rate of once per decade, century, or more, but lessons from black swan theory suggest that recognizing that the threat may manifest unexpectedly at any point in that timeframe demonstrates the benefits of beginning preparations sooner rather than later (Melamed and Melamed 2020).Traditional analyses focus on the hazard of asteroid impact as the sole risk involved, but planetary defense can involve other forms of mission failure. Some, like malfunctions in a deflection mission, may simply modify the original impact risk, but others, such as opportunity costs of investment into a program whose expensive application may be wasted on a later-revealed non-threat (Melamed and Melamed 2018), also remain underexplored.

To overcome challenges to statistical inference, public risk evaluations can depend heavily on the context of informational receipt (Fischoff 1981), such that factors like topical familiarity can greatly influence interaction with frames, and therefore their risk calculations as well. In the absence of familiarity, without even limited experience necessary for moderation of elite cues (Bullock 2011), the credibility of the source of what little information there is plays a much larger role (Page et al. 1987, Druckman 2001, Witte et al. 2001, Brown and Bruhn 2011).

The disaster management literature offers an especially fruitful survey of individual engagement with risk from both top-down and bottom-up perspectives. From the view of planners and leaders, risk stems not only from the external threat they seek to prepare for, but also the expected response of their constituencies. Agencies and leaders can face backlash for perceived policy failures, even for rare and unexpected natural disasters (Hilgartner 2007, Atkeson and Maestas 2012), provoking an oft-overestimated fear among elites of mass public panic (Clarke and Chess 2008). Researchers observe this pattern in politics, where cognitive biases of political leaders lead them to often pass on enticing opportunities due to risk aversion (Welch 2005). Thus, leaders have incentives to exert as much control over their policy response as possible, fundamentally shaping policies and institutions to deflect any

potential blame (Hood 2010). This may constrict policy effectiveness, particularly if risky options might contribute comparatively more than policies that are only safer in the political sense. Only understanding which policies cross this line can allow policymakers to determine the ideal trade-off between political and material risk.

From the public perspective, individual reasoning and willingness to support proactive risk mitigation programs vary widely. Civilians sometimes actively avoid voluntary disaster mitigation and preparedness measures, to their own detriment. Common causes for such reluctance include personal underestimation of threat likelihood (Royal and Walls 2019), short time-horizons, concern over budget constraints, relating their position to the rest of the local community (rather than the underlying threat situation), and the assumption that existing government efforts alone provide sufficient protection (Kunreuther 2006). Therefore, advocacy of preemptive mitigation policies may require additional motivations when security alone is obstructed by misconceptions and cognitive biases.

In other cases, many individuals do comply with government-led disaster preparedness policies, though again rationales vary. For example, the Federal Emergency Management Agency's policy of buying homes in flood-prone territories has been broadly successful, relocating at-risk civilians before unexpectedly rare floods appear (De Vries and Fraser 2012). And yet, inconsistent justifications for this policy led some citizens to require compensatory policies, community engagement, and additional information from the agency to be convinced. This suggests that the public's tolerance for preparatory policies, particularly against rare threats, may depend on considerations besides the threat itself. In particular, secondary characteristics of the government's policy, with externalities for citizens beyond threat neutralization, may inform their risk-assessments and support for a particular response. For policies like planetary defense, which may have significant effects on technology, economics, and politics (Schmidt 2019), these elements could factor into evaluations as much as the hazard they address. However, for externalities to convince individuals to value a policy for its secondary effects, rather than its primary mission, they must become salient enough to the public to deserve consideration. Therefore, determining which issues can effectively link to planetary defense must precede any attempt to shape public engagement with current and future policy proposals.

A Behavioral Theory of Planetary Defense

We theorize that the public is aware that low-probability/high-consequence black swan events like asteroid impacts are rare, but that their views on how to respond are ambivalent. Individuals might support or oppose a particular position but the "considerations" that lead them to express that position might also lead them to the opposite perspective, or to weight their opinions differently (Zaller and Feldman 1992, 585). In this section, we advance a set of analytical expectations about the particularities of those salient "considerations" in the context of planetary defense.

Although asteroids periodically do impact with short notice, few cause widespread damage and, by chance, none have caused casualties. Furthermore, traditional probabilistic risk calculations can artificially suppress expectations and obscure the high damage that could ensue from an actual disaster (Melamed and Melamed 2020). As such, policies like planetary defense should logically result in miniscule expected utility calculations for a purely rational public. An example of this traditional measurement would be:

Expected Utility = Probability(Value of Risk Mitigated) - Cost of Mitigation

However, in the absence of experience, new information weighs especially heavily (Douglas and Wildavsky 1982, Griffin and Tversky 1992). This new information can take multiple forms, which likely appeal to specific different subsets of the public. Specifically, we theorize three pathways that may influence the public's view of risk mitigation policies. First, a trusted authority can lead the public to revise their personal estimations of danger, leading them to accept that a policy solution is necessary. Second, expectations of a credibly effective policy response may appeal to especially risk-averse publics, convincing them to hedge against a low-probability threat through confidence in the specific solution proposed. Finally, it may simply be that the public's expected utility calculation for risk-mitigation relies not on the threat itself, which is probabilistic, but rather on corollaries of the policy response which are guaranteed by its implementation.

Information Authority Trust

Authority can serve as a logical shortcut for a public seeking guidance on an unfamiliar policy set to address and an even more unfamiliar issue. Expert forecasts are often wrong, yet still applied regularly as a baseline for judgements (Tetlock 2005). The sheer presence of a perceived expert opinion should cause the public to reimagine a potential hazard as more realistic, simply because it has come to the attention of the authority providing the information. So long as the public views experts as invested in the issue due to its importance, and not out of their own self-interest, they should reevaluate their probability of the danger, and thus increase the expected utility of mitigation. However, publics attribute different credibility to specific sources, even if receiving essentially the same information (Nisbet, et al. 2003, Boykoff and Boykoff 2004, Anderegg, et al. 2010, Lachapelle et al. 2014). Therefore, if different portions of the public trust divergent sources to inform them, then they will also thus revise their own estimates dissimilarly. These varying estimates can, in turn, produce inconsistent pressure to actively mitigate a risk.

We test a broad range of informational sources and more accurately test their relative strengths. These sources are: 1) domestic government leaders, 2) foreign state leaders, 3) an intergovernmental organization, 4) purely-scientific organization, and 5) a commercial organization. To start, overtly political sources are at once one of the likeliest sources of information on government policy, and also one of the most sensitive heuristics due to their own high salience. Domestic leaders can provide a familiar authority, are expected to be less biased (Gelpi et al. 2009), and enjoy the legitimacy of democratic selection, imbuing planetary defense with credibility. However, partisanship may actually reduce credibility, as party affiliation of the current leadership can serve as a negative heuristic for supporters of different factions (Hayes 2005, Bittner 2014). From issues ranging from climate change (Bolsen and Druckman 2018) to the COVID-19 pandemic (Kreps and Kriner 2020), certain populations have dismissed or rejected guidance from their own representatives and bureaucrats. Even if the lack of politicization of planetary defense so far may reduce some of this effect, skepticism of political leaders based on identity alone may be sufficient to induce some cognitive biases.

International joint missions generally face increased scrutiny over perceptions of fairness of each state's contributions (Tzeng et al. 2007). Likewise, perceptions rely on authorities meeting milestones of effort, such as making contributions on schedule (Adivar and Mert 2010). The public should face significant difficulties in estimating these hypothetically, perhaps instead relying on assumptions and heuristics about the foreign nature of the informer. Foreign leaders are sometimes viewed with greater suspicion by audiences (Hearn 2019), and can carry connotations of their nation's political controversies with them (Katzenstein and Keohane 2007), making them a potentially riskier source of information on risk-mitigation. Certain publics may discount proposals of foreign sources as biased or untrustworthy; a particular concern when seeking public support for international cooperation. Intergovernmental organizations may provide an alternative, though still political, authority on transnational concerns, unbiased by particularistic interests of a specific member. Although some view such organizations as mere reflections of powerful state interests (Mearsheimer 1994, Abbott and Snidal 1998, Koremenos et al. 2001, Hawkins et al. 2006), their provision of an alternative viewpoint to that of domestic authorities can shift public opinion opposite to those authorities (Murdie and Davis 2012).

Apolitical sources may serve as an alternative heuristic, and could be particularly well-suited to appeal to publics on risk-mitigation. These authorities may have more specialized experience and narrower focus on the policy area that allows them to credibly argue for action without appearing untrustworthy. One such source is scientific authorities, which can leverage their expertise to appeal to trust in authorities with greater experience. For low-polarization issues, the salience of expert opinions can increase and effectively shape public opinion (Guisinger and Saunders 2017). For the most part, scientists can engage in policy advocacy without reducing their credibility, though there may be exceptions for few especially controversial policies (Kotcher et al. 2017). However, other research suggests that personal demographic characteristics, such as political polarization (Hardy et al. 2019), inconsistent information (Jensen and Hurley 2010), and an inability to parse the "marketplace of [scientific] ideas" (Kreutzberg 2005) can all reduce scientist credibility.

In parallel, a relatively newer apolitical source of information, particularly on policy responses is private actors. As those invested in the niche market of a particular risk or policy response, private actors

may appeal to the public on the basis of their need to provide the best service in a competitive market environment. Private actors providing goods and services in parallel or separately from governments are also greatly concerned with their credibility (Gourevitch et al. 2012). They often attempt to establish this credibility through "transparency, expertise, and independence" to simultaneously appeal to as many different audiences for legitimacy as possible (Bullock 2015). However, as profit-driven organizations, private actors may also be suspected of suppressing risks whose solutions threaten their interests, or overemphasizing threats specific to their area that may not be a concern for the broader public. Likewise, media reporting of controversies and mismanagement by non-governmental actors can greatly undermine their credibility (Gibelman and Gelman 2004). As such, it is important to test this relatively unexplored source of information.

