The Tragedy of the Uncommons: On the Politics of Apocalypse

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Special Issue Article

Abstract

The 'tragedy of the commons' is a classic type of problem, involving multiple actors who face individual incentives to deplete shared resources and thereby impose harms on others. Such tragedies can be overcome if societies learn through experience to mobilize collective action. This article formulates a distinct type of problem: 'the tragedy of the uncommons', involving the misperception and mismanagement of rare catastrophic risks. Although the problem of rare and global catastrophic risk has been much discussed, its sources and solutions need to be better understood. Descriptively, this article identifies psychological heuristics and political forces that underlie neglect of rare catastrophic 'uncommons' risks, notably the *un*availability heuristic, mass numbing, and underdeterrence. Normatively, the article argues that, for rare catastrophic risks, it is the inability to learn from experience, rather than uncertainty, that offers the best case for anticipatory precaution. The article suggests a twist on conventional debates: in contrast to salient experienced risks spurring greater public concern than expert concern, rare uncommons risks exhibit greater expert concern than public concern. Further, optimal precaution against uncommons risks requires careful analysis to avoid misplaced priorities and potentially catastrophic risk–risk trade-offs. The article offers new perspectives on expert vs public perceptions of risk; impact assessment and policy analysis; and precaution, policy learning and foresight.

Policy Implications

- As societies succeed in overcoming 'tragedies of the commons', they can and should pay increasing attention to 'tragedies of the uncommons'.
- Public perceptions may neglect routine familiar risks, and may overreact to unusual experienced risks (especially crises affecting identified individuals). But a third type – ultra-rare catastrophic risks – may be neglected due to factors such as psychological unavailability, mass numbing, and underdeterrence. Expert assessment is needed to overcome public neglect of such uncommons risks.
- Much risk regulation is spurred by policy learning from experience and experimentation. But rare one-time threats to the existence of life or civilization will not offer such opportunities for learning. This absence of adaptive learning offers a stronger rationale for precaution than mere uncertainty. Foresight and anticipation are essential to preventing such rare catastrophic risks.
- Overcoming neglect of rare catastrophic risks is necessary but not sufficient to choose optimal policy responses. Policies to prevent rare catastrophic risks may also misplace priorities, or induce catastrophic risk–risk trade-offs. Optimal precaution against tragedies of the uncommons must be based on careful foresight, impact assessment and policy analysis.

1. From the commons to the uncommons

In the classic 'tragedy of the commons' (Hardin, 1968), a shared open-access resource is overused by multiple individuals, with damaging consequences for all. Many environmental problems reflect such tragedies of the commons, such as overgrazing (a key example in Hardin's essay), deforestation, overfishing, air pollution (also noted by Hardin) and global climate change. The challenge of mobilizing collective action to restrain overuse of open-access shared resources is pervasive; it confronts societies – locally, national and internationally – when multiple actors share a resource and their individual incentives favor greater resource use than would be best for the collective society (Barrett, 2007; Keohane and Ostrom, 1995).

While we continue to face such commons problems, societies have also learned ways to mobilize collective action and protect shared goods from depletion, thereby alleviating some tragedies of the commons. A toolbox of potential remedies for tragedies of the commons has been developed – notably private property rights (as advocated by Hardin, 1968, p. 1245), group management systems using social norms (Ostrom, 1990; Dietz, Ostrom

and Stern, 2003), and administrative regulation using policy instruments such as technology standards, performance standards, taxes, tradable allowances/permits, information disclosure and others (which Hardin (1968, p. 1245) also advocated, though he worried that bureaucrats could be corrupted, so he favored oversight bodies (pp. 1245–46)). There is no one perfect remedy; different tools may be best suited to different commons problems. Research on the design and effectiveness of such tools has been translated into practice with many successes. For example, air pollution in the US and many other countries has been dramatically reduced over the last four decades (even as economies grew). Many local commons problems have been better managed (Dietz, Ostrom and Stern, 2003), ameliorating the 'tragedy' toward the 'drama' or even the 'comedy' of the commons (Ostrom et al., 2002; Rose 1986). That the phrase 'tragedy of the commons' has become so universal shows that the idea has influenced thinking and policy responses around the world.[1]

Still, difficult commons problems persist. Incentives for overuse, and obstacles to collective action, are often powerful. Hardin warned that in unrestricted commons, 'ruin is the destination toward which all men rush' (p. 1244), and there are accounts of some cases in which societies have depleted their way to collapse (Diamond, 2005). Where transaction costs are high, collective action may be thwarted. Actors may perceive high costs from individual action, and strong gains from free riding on others' efforts, in turn discouraging cooperation by others. Diverse actors may face heterogeneous benefits and costs, potentially leading some actors to prefer not only individual inaction but even collective inaction. The underlying legal and institutional framework may vary, in some settings (such as in national law) enabling powerful regulatory remedies that are binding and enforceable on dissenters (as Hardin also advocated, using the phrase 'mutual coercion mutually agreed upon', p. 1247); but in other settings (such as in international treaty law) only enabling effective cooperation via consent and side payments or issue linkage (Wiener, 1999). Even strong institutions may go awry if riven by factions or harnessed for rent-seeking; mobilizing efficient collective action is a persistent challenge (Wiener and Richman, 2010). Even looming threats of disaster may not always motivate effective collective action by multiple actors, depending on the perceived consequences of waiting for others to act (Barrett, 2016; Sandler, 2016). 'Global commons' problems, such as overuse of fisheries and the climate/atmosphere, illustrate the persistence of tragedies of the commons, where institutions for international collective action are weak (Dietz, Ostrom and Stern, 2003; Walker, Barrett et al., 2009).

Still, societies have often successfully learned through experience to mobilize collective action and design institutions to overcome tragedies of the commons (Ostrom et al., 2002). In so doing, they reduce their risks of degradation and depletion, and they prosper economically and environmentally. It seems plausible – and arguably desirable – that having overcome commons problems, they may then turn to confront longer-term and more remote risks. Several factors may contribute to this path. Reduced commons risks and greater prosperity mean that people are less concerned with daily struggles and able to turn their attention to the longer term future. Risks are perceived relative to the baseline, so as society becomes safer and baseline risks decline, smaller residual risks can spur public demand for action (Pinker, 2011, p. 220). Reduced commons risks and greater prosperity also increase human longevity, and these longer lifespans may encourage people to think more about longer-term effects on themselves and their descendants. Advances in science, partly financed by prosperity, may enable detection of more remote and rare risks that had been previously unknown. The technological change that prosperity brings may itself reduce some risks while introducing others. Together, these increases in prosperity, longevity, science and technology reduce the costs and increase the benefits of addressing more remote and yet potentially catastrophic risks.

Thus a distinct type of problem looms: the 'tragedy of the uncommons' (a phrase I have used in Wiener, 2005, 2008, 2011, 2013). Such 'uncommons' problems involve a rare extreme catastrophic risk which is misperceived and mismanaged. Examples of this type are mega-catastrophes of extremely low frequency and extremely high damage – such as a one-shot existential global catastrophe, one that could destroy all life on earth, or all human life, or at least human civilization. The problem of such global catastrophic mega-risks has been much discussed (see Rees, 2003; Farber, 2003, 2010; Posner, 2004; Sunstein, 2007; Bostrom and Cirkovic, 2008; Weitzman, 2009; Wells, 2009; Baum and Tonn, 2015). Calamities afflicting large regions or populations, such as pandemic disease or major war or genocide or climate change, can also exhibit the low frequency and high damage that are features of tragedies of the uncommons, even if they are more frequent and less damaging than an existential global catastrophe (Slovic, 2007; Slovic et al., 2013). It may thus be helpful to speak of a spectrum or dimensions of uncommons risks, rather than a single category. At the far end of this spectrum, the tragedy of the uncommons is most acute for extremely rare risks (perhaps occurring only once) posing global existential impacts (ending all life on earth, or all human life, or civilization). In this usage, rare catastrophic uncommons risks are far rarer and far more damaging than more frequent and local disasters that are sometimes labeled catastrophes, such as hurricanes or tsunamis or terrorist attacks killing thousands.