- *Hypothesis 1a: Respondents will trust apolitical, scientific sources relative to political or business sources on the issue of planetary defense.*

- *Hypothesis 1b: Respondent assessments of the probability of asteroid impact will correlate with their preferred informational authority for planetary defense.*

For the effect of authority-derived probability estimates, if a potential hazard is viewed as less common than its actual occurrence, updated opinions can highlight the need to act. However, for a threat like planetary defense, there may be shifts from several directions. Citizens who never considered the threat at all may recognize a danger worthy of addressing in the first place. Alternatively, those who privately overstate the danger may reconsider after receiving a realistic estimate from a trusted authority, though we do not test this possibility here. However, because the average major asteroid impact rate is sparse, it may in fact be the least accurate assessments that should produce the greatest drive to act. Thus, we add that the prediction from our expected utility formulation described above lends naturally to assuming that those who predict asteroid impact probability as higher should support greater spending on planetary defense.

- *Hypothesis 1c: As respondent assessments of the probability of asteroid impact become less accurate their support for planetary defense will increase.*

Approach to Deflection

The approach to asteroid deflection may also affect public attitudes. Some scholars and policy analysts have proposed carrying out planetary defense in several ways that could affect how individuals perceive the costs and benefits of such an endeavor. First, certain approaches build on the current information-sharing and coordinative bodies of the International Asteroid Warning Network (IAWN) and the Space Missions Planning Advisory Group (SMPAG) (Kofler et al. 2019). Such proposals include arguments for deepening coordination into a common "decision-making protocol" for deflection missions (Perna et al. 2015,) ratification of an international collective security treaty (Bruner 2019), the establishment of entirely new decision-making multilateral political bodies to govern space affairs (Schmidt and Boháček 2019), and even a world state (Dufek 2019). Despite this broad range, the majority of near-term opportunities for multilateralism by national space agencies focus on the foremost options of deepening existing coordination, decision-making, and conduct of joint deflection operations.

Multilateralism, in particular, can signal greater resources and the confidence of other nations in a specific solution. The public should be, on average, more receptive to working with a larger group of states in ensuring planetary defense. We are guided primarily by the collective action problem literature (e.g., famously, Olson 1966) which stresses the rational incentives to not distribute costs across a group of optimal size, as long as the marginal benefits outweigh risks of free riding. However, since Olson, numerous empirical studies have also stressed the desire for multilateralism (Todorov and Mandisodza 2004, Milner and Tingley 2013, Bechtel et al. 2022, Lushenko, et al. 2022). Multilateral approaches to planetary defense are often advocated in academic and policy circles (Schmidt 2019, Mayer 2021). Scholars have pointed to the legitimation of multilateralism in that gaining consent from a diverse group of actors acts as a "second opinion" that validates the wisdom of a particular policy (Grieco et al. 2011). Others have speculated that multilateralism can signal burden-sharing in which the United States or

primary actor would have to appropriate fewer resources amidst a substantive coalition of support (Tomz and Weeks 2021). Based on research about the public opinion upside of multilateralism in other security contexts, we expect this enthusiasm to extend to the public on planetary defense as well.

- *Hypothesis 2a: Respondents are more likely to support multilateral missions over unilateral missions.*

Second, mission designs that match an individual's personal risk acceptance or aversion should appeal more than methods or parameters deemed to place their investment at risk of waste or failure. For negatives, proposals that make use of controversial methods or take greater risks may reduce the public's confidence, leading prospective supporters to hold back and previous backers to retract their endorsement. In particular, the question of nuclear explosives as a tool of planetary defense remains a central concern for social scientists and space law. Scholars have theorized about the use of nuclear weapons to manage asteroid impacts in the literature (Baum 2019, Green 2019, Bohumil, et al. 2020, Osburg 2020, Doboš 2022, Marks 2022), noting the efficiency of the method, which stands in stark contrast to its illegality under the Partial Test Ban Treaty and Outer Space Treaty.

When pertaining to public potential acceptance of nuclear explosives, our beliefs are most guided by scholars of the "nuclear taboo" (Tannenwald 2007, Smetana and Wunderlich 2021) and associated anti-nuclear sentiments. Baron and Herzog (2020) demonstrate that even support for peaceful nuclear energy might be contaminated by the association with violent nuclear weapons. However, some (notably, Press et al. 2013), find that the public actually prefers nuclear weapons when contrasted with a less effective conventional weapon. Likewise, Horschig's (2022) study suggests, the public might be inordinately primed to use nuclear weapons when confronted with their own mortality. It is unclear whether, however, the recorded aversion against, or affinity for, nuclear explosives carries in the planetary defense context, where the target is not only non-human, but not even terrestrial. While there is certainly the possibility that the public would set aside legal constraints and normative concerns for the sake of a successful mission, deployment of nuclear explosives in space remains a relatively abstract and untested concept, relative to the primary modern alternative.

Successful testing of a method may signal a higher chance of mission success, thus enhancing the perceived viability of the mission as a whole. An alternative method to nuclear explosives is deflection by a kinetic impactor, which has been suggested as optimal for the "mid-size near-earth asteroids" (Sánchez-Lozano et al. 2020) that are relatively more common than larger, better-documented asteroid threats, but still quite dangerous. Kinetic deflection remains the only current planetary defense method tested, as of NASA's DART experiment in September of 2022 (Rivkin and Cheng 2023). The test, which successfully shifted the orbital period of asteroid Dimorphous, demonstrated the capability to target, intercept, and redirect a dangerous asteroid; providing a template for a future mission (Daly et al. 2023). As such, respondents may prefer the use of a successfully tested design that does not carry either the normative stigma or legal ambiguity of the nuclear explosive design.

- *Hypothesis 2b: Respondents are more likely to support a kinetic impactor vessel relative to a nuclear explosive.*

Lastly, the question of mission timing is fundamental to mission considerations. Simulations demonstrate that the launch period of a mitigation mission strongly mediates the effectiveness of any payload sent (Melamed and Melamed 2018). Early-launched missions can massively reduce mission costs, redirecting an asteroid with smaller payloads and fewer launches, and with room for follow-up missions in the event of a failed deflection. However, it takes time to characterize the trajectory of an incoming asteroid, and many such objects of initial concern are later revealed to pose no threat to the Earth. In contrast, later launches resolve the information problem by providing sufficient observation to confirm an asteroid's threat, and the necessity of a deflection mission. But by this time, launch costs can increase dramatically, depending on the remaining time until impact.

However, we theorize that the public is more likely to launch planetary defense missions early rather than late, displaying an aversion to security risks over material waste. The tendency towards risk-aversion for low-probability/high-consequence events has been observed in areas such as terrorism prevention (Stewart et al. 2011, Mueller and Stewart 2014), and many probabilistic assessments for risk

mitigation likewise support preemptive investment when vulnerability or potential damage is high, such as for climate change (Stewart and Deng 2015) or infrastructural damage (Cha and Ellingwood 2013). Given the large stakes, the public should be more likely to hedge against asteroid risks despite the compounded risks of mission waste.

- *Hypothesis 2c: Respondents are more likely to support missions that launch early rather than launch late.*

Issue Linkages

Lastly, we believe that issue-linkages may be associated with broader public support. Observed as a successful bargaining tactic to make palatable challenging international agreements (Poast 2012). These allow planners to optimize the timing of costs and benefits of policy to secure either public support or compliance from foreign partners. In particular, a dynamic issue linkage through side benefits can convince key actors to view even large-scale investments not in terms of the current costs but rather the future benefits that can offset them. Linkages can take multiple forms, supporting enforcement, participation, and negotiation of agreements (Maggi 2016). For this latter practice, by negotiating economic policy jointly with non-economic benefits, externalities justify a costly policy where it may not stand on its own. Likewise, issue linkage changes the calculus for interest groups, providing targeted benefits that recontextualize negotiations to give them a stake in the results of the linked policy (Davis 2004).

Risk-mitigation can be linked with parallel benefits, which can be guaranteed by implementation, even if the primary risk the policy is meant to prevent never comes to pass. Logically, risk-mitigation against extreme risks pose the potential for waste, particularly if implemented on a large scale. However, the very nature of large-scale projects involves distributional effects that can create constituencies for the policy who are more concerned with implementation than the objective of the policy itself. Large-scale projects can employ significant numbers of workers, subsidize specific industries necessary for risk-mitigation, and provide prestigious political capital for the implementor. The guarantee that these additional benefits will be available, regardless of whether the risk-mitigation policy they accompany is necessary, may outweigh the costs of even an expensive project. Thus, issue linkages serve as an addition to the expected utility equation as follows:

Expected Utility =Probability(Value of Risk Mitigated) - Cost of Mitigation + Secondary Benefits

For planetary defense, we test three possible benefits unrelated to asteroid impact prevention: political, economic, and security payoffs; and one potential drawback: the opportunity costs of multi-billion dollar investments into planetary defense. Politically, planetary defense may provide significant prestige for any country that achieves the capability, and particularly in exercising it. A successful deflection would be hailed as a defense of the international community and allow countries to assert their desired status, a major concern for many who believe themselves to be “great powers” (Larson and Shevchenko 2010, Heimann 2015). Thus, planetary defense could serve as a status improvement project; one much more affordable than other past prestige projects, such as colonies, military conquests, or even space projects like the Apollo program.