My point is not that rare global catastrophic 'uncommons' risks outweigh other risks. That depends on their probability and consequence compared to other risks, and the appropriate response to each will depend on the merits of the policy options. And I do not mean to say that uncommons risks are now (or should be) replacing or superseding commons risks, or that the two types necessarily proceed in sequence through time. Both types of tragedies may be occurring at the same time in different settings, or combined in the same setting. For example, extreme climate change may exhibit both a tragedy of the commons (free-riding by multiple actors who would share the benefits of abatement, hence a need for collective action) and a tragedy of the uncommons (rare extreme risk of global catastrophe that remains underappreciated, regardless of the number of actors). Nor are uncommons risks an inevitable result of new technology. The main point here is that tragedies of the uncommons are a distinct problem from tragedies of the commons, with distinct causes and potential solutions.

2. The tragedy of neglect

Tragedies of the commons arise when multiple rational actors, perceiving their options and individual payoffs, choose actions that are collectively undesirable (Hardin, 1968, p. 1244; Barrett, 2007). Tragedies of the uncommons, by contrast, can arise when even one actor neglects to appreciate a looming risk or mass damage, and mismanages the risk.

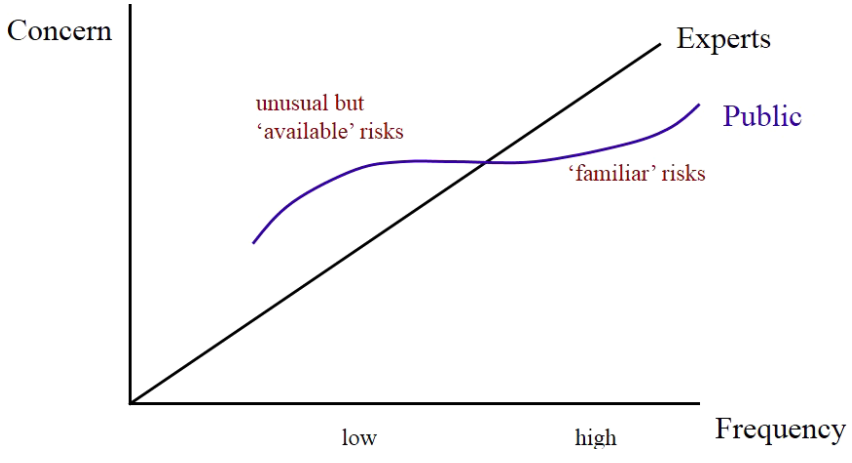
Research in psychology and political economy indicates several reasons why extreme mega-catastrophic risks are systematically neglected. Here I seek to bring greater clarity to the causes of rare catastrophic uncommons risks by identifying three main sources.

Unavailability

One important source of the neglect of uncommons risks is their very rare or ultra-low-frequency character. Extensive research shows that people exhibit heightened concern about risks that are 'available' to the mind, both in the sense of awareness and affect – the ability to envision and feel the importance of the event. These are often recent, visible, salient events that trigger strong visual images (Kahneman, Slovic and Tversky, 1982; Kuran and Sunstein, 1999; Weber, 2006; Pinker, 2011, p. 220). Such 'available' risks are then seen as more worrisome for the future. The 'availability heuristic' helps explain why so much regulation is crisis-driven, adopted only after a crisis event spurs public outcry and mobilizes collective political action to overcome interest group opposition (Percival, 1998; Kuran and Sunstein, 1999; Birkland, 2006; Repetto, 2006; Wiener and Richman, 2010; Wuthnow, 2010; Barrett, 2016; Balleisen et al., 2016).

A standard depiction of this phenomenon is that the public is more concerned about unusual dramatic risks, and less concerned about familiar routine risks, than are experts who take a quantitative approach combining likelihood and consequence (Breyer, 1993; Sunstein, 2005). This relationship is illustrated conceptually in Figure 1. The 'availability heuristic' helps explain why people appear to express greater concern about airplane accidents than automobile accidents, even though the statistical risk of airplane accidents (per km traveled, and possibly per trip) is lower: airplane accidents are shocking and dramatic and make news headlines, while automobile accidents are routine and familiar and become ordinary.[2] Similarly, public concern may be greater regarding coal mining accidents than the (larger) public health risks from coal combustion air pollution, and regarding ebola than the (larger) toll from malaria.

Figure 1. 'Availability' in expert vs public perceptions of risk



Note: The graph is illustrative and hand-drawn by the author.

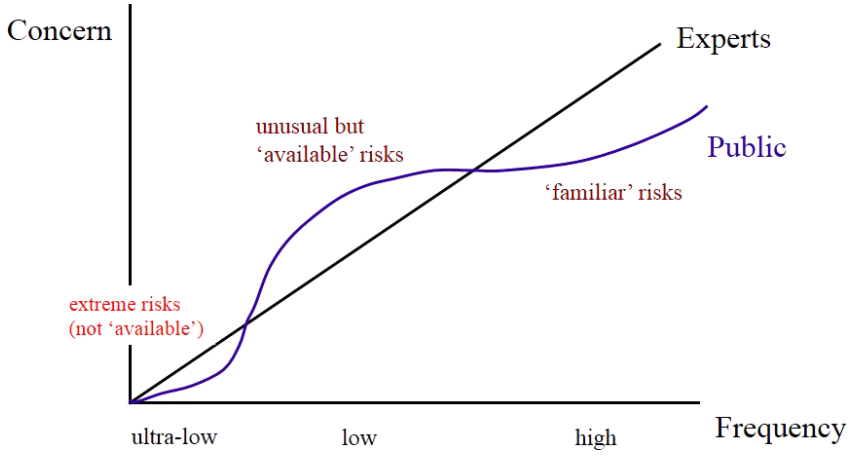
This difference in perspectives, depicted in Figure 1, also corresponds to many debates over the proper role of expert vs public appraisal of risk. Early studies showed significant differences between public vs expert appraisals of risk (Slovic, 1987; EPA, 1987; EPA, 1990). Some argued that these differences occur because the public makes errors about risks, such as exaggerating concern over unusual risks, while experts are more accurate, and that therefore policy should be based more on experts' views in order to avoid overregulating small (but unusual) risks while underregulating large (but routine) risks (Breyer, 1993). Others argued that public appraisals were based not on factual errors but on value choices, such as preferring to avoid involuntary risks, which should govern public policy (Shrader-Frechette, 1991). Still others argued that public values about risk might reflect prejudice and bias and should not necessarily be the direct basis for public policy (Cross, 1997).

A typical assumption in these debates was that the public favored more regulation (at least of unusual risks) and the experts favored less. Thus this relationship might suggest that the public would also be more worried than experts about rare 'uncommons' risks. Indeed, some commenters have suggested that the public exhibits exaggerated paranoia about remote risks, overstating the likelihood and calling for precautionary policies that would be (in experts' views) an overreaction (Efron, 1984; Wildavsky, 1997; Mazur, 2004). This may be the case for unusual *but experienced* events that are 'available' in the public mind and induce strong feelings such as dread; in response to experienced calamities, people are often highly motivated to take action, even if that action is ineffective or excessively costly (Wuthnow, 2010). For example, public reactions to the tragic 9/11 terrorist attacks included shifting from flying to driving with potentially greater injury risk (Deonandan and Backwell, 2011; Gaissmaier and Gigerenzer, 2012), and supporting two wars that were costly in money and lives (Stern and Wiener, 2008; Wuthnow, 2010). But with regard to ultra-low-frequency catastrophic risks, events that perhaps only occur once in eons, and hence are *not experienced,* it is not the case that the public is calling for overreaction while experts urge calm (Weber, 2006). Rather, it is experts, applying their quantitative methods, who are warning about future rare extreme risks such as abrupt climate change, artificial intelligence and large asteroid collisions (Posner, 2004; Bostrom and Cirkovic, 2008; Weitzman, 2009), while the public seems less interested if it takes these extreme risks seriously at all.