Economically, planetary defense’s costs will undoubtedly please those directly employed, but economic benefits will spread far beyond direct participants. The most recent NASA Economic Impact Report finds that the agency provides a return on its funding three times over (Highfill and MacDonald 2022, NASA 2022). Likewise, specialists predict that planetary defense will support the development of new technologies (Schmidt 2019), some of which may have commercial applications. Planetary defense could therefore serve as a catalyst to the space industry and meaningfully contribute to the broader national economy. Such motives have been observed to apply even when both the technologies in development and risk being mitigated remain distant in the future, such as for climate change management R&D (Kemfert 2004), and thus should apply for future-oriented planetary defense. Next, because some of the developed technologies are dual-use with both civil and military applications (Miyano 2018, Boháček 2022), planetary defense can contribute to security not only from asteroid impact but also from terrestrial conflicts by improving deterrence. Lastly, we also include a clear negative

treatment, highlighting potential opportunity costs stemming from planetary defense, where drawing funds from other programs should test the sensitivity of the public to linkages to drawbacks, rather than side-payments. As such, we propose the following hypotheses:

- *Hypothesis 3: Exposure to economic, political, or security side benefits will increase support for planetary defense whereas exposure to opportunity costs will decrease support for planetary defense.*

Research Design

To test our hypotheses, we deployed an international public opinion survey to evaluate different causes of support for planetary defense, as an exemplar of low-probability risk-mitigation. In sum, we garnered 2,971 respondents using the Prolific and Qualtrics survey platforms together on February 25th, 2023. For our samples, we selected the United States, as the operator of the longest-running and highest-funded planetary defense program. Past survey data has focused on the U.S., and our survey deepens and further characterizes this baseline for international comparisons. For comparison, we collected data from respondents in the United Kingdom, a member of the European Space Agency (ESA), which operates another longstanding planetary defense program and conducts field tests on a comparable scale to NASA. Both are English-speaking countries with continuous participation in space activities, but differ in several areas that could affect the inclinations of survey respondents. The American space program spends more in general where its annual funding is four times greater than the entire European Space Agency's. For planetary defense both NASA and ESA have funded projects worth hundreds of millions of dollars, such as the American DART mission or Europe's upcoming Hera program, though the U.S. still provides greater annual funding, on average. Likewise, NASA and ESA have conducted different missions relating to planetary defense at different times, allowing for different prior exposure to the policy for their citizens. Thus, populations in either region may have different frames of reference when considering planetary defense. We present sample differences to support stakeholders in either country in their planning for their respective planetary defense programs, and to identify any major distinctions that may affect the opportunity for future interactions between NASA and ESA programs.

The survey makes use of a mix of standard survey instruments and two survey experiments. The questionnaire can be divided into three parts: first, a narrative framing vignette experiment; second, a factorial conjoint experiment; and third, a battery of non-experimental questions. We stress that only the first two components are direct, design-based inferential tests for hypotheses; the third component of our survey is designated for exploratory analyses.

The narrative framing experiment tests sensitivity to issue-linkages and side-benefits of risk-mitigation policy. Participants viewed one of five possible vignettes on planetary defense, four experimental and one control, followed by a Likert scale on their support for funding planetary defense in light of that policy. A control group provided neutral information about planetary defense itself, without identifying any additional benefits besides protection from asteroid impacts. The positive frames included a political vignette, which emphasizes that planetary defense will increase prestige and assert international leadership, an economic frame, which suggests that planetary defense will catalyze the growth of the commercial space industry, and a security frame, which notes that the dual-use nature of planetary defense technologies will facilitate national security applications.

Drawing on Chong and Druckman (2007), who presented affirmative and adversarial approaches to assess the strength and position of public opinion on public policy questions, we also included an overtly negative frame, using a vignette that emphasized the opportunity costs of funding planetary defense instead of alternative government programs. The effect of vignette treatment on the Likert scale, which provides options to (greatly or slightly) reduce, maintain, or expand funding for planetary defense, is estimated with OLS regression in three models. The first model regresses only treatment and the outcome variable, which in our randomized experimental conditions may provide the purest test of the theorized relationship. The second and third models add more controls to reduce standard errors in the estimation model. Model 2 exclusively includes standard demographic controls, which cannot be affected by the treatment, while Model 3 applies additional controls relating to respondents' more general views on

planetary defense and space policy. Because the order of the questions providing controls is randomized, we do not expect a danger of post-treatment bias in our regression analysis.

As an added robustness check for longer-lasting effects of the treatments, we additionally include a more granular budget allocation question (with a baseline and endline). The budget allocation question allows us to, at the very least, obtain a naive estimator for exposure to information about planetary defense whatsoever; and separately, it allows us to detect a potential effect of the narrative treatments on the budget question as well. Because the budget question contains an endline after all other substantive questions are asked, we retain our hypotheses for "support" in general as it is tied to the narrative frames; we are agnostic and make no test for the conjoint combinations given that they involve several differentiated combinations of mission parameters.

To test preferences for mission parameters, we used a conjoint design, which is often used in marketing to understand preferences on a wide array of features. In scientific study, it has been used for behavioral studies on vaccine acceptance, for example, to assess the features of a vaccine or its policy that would affect individuals' willingness to accept a vaccine (Kreps et al. 2020). In our case, we were interested in understanding how different aspects of a hypothetical asteroid deflection mission affect support, as well as the specific trade-offs participants make when evaluating potential risk-mitigation solutions. Participants received background information on varied mission parameters to provide a common informational foundation for judgment, and then rate their level of support for a series of hypothetical missions with three unique configurations of these components. Specifically, we varied mission parameters on the type of cooperation involved (multilateral versus unilateral); the deflection method/payload (nuclear explosive versus kinetic impactor); and the timing of the deflection mission (launching early versus launching late). Respondents answered a Likert scale after each of the three hypothetical missions, rating their level of (dis)approval for such a mission. For analysis, we apply the OLS method for conjoint analysis from Hainmueller, et al. (2014). Table 1 presents the key attributes and the levels within that we manipulate. (See our survey questionnaire in the appendix for the specific wording of the conjoint and vignette prompts.)

Conjoint Attributes and Levels	
Attributes	*Levels*
Cooperation	Unilateral Multilateral
Payload	Kinetic Nuclear
Timing	Launch late Launch early

Table 1. Attributes and Levels for Hypothetical Planetary Defense Missions. *Our conjoint vignette presents all three attributes with randomized levels therein. Respondents are not given a dual-choice conjoint, but rather proposals one by one.*

We also included several questions pertaining to our non-causal, exploratory analyses. First, a matrix of authority trust measures support for potential specific sources of information on planetary defense. Respondents rank a series of five potential informational authorities on how much they are trusted to provide credible information on planetary defense. Options here include a domestic head of state, scientists and researchers, a foreign state leader, the United Nations Secretary-General, or private space companies. This initial ranking allows us to directly compare between sources. We follow this trust ranking with respondents' probability assessment of an asteroid impact in their lifetime. The options for this probability measure are non-linear (Less than 1%, 10%, 25%, 50%, 75%, or Greater than 75%), so we estimate the relationship between informational authorities and probability with an ordinal logistic regression and OLS. Lower probabilistic estimates are considered more accurate, in line with the

predictions of standard asteroid impact risk models (Mathias et al. 2017). Then correlation between estimated probability and the two support measures applied elsewhere in the survey test the connection between these estimates and the practical consequences for policy preferences. Support for investment, drawn from the narrative treatment experiment, serves as a direct test, but to avoid conflating the role of probability with the effect of the vignette matched with that outcome variable, we also tested correlation between probability and the change in baseline and endline budget allocations for comparison of effects.

Second, we explored the alternative explanation that ideational-normative beliefs are responsible for support for planetary defense. To measure the distribution of factors like altruistic motives and identification with different populations, we included survey questions on perceived moral obligation to provide protection to the respondent's own country, allied, rival, and unaffiliated foreign states, and the world in general. A stated stronger moral obligation to defend additional populations, particularly foreign ones outside one's own immediate national community, indicates a role for ideational factors and motives outside of rational self-interests indicated by the previous hypothesized heuristics. Likewise, we directly measured the role of status and prestige considerations in supporting planetary defense. Respondents identify, via Likert scale, how much they expect their country's national status and prestige to decline, in the absence of any greater investment into planetary defense. These factors indicate whether the respondents view planetary defense as important for their country's reputation, and how much they consider the policy in social terms of how their decisions would be interpreted by the international community.

Third, we collect other relevant exploratory information, both for its own sake as well as use as controls to dampen standard errors for any design-based inferential models. A measure of media awareness provides a non-comprehensive list of depictions of asteroid impacts in modern media, to control for the often variably realistic depictions of planetary defense therein that could bias participant expectations and understanding of survey instruments. Depictions are limited to works of film and television that explicitly center asteroid impacts, or risks thereof, as the primary focus of the work as a whole. Next, a binary variable for participant awareness of NASA's recent Double Asteroid Redirect Test (DART) mission, which was a successful test of planetary defense methods conducted in September of 2022 to identify familiarity with planetary defense prior to the survey. We also account, with a binary variable for an underlying preference for increasing support for space activities in general, which respondents may interpret as simply including planetary defense within the umbrella of the broader expansion of activities. Lastly, we include a question asking of potential concern of free-riding by other states.