My conjecture, supported by the evidence cited above (but worth further study and refinement), is that 'tragedies of the uncommons' add a twist to the typical debate about public vs expert risk appraisal. Adding ultra-low-frequency (not experienced) risks to the picture shows that it is not the case that the public always favors more regulation and experts less. For both routine risks and ultra-rare risks, it is often experts who favor more regulation than the public. My conjecture of this twist in relative concern is depicted conceptually in Figure 2. Here, public concern is higher than experts' concern for unusual and experienced (hence available) risks, in the middle region of the frequency dimension; but public concern is lower than experts' concern both for routine familiar risks, and for ultra-low-frequency rare extreme risks.

The reason for this reversal in relative appraisal at the very low end of the frequency spectrum is again related to the 'availability' heuristic. It predicts that people become concerned about recent, visible, salient events that trigger strong feelings. But the rare mega-catastrophic risks are not recent, visible or salient. They have

Figure 2. 'Unavailability' of extreme risks in expert vs public perceptions of risk



Note: The graph is illustrative and hand-drawn by the author.

not been experienced, so the trigger for mental availability is lacking (Weber, 2006).

Describing such rare risks, such as in a speech or in an opinion survey, is less effective in stimulating public reaction than an experienced risk (Weber, 2006). Relatedly, a longer time interval without experiencing a recurrence of a damaging event can lead to complacency (neglect due to unavailability) and increased vulnerability to a recurrence (which can then trigger new availability and alarm) (Turner, 1976). Although people may envision humans going extinct at some point centuries in the future (Tonn, 2009), and express pessimism about the future direction of humanity (Randle and Eckersley, 2015), that viewpoint may not translate into concern about specific risks warranting policy responses in the present (nor did these studies compare public with expert perceptions).

Movies depicting rare unexperienced risks (e.g. the large asteroid collision in *Deep Impact* or *Armageddon*; alien pathogens in *The Andromeda Strain*; the rise of the machines in *The Matrix*) may be viewed as humorous entertainment and even elicit laughter – though perhaps that is nervous laughter rather than neglect. There is some evidence that those who watched the film *The Day After Tomorrow* were more concerned about climate change afterward (Leiserowitz, 2004), though the audience was not randomly selected and may have been more concerned going in. It is unclear whether films can effectively 'synthesize availability'; perhaps new techniques of virtual reality can do better, but they still may not call public attention to the most important uncommons risks, nor to the best policy responses.

The role of experience in triggering the availability heuristic, and raising concern about available events in public appraisals of future risks, may be rooted in the ways the brain processes information. Humans process immediate risk stimuli in part through the amygdala, which manages fear and the instant choice to flee or fight (Ledoux, 2007). At the same time, using the prefrontal cortex, humans are able to envision hypothetical future scenarios and analyze choices among them (Gilbert and Wilson, 2007). These two neural pathways are sometimes dubbed 'system 1' and 'system 2' (Kahneman, 2011). One possibility is that the faster processing of system 1 is generating fear before the slower processing of system 2 can develop a more analytic appraisal; but the two systems may also be interacting, and system 2 can also generate fear after its analysis.

Even if system 2 analysis is applied, the prefrontal cortex, when it envisions hypothetical scenarios of the future, appears to draw on experienced events (from the brain's memory centers) in order to construct a collage or pastiche of the future – a 'prospection' (Gilbert and Wilson, 2007; Schachter et al., 2008). Thus the human brain typically relies on 'available' experienced events even for its analytic prospection about future scenarios.[3]