Results

		UK	US	N	Percent (%)
Support	Greatly Reduce	68.00	67.00	135	4.54
	Slightly Reduce	111.00	101.00	212	7.14
	Kept at Present Level	859.00	720.00	1579	53.15
	Slightly Increase	404.00	488.00	892	30.02
	Greatly Increase	48.00	105.00	153	5.15
Treatment Group	Control	284.00	300.00	584	19.66
	Economic	328.00	305.00	633	21.31
	Leadership	288.00	267.00	555	18.68
	Opportunity Cost	299.00	290.00	589	19.82
	Security	291.00	319.00	610	20.53
DART	Have heard of	403.00	442.00	845	28.44
	Have NOT heard of	1087.00	1039.00	2126	71.56
Party	Very Liberal	287.00	278.00	565	19.02
	Moderate	468.00	390.00	858	28.88
	Slightly Conservative	231.00	262.00	493	16.59
	Very Conservative	54.00	44.00	98	3.30
	Slightly Liberal	450.00	507.00	957	32.21
Gender	Female/Other	772.00	761.00	1533	51.60
	Male	718.00	720.00	1438	48.40
Gender	Non-white	192.00	348.00	540	18.18
	White	1298.00	1133.00	2431	81.82
Age	18-19	47.00	52.00	99	3.33
	20-34	428.00	438.00	866	29.15
	35-44	284.00	249.00	533	17.94
	45-54	248.00	247.00	495	16.66
	55-64	345.00	330.00	675	22.72
	65+	138.00	165.00	303	10.20
	All	1490.00	1481.00	2971	100.00

Table 2: Summary Statistics. *Our total* N *is 2,997; we fielded our survey to respondents in the UK and US in two independent, simultaneous disbursements.*

Authority Trust and Probability

We are interested in the relationship between authority trust ranking and prediction probability; secondly interested in the relationship between prediction probability and support; lastly, seeking to determine whether full chain carries, through the trust ranking's association with support. In our battery of regression tests, the probability variable is a 5-point Likert that scales non-linearly: the lowest response is <1%, with subsequent levels of the variable increasing to <10%, <25%, 75%, and then >75%. We make use of an ordinal logistic regression for the first model; and then revert to our usual OLS for the subsequent models. We include a regression for budget change as a robustness check for support (results in the Appendix).

	Dependent variable:				
	Asteroid Disaster Probability *(Ordered Logistic)*	Support *(OLS)*		Budget Change *(OLS; robustness)*	
	(1)	(2)	(3)	(4)	(5)
Distrust of Scientists	0.130***		-0.013		0.099
	(0.048)		(0.019)		(0.213)
Asteroid Disaster Probability		0.077***		0.533***	
		(0.011)		(0.131)	
Conservatism	0.091***	-0.025**	-0.019	0.543***	0.565***
	(0.034)	(0.013)	(0.013)	(0.148)	(0.150)
Male	-1.031***	0.169***	0.123***	-0.942***	-1.255***
	(0.072)	(0.028)	(0.027)	(0.321)	(0.313)
White	-0.459***	0.007	-0.015	-0.034	-0.169
	(0.091)	(0.036)	(0.036)	(0.412)	(0.412)
Age	-0.004*	-0.003***	-0.003***	-0.045***	-0.046***
	(0.002)	(0.001)	(0.001)	(0.010)	(0.010)
Income	-0.015	-0.002	-0.003	-0.082	-0.088
	(0.012)	(0.005)	(0.005)	(0.054)	(0.054)
Education	-0.133***	-0.001	-0.007	-0.053	-0.090
	(0.025)	(0.010)	(0.010)	(0.111)	(0.111)
Reputation	0.213***	0.083***	0.091***	0.378***	0.440***
	(0.032)	(0.012)	(0.012)	(0.142)	(0.142)
Space Priority	0.290***	0.313***	0.325***	0.192	0.282*
	(0.036)	(0.014)	(0.014)	(0.158)	(0.157)
US Sample	0.020	0.034	0.038	-0.407	-0.401
	(0.074)	(0.029)	(0.029)	(0.328)	(0.330)
Constant		1.747***	1.907***	1.610	2.486**
		(0.087)	(0.088)	(0.998)	(1.005)
Observations	2,971	2,971	2,971	2,971	2,971
R^2		0.249	0.237	0.027	0.021
Adjusted R^2		0.246	0.235	0.024	0.018
Residual Std. Error (df = 2960)		0.727	0.733	8.354	8.377
F Statistic (df = 10; 2960)		98.082***	92.081***	8.166***	6.488***
Note:					*p**p***p<0.01

Table 3. Authority Trust and Probability. *We find an association between (dis)trust of scientists and more imprecise asteroid disaster probabilities; and separately, more imprecise (higher) asteroid disaster probabilities on support for planetary defense. However, we do not find any link between (dis)trust of scientists and support of planetary defense.*

As Figure A1 in Appendix I demonstrates, scientists are indeed by far the most popular first choice in rankings, suggesting that they have perhaps not yet been politicized in a manner that would detract from the appeal of their topical expertise. This naive estimator thus helps us garner some support for Hypothesis 1a. However, both the domestic head of state and the UN Secretary-General are popular second and third choices, suggesting a space for political authorities to make credible statements in this information space as well. Unsurprisingly, foreign states are relatively less trusted by most, even though

the survey does not specify if the source is an affiliate of the respondent's state or an experienced authority on planetary defense, which would logically make such sources well-suited to advise. Private space companies, while less trusted similarly to foreign governments, still appear more often as second and even first choices, suggesting perhaps that their association with space still denotes sufficient topical expertise. Although these various sources were tested in separation, nothing strictly prevents joint statements between different authorities, and future research may benefit from testing how such relationships add to or undermine the respective credibility of each source.

Table 3 shows, when including control variables, there is a statistically significant positive relationship between trust ranking and prediction probability; and also between prediction probability and support; however, there is no direct relationship between trust ranking and support itself. We surmise that there may be other factors that confound this last relationship which are unincorporated in this model. Mechanisms tested in the two experiments may explain some of this variation, though the low adjusted R-squared across experimental and exploratory statistical models leave room for omitted variables. Despite the directly link between probability and support, patterns of (dis)trust may also affect other variables in the expected utility calculation. Respondents' distrust may shape their perceptions of mission feasibility, costs, and the opportunity for side-benefits. Though this is an acausal (purely observational) test, we find some preliminary support for hypotheses 1a and 1b, yet not 1c. We see in Figure 1, as distrust increases, the prediction decreases. For the UK sample, this decrease is non-linear and sharp; in the US sample, the decrease is gradual. Notably, more than half of respondents did not pick the most accurate response ("<1%"), and thus are largely out of sync with current standards (Mathias et al. 2017) for accurately assessing impact risk. Future studies should more directly and causally test these relationships to explicitly confirm the causal chain as theorized.

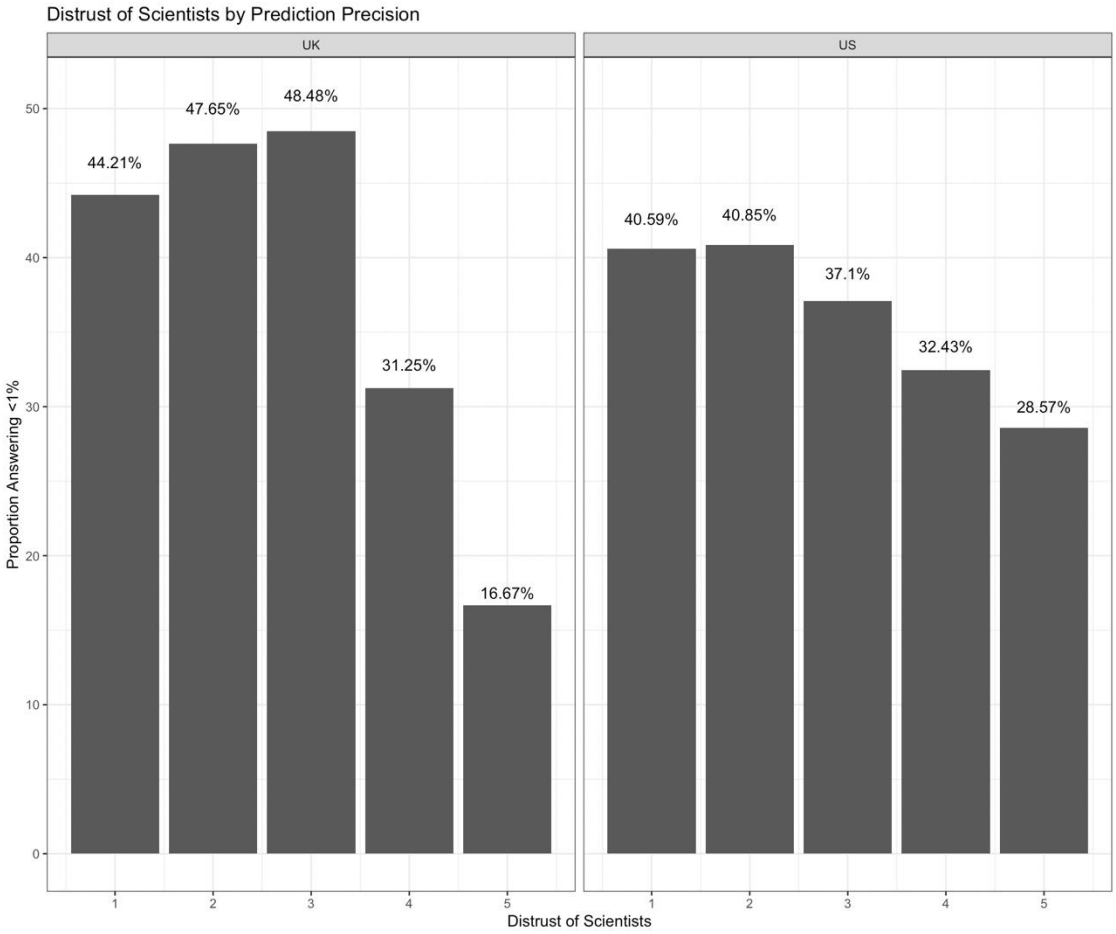

Figure 1. Distrust of Scientists and Probability Imprecision. *While in the UK, distrust of scientists eventually sharply plummets the asteroid disaster prediction rate, the US has a more even drop. Not one scientist trust group has more than 50% of respondents answering with the most precise probability estimate, <1%.*

Mission Characteristics Conjoint Experiment

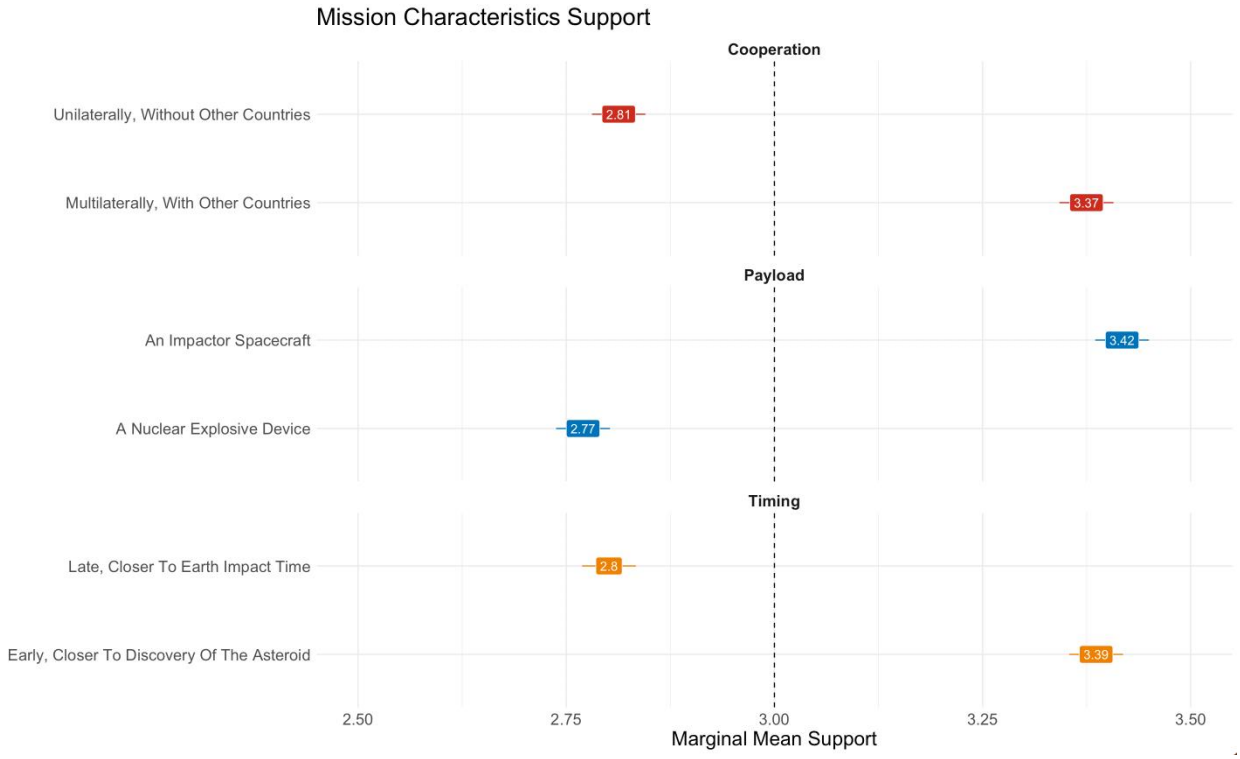

Figure 2. Conjoint Marginal Means. *The figure shows the marginal means for willingness to support a mission including each attribute value of mission characteristics. Table 4 below includes numerical point estimates and confidence intervals. (We present the x-axis as including the entire Likert range, from 1 to 5 in Figure A7; as Table 4 shows, standard errors are very small.)*

The conjoint experiment's results, illustrated in Figure 2 above, show that all attributes in all categories of mission parameters are highly statistically significant, offering strong support for hypotheses 2a, 2b, and 2c. For all attributes, there is a strong contrast between the levels, with one policy increasing approval and the alternative decreasing it.

	DV = Support
(Intercept)	3.991***
	(0.023)
Cooperation = Unilaterally, without other countries	-0.562***
	(0.025)
Payload = A nuclear explosive device	-0.647***
	(0.027)
Timing = Late, closer to earth impact time	-0.585***
	(0.026)
Num.Obs.	8913
R2	0.179
R2 Adj.	0.179
RMSE	1.10
Std.Errors	by: id

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001 *Note: we represent a larger* N *given each observation is presented three randomized conjoint selections.*

Table 4. Conjoint Analysis of Support for Variable Mission Characteristics. *These are causal effects of each attribute level change on support for the mission. We note that each treatment here is highly significant, implying the public has stark preferences for operational parameters.*

Table 4 presents the regression coefficient outputs. Of all attributes in our survey design, the use of nuclear weapons especially degrades support for planetary defense. On average, the inclusion of a nuclear explosive reduces approval by over a half-point on a Likert scale. This disapproval is made even more interesting as the use of nuclear explosive here entails the use on an extraterrestrial, non-human target, ostensibly meant to protect the planet itself. It appears that the nuclear taboo extends to use in planetary defense, though these results may relate to subsequent findings on multilateralism. While the background information on deflection methods emphasized the efficiency of nuclear explosives, the current illegality of deployment of such devices in space may have resonated with audiences who seek compliance with international law.

The public also strongly prefers multilateral missions to unilateral missions, with the average negative effect of unilateralism slightly smaller than that of nuclear deflection methods. Given that the mean Likert response for the question of expectation of collective action problems in a multilateral planetary defense coalition is positive, around 3.89 on a five-point scale, implying mild concern, a preference for these exact situations is somewhat surprising. Multilateralism may appear beneficial to the public because it suggests burden-sharing, although we do not directly test this mediating mechanism here (for the distribution of concerns for collective action problems, see Figure A3 in Appendix I). The public may also be attracted to the legitimacy of a larger coalition, in line with research on alliances for military intervention (Kreps 2011).

Lastly, despite the greatly heightened risk of a mission being wasted on an asteroid that would have been eventually discovered to be a non-threat, the public prefers to launch early, closer to the time of a potential threat's discovery, rather than waiting for greater certainty. In an actual scenario, once a NEO threat *is* detected, emotive fear might override rationalist expected utility calculus. But even in the abstract scenario presented here, the public appears to err on the side of caution in preventing potential impacts, showing less concern for the risk of wasting resources on an unnecessary mission. Respondents may have also been attracted to the opportunity to make multiple deflection attempts if a mission fails, which ties into hedging against impact risk over deflection costs risk. The public may prefer to maintain the greatest freedom of action, with the cost of a single deflection mission remaining sufficiently low to justify this premium.

Importantly, we find that all three less-favored attributes are not simply lesser options relative to their preferred counterparts. While the coefficients on suboptimal mission parameters are consistently negative the inclusion of any of these options also lowers support *below* the Likert scale's point of indifference, three. Therefore, a proposed deflection mission must be multilateral, utilize kinetic impactor methods, and launch early simply to maintain net-positive public support. This drastically reduces the freedom of action available to policymakers considering alternative mission proposals. The unpopularity of some parameters may also reinforce the lack of access to others. It may be harder to justify relying on waiting to launch later into a near-earth object's approach if *ex ante* opposition from foreign or domestic audiences to nuclear explosives disrupts preparations.

Issue-Linkages Narrative Experiment

As Table 4 above shows, economics and security narratives increase support in the full model. We find that these effects are detectable, in that they are statistically significant, but are not as substantively meaningful as other findings. By way of illustration, if we were to rescale the 5-point Likert to a 100-point scale (multiplying by 20), the economic treatment effect is only a 2.46 point increase, and the security treatment corresponds to a 1.66 point increase. While these show some support for hypothesis 3, the results remain modest.

	Treatments	With Demographics	With Space-relevant Controls
(Intercept)	3.179***	3.281***	1.915***
	(0.038)	(0.084)	(0.090)
Economic	0.083+	0.095*	0.140***
	(0.048)	(0.047)	(0.042)
Leadership	-0.112*	-0.118*	-0.054
	(0.049)	(0.049)	(0.043)
Opp. Cost	-0.082+	-0.094+	-0.029
	(0.049)	(0.048)	(0.043)
Security	0.054	0.060	0.093*
	(0.048)	(0.048)	(0.042)
US Sample	0.141***	0.148***	0.031
	(0.031)	(0.032)	(0.029)
Male		0.218***	0.105***
		(0.031)	(0.028)
White		0.047	-0.028
		(0.040)	(0.036)
Age		-0.003**	-0.004***
		(0.001)	(0.001)
Income		-0.002	-0.002
		(0.005)	(0.005)
Education		-0.009	-0.012
		(0.011)	(0.010)
Party		-0.033*	-0.017
		(0.015)	(0.013)
Reputation			0.093***
			(0.012)
DART			0.149***
			(0.031)
Space Priority			0.314***
			(0.014)
Num.Obs.	2971	2971	2971
R2	0.015	0.037	0.251
R2 Adj.	0.014	0.034	0.247
AIC	7345.0	7289.9	6551.5
BIC	7387.0	7367.9	6647.4
Log.Lik.	-3665.516	-3631.971	-3259.728
F	9.246	10.434	70.650
RMSE	0.83	0.82	0.72

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Table 5. Issue-Linkage Treatment Effects. *The Economic and Security treatments are significant, yet Opportunity Cost and Leadership are not. We find that the Leadership effect might be dragged down by*

very conservative Americans who reacted strongly in a negative way to the treatment, whereas other ideological groups were unmoving or increased slightly.

Surprisingly, while the political leadership treatment, which markets planetary defense on the potential to raise status, is significant in the first two models, the effect is negative. However, when subsetting the sample by country and political ideology, we find that this effect is disproportionately concentrated among conservatives (see Figure A2 in Appendix I). Highly conservative Americans respond negatively, statistically and substantively significantly, to the status leadership treatment even though the framing is explicitly positive. This may correspond to more isolationist or non-internationalist preferences among some conservative audiences.

Surprisingly, the opportunity cost, the only overtly negative treatment arm that emphasizes additional costs rather than side-benefits, does not seem to dampen support in practice. This casts some doubt on the second clause of hypothesis 3, but while respondents may accept these opportunity costs as acceptable, they may also simply lack sufficient information to predict what alternative programs would compete with planetary defense for funding. Respondents might have reacted differently had they been informed that planetary defense was, for example, competing with space projects, risk-mitigation programs (though the budget preference measures account for this separately), or other alternatives outside this policy area entirely.

We are wary to ascribe too much interpretation to controls, as they are not randomly assigned. However, we find additional interesting phenomena at work that might be of interest for future studies. Male respondents and proponents of prioritizing space as a key policy area show an association with the dependent variable at a magnitude close to those of the narrative treatments. Both findings align strongly with research that suggests a gender gap in support for increasing space activities (Whitman Cobb 2011, 2020, Cook et al. 2011, Nadeau 2013). However, despite the positive coefficient of support for prioritizing space, the effect size is comparable to that of the treatments, in that it too is relatively modest. This suggests that preexisting affinity for increased space is a supplement, but not a prerequisite for also supporting planetary defense.

While the treatment effect sizes appear relatively small here, they may indicate a foundation to build upon, both in future research and for application by policymakers. Planetary defense is a new topic for most of the general public, so the relatively small average treatment effect across groups for an abstract Likert scale is understandable. The vignette treatments included only limited information for their respective primes, only a single sentence suggesting planetary defense could prospectively support additional applications or benefits. This treatment may have been too limited, abstract, hypothetical, or open ended. In practice, the public may be exposed to longer, more specific justifications in these categories, perhaps grounded in concrete examples of these side-benefits. Likewise, nothing prevents policymakers from combining these frames, which may be more effective in conjunction than they are in separation. For example, the argument that planetary defense may catalyze the growth of the space industry may indirectly factor into the plausibility that investments would increase national prestige, as the accomplishments of private space companies have become increasingly salient in recent years. As such, the public may simply require sustained interaction with these arguments to build on the foundational effects observed here.

Conclusion

Black Swan threats present a difficult policy challenge for the public and their representatives in government alike. Their inherent rarity makes them unappealing targets for the limited resources available for preemptive disaster mitigation. And yet, their consequences are so great that it can be unwise to ignore them entirely. Publics may not fully recognize their own vulnerabilities, or else overestimate their safety in the absence of greater protection. These misunderstandings can leave

policymakers hesitant to go against public preferences, potentially undercutting national preparedness, especially for threats that can manifest with little warning.

Near-earth objects represent one such threat, with asteroid impacts being very rare but capable of occurring unexpectedly and requiring little mass to do significant damage. The current government response, planetary defense, surveys potential threats and invests in capabilities to identify and defend against collisions with near-earth objects, but will require much greater resources to achieve effective security. To understand how the public would engage with rare risks and their proposed solutions, we theorized that support for addressing such hazards depends on informational cues that shape the public's perception of the threat's probability, as well as the costs and benefits involved in any potential response. First, informational sources seen as especially credible would make the rare threat seem more realistic. Second, preferences for the specific configurations of methodologies used in risk mitigation can mediate support for the policy as a whole. Third, because the public would experience the costs and benefits of mitigation policies regardless of whether the threat they're meant to address actually appears, the side-benefits and externalities from investment into preparations would be more effective in raising support than one advocating on the basis of potential benefits alone.

Therefore, we conducted our survey to identify patterns in views and gauge sensitivity to specific informational cues. Altogether, the results of the survey suggest varying levels of support for our argument. Respondents display a strong preference for scientists and researchers as their authoritative source of information, and this stronger trust correlates with a more accurate understanding of the realistic probability of asteroid impacts, which in turn correlates negatively with preferences for increased investment into planetary defense. For addressing such threats, respondents show a strong preference for multilateral missions that employ a kinetic impactor and launch early, closer to a potential threat's time of discovery. Deviation from any of these parameters, including the application of nuclear explosives, greatly degrades support for the entire mission. Lastly, side-benefits play a small role in shaping support for increased investment.

Future work can build on this foundation and improve our understanding of how the public engages with black swan hazards. There is much room left to characterize public engagement with risk, particularly when different informational cues appear in concert, rather than in isolation. Likewise, it would be useful to observe the marginal effect of such information after sustained interaction, rather than one-off disclosures. Furthermore, exploratory statistics highlight the importance of subsequent examination of ideological factors, such as moral obligations[1]. These findings would assist not only in optimizing specific messages, but also improve design of the long-term information and outreach campaign to sustain risk-mitigation policies across administrations, countries, and phases of implementation. Additional research can help policymakers pursue and make available opportunities for policy optimization. Likewise, further exploration will assist planners in addressing the costs of more controversial policies to achieve effective domestic policy and international cooperation on challenging security concerns.

[1] See Figure A6 in Appendix 1

Appendix I

Authority Trust Matrix, All Rankings

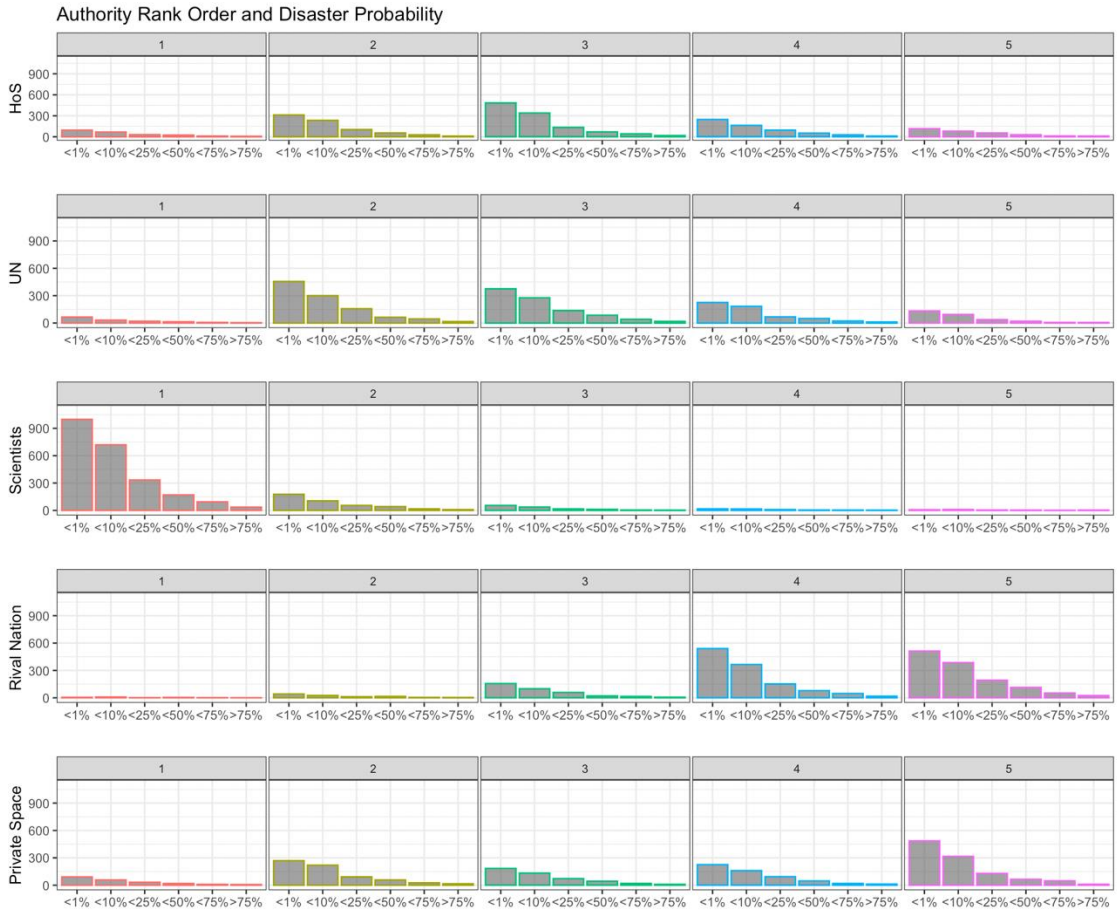

Figure A1. *This graph shows respondent asteroid disaster probability counts by rank order of authority. (I.e., the first column shows counts of how many respondents selected the respective authority as "rank #1"). Perhaps unsurprisingly, an overwhelmingly large number of respondents selected scientists as their first rank on where to learn about space news. What we do find as somewhat surprising, however, is the relatively large number of respondents who placed private space companies as a runner up authority.*

Heterogeneous Treatment Effects

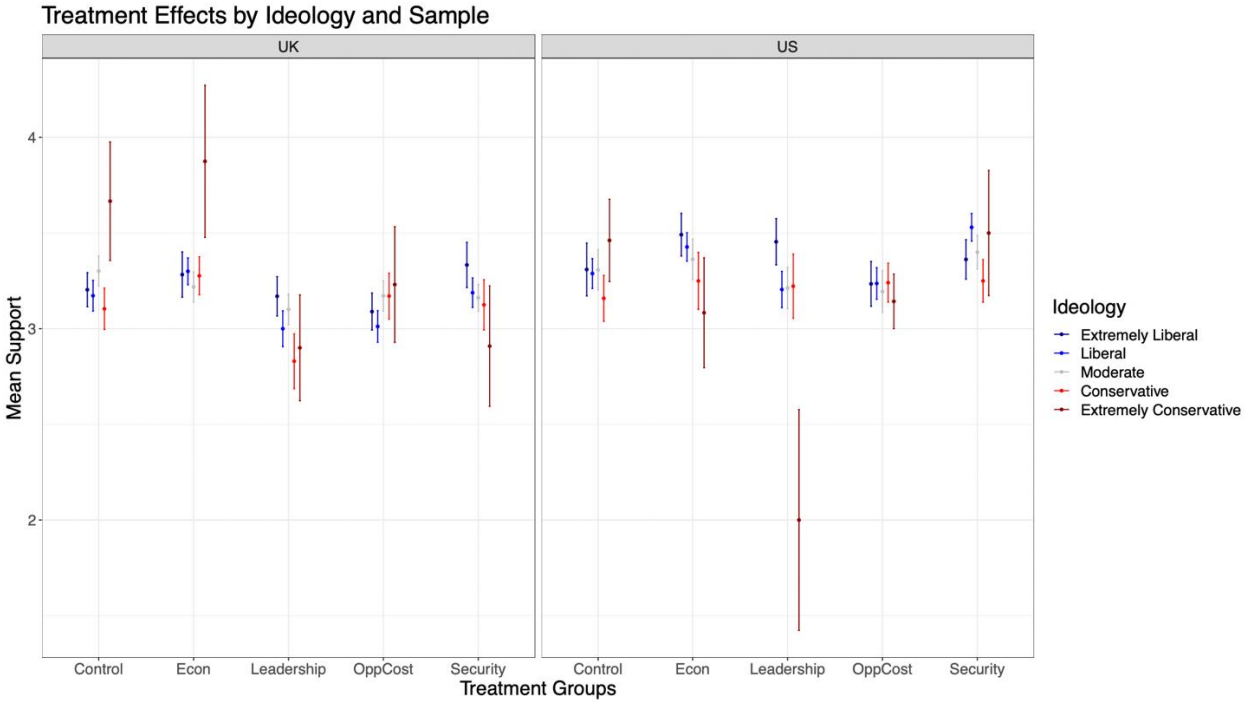

Figure A2. *We find most remarkable the dramatic decrease in support amongst very conservative Americans when treated with the status leadership vignette. While we do not directly run a mediating variable analysis in this study, our supposition is that the result might emerge from a preference for isolationism amongst very conservative Americans. However, because the political ideology of respondents is not randomly assigned, we cannot attribute a strong causal claim to ideology in of itself. Conversely, relative to control, Leadership, Opportunity Cost, and Security present noticeable drops in very conservative UK respondents' support. We find this puzzling given Opportunity Cost is a clear negative vignette.*

Media and Support

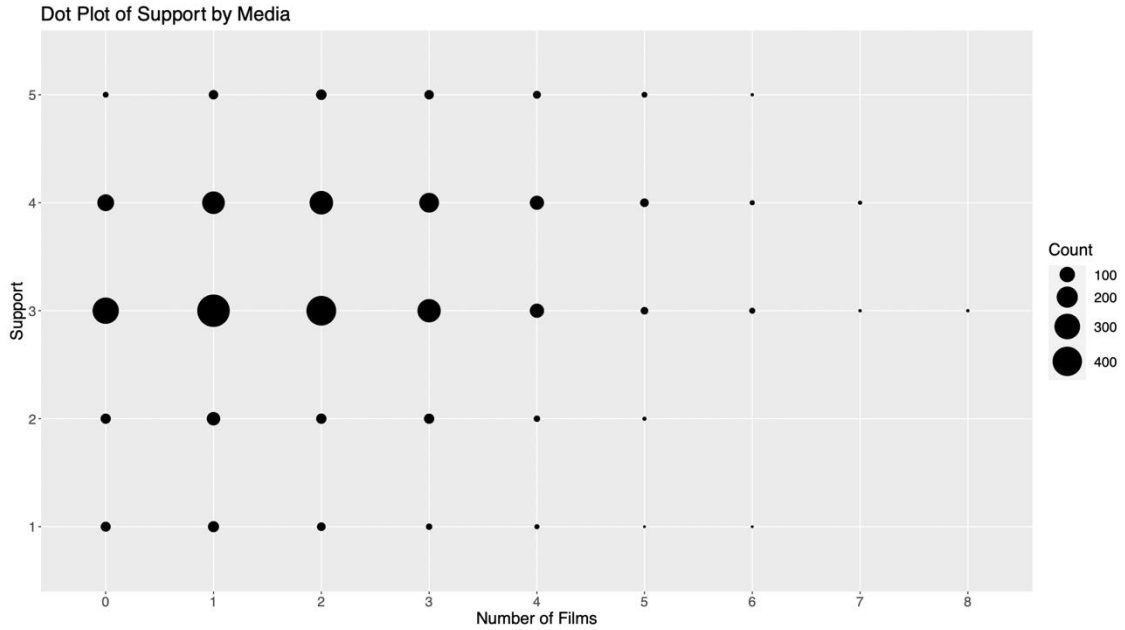

Figure A3. *Respondents were asked how many out of 8 asteroid impact-related films they have ever seen. It appears that an increase in the number of movies about asteroids seems to be mildly associated with increases in support for PDC. However, we stress that this association is not appreciably strong. A simple correlation test shows a weak, positive r value: 0.17. In short, it is unclear whether respondents who see asteroid disasters in the movies particularly care to increase PDC spending.*

Collective Action

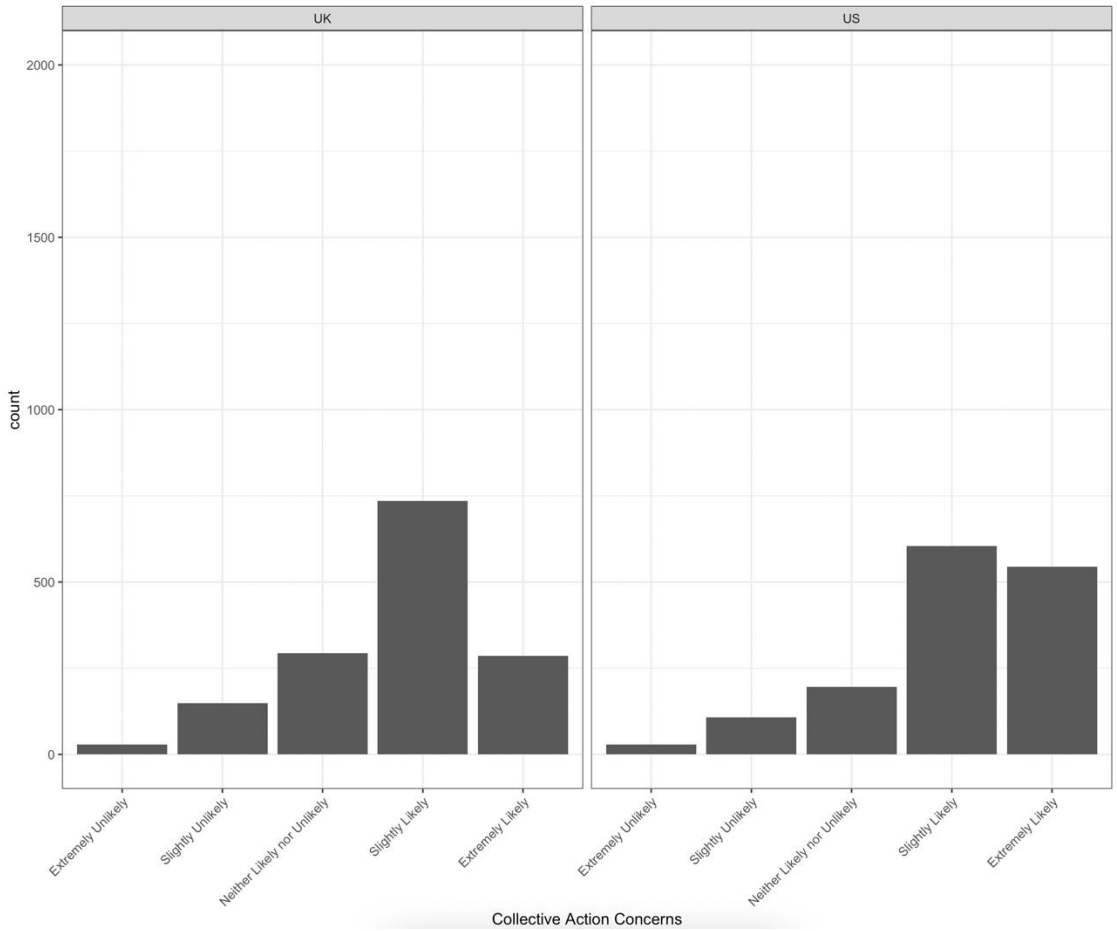

Figure A4. *Both samples skew towards having collective action fears. However, the US sample is especially more skewed. It is plausible that the negative conjoint unilateral effect is partially driven by these concerns.*

Robustness: Budget Change

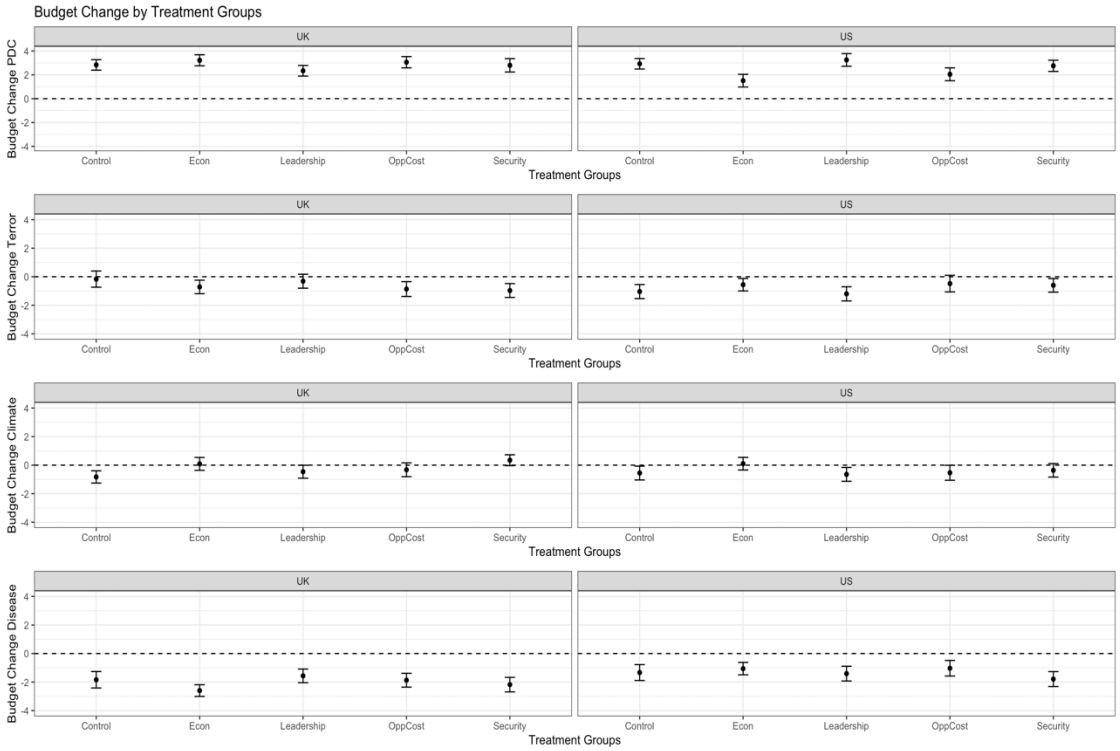

Figure A5. *We find that respondents tended to increase spending for planetary defense after the survey, usually vitiating the budget allocation for infectious diseases. We conjecture that this might be borne about by two concomitant mechanisms: first, that respondents–all of whom took the survey in 2023, the third year since the COVID-19 pandemic–deemed that the pandemic might have been "over"; and second, that respondents might have been educated on planetary defense and thus what we might be observing is attributable to education. Of course, a simple "before and after" comparison is acausal. However, the differential treatment effects for the vignette treatment are indeed causal: however, the treatment effects are relatively small, with perhaps the US leadership increase being most significant. We note that this treatment showed support (especially amongst very conservative respondents) plummet, and so subsequent information gleaned during the survey may have had them "calibrate" their beliefs upward.*

Utility Calculus, or Simply the Right Thing to Do? The Prospective Role of Moral Obligation

As an exploratory analysis of ideational and normative influences on support for planetary defense, the survey measures the degree of moral obligation respondents feel to protect specific populations. Predictably, most individuals report the highest moral obligation to protect their own countries, followed by high levels of slight obligation to protect the world in general, foreign allies, and unaffiliated states. Interestingly, while respondents show the least obligation to protect foreign rival states, the average is still positive. This finding may assuage some concern about motives for opportunistic

exploitation of planetary defense crises to undermine rival states. Finally, the distributions for neutral countries and the planet, conversely are somewhat similar. It is important to note that the defense of the planet in general shows lower average support than that of one's own country even though global defense entails defending one's own country. The addition of enemies and allies both may distort this definition, either through concern over free-riding or reluctance to include rivals automatically.

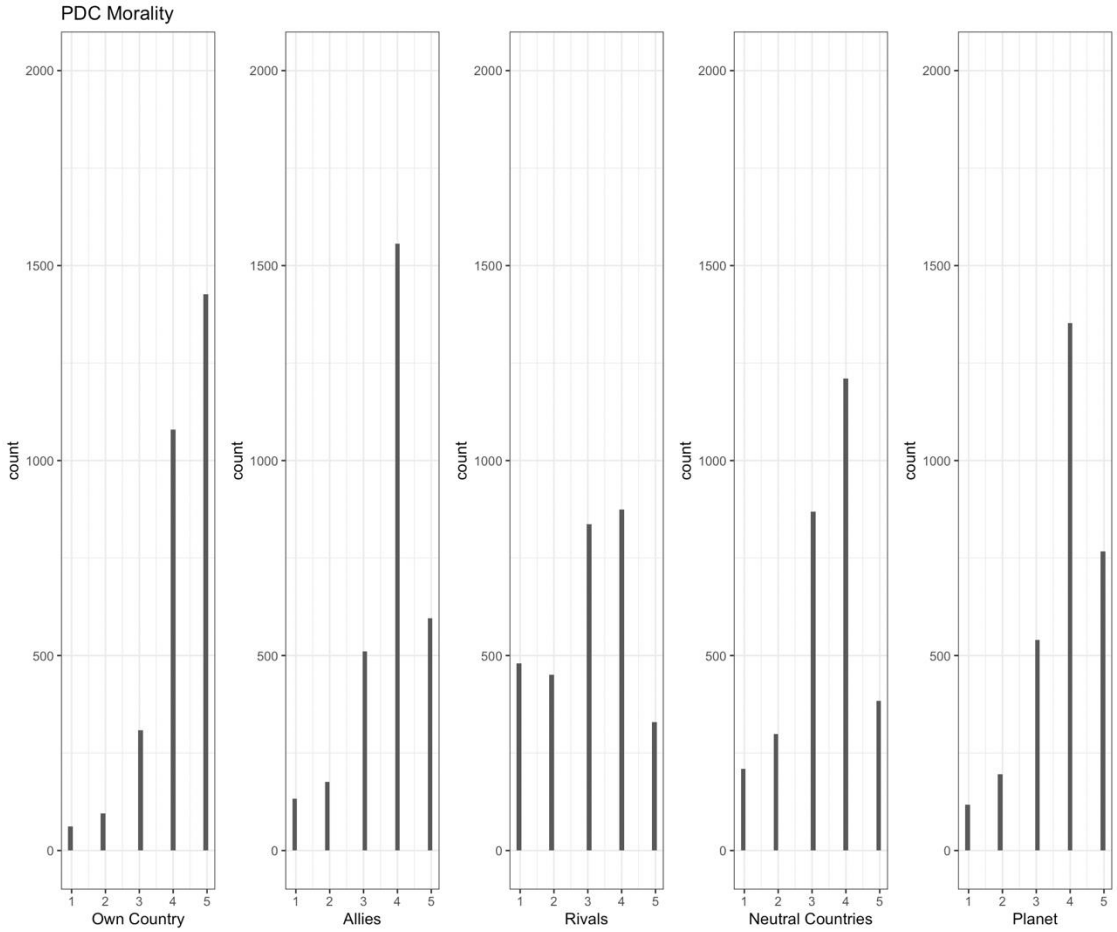

Figure A6. Distributions of Degree of Responsibility to Protect by Target. *Respondents were prompted to evaluate how much of a responsibility they felt their country had to protect each of the above targets. Unsurprisingly, most respondents strongly favored protecting their own country. However, we find the desire to protect rivals and the entire planet (the former a subset of the latter) puzzling. We conjecture that part of the support for planetary defense may be borne about by moral concerns rather than a pure, rationalist self-serving utility maximizing calculation.*

Conjoint Marginal Means (Full Scale)

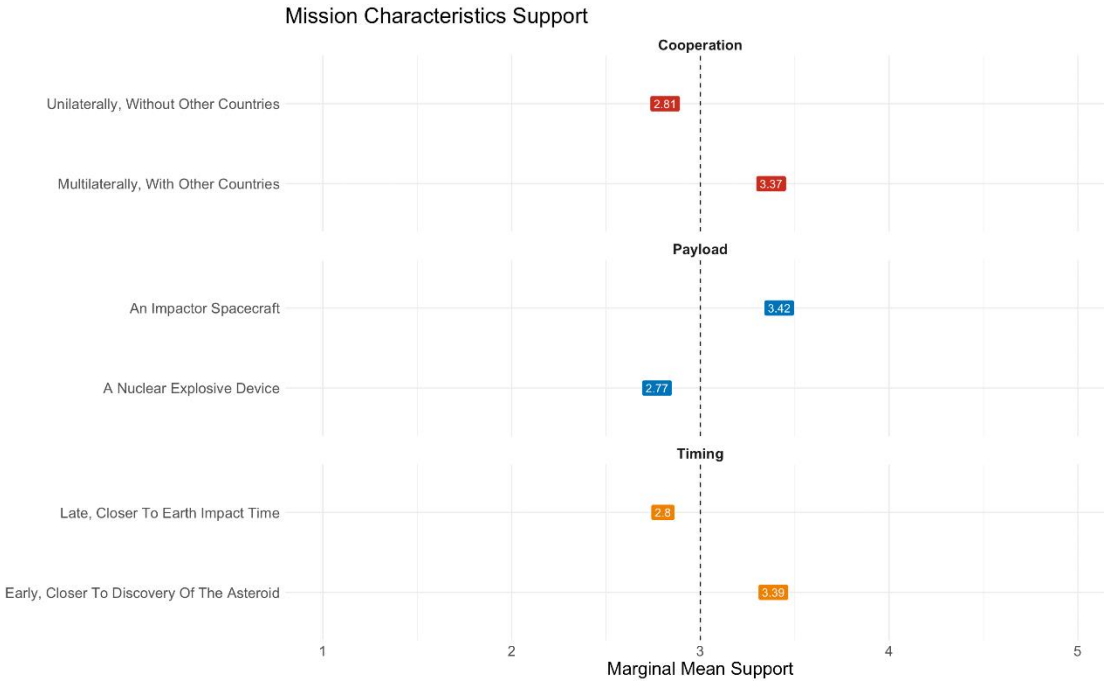

Figure A7. *Conjoint marginal means with full 1 to 5 Likert scale. We present a restricted scale in the document above to show 95% confidence interval bars. Because of the small standard errors, confidence interval bars are not visible in this graph.*

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