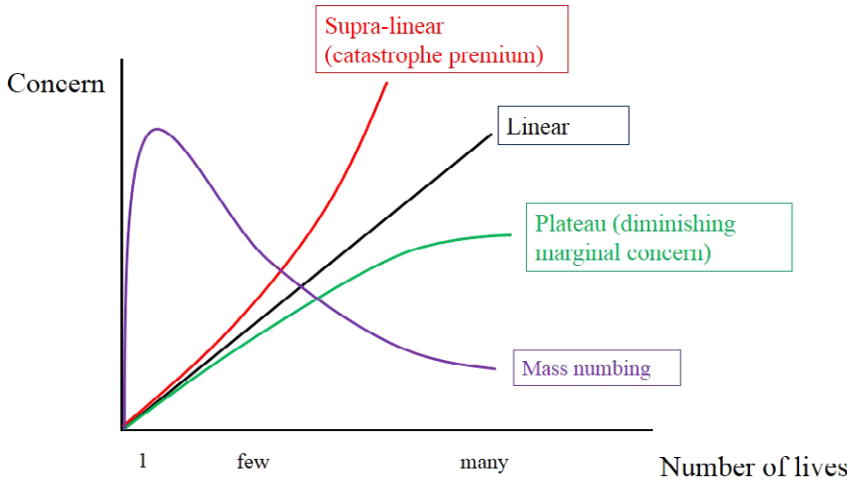
If so, the 'unavailability' of rare extreme risks contributes importantly to their being neglected in public concern. A mid-level example is the increase in parents seeking exemptions from vaccines for their children: past success in controlling a disease may create unavailability and neglect (though subsequent disease outbreaks may revive concern). A more extreme example is that a very large asteroid (> 10 km diameter) has not hit the earth for about 65 million years (Reinhardt et al., 2016), evidently causing the demise of the dinosaurs and about 75 per cent of all life on earth (a 15 km asteroid hit Chicxulub, off the Yucatan peninsula of Mexico, and another dubbed Shiva may have hit near the Indian land mass about 40,000 years later (Lerbekmo, 2014)). Smaller objects hit the earth frequently, and regional damage was caused by the impacts at Tunguska (1908) and Chelyabinsk (2013) (about 19 m in diameter, see Borovicka et al., 2013). The Chelyabinsk impact prompted calls for increased detection efforts. Early detection enables a longer lead time to devise new deflection methods. Improved probabilistic analysis indicates that rare asteroid impacts, even < 1000 m diameter, may be more risky than commonly thought (Reinhardt et al., 2016).

The neglect of rare uncommons risks in public psychology may in turn yield neglect in politics. This is a distinct additional factor on top of others that may also contribute to such neglect, such as free-riding (if the problem is also a 'commons' problem requiring collective action by multiple actors); short-term costs vs long-term benefits (if the risk would occur in the long-term future) mismatched with the short-term election cycles; inattention to the plight of people far away in other countries and cultures; and others. Individual neglect of rare global catastrophic risk may be compounded by societal disdain for such warnings; despite the prevalence of apocalyptic scenarios in religion and literature (Lisboa, 2011), the person warning that 'the end is near' is often viewed as insane (and might be). That most doomsday stories are unfounded, though, does not mean that all rare catastrophic risks are illusory.

To be sure, the public may have good reasons to focus on present needs. And experts may make mistakes too. Ideally, experts and the public would communicate with each other to improve both kinds of understanding (e.g. Tetlock and Gardner, 2015).

Moreover, neither 'the public' nor 'experts' is a homogeneous group; views vary among the public and among experts. Public opinion about catastrophic risks may vary with cultural identity (Kahan, 2010). Some subgroups may worry about global catastrophe, while others welcome the 'end times' and others dismiss alarmism. Further research could assess the influence of the 'unavailability' across these varying subgroups.

Figure 3. 'Mass numbing' in valuation of risk



Note: The graph is illustrative and hand-drawn by the author.

Mass numbing

A second source of the neglect of uncommons risks is their large magnitude of impact. It might seem that larger impacts should prompt more, not less, concern. For experts applying quantitative analytic methods, this appears to be the case. But for the general public, a surprising finding of recent psychology research is that a large or 'mass' impact yields 'numbing' (Slovic, 2007; Slovic et al., 2013). In these studies, people are asked in opinion polls (stated preference surveys) their willingness to pay (WTP) to save different numbers of other people from some risk. One might expect people to offer more money to save more people (a linear relationship, with each life valued the same), or even an increasing amount to reflect the greater value of averting a catastrophe (supra-linear). Or, one might expect people to offer amounts that rise but at a declining rate, such as if willingness to pay (WTP) reaches some plateau when the risk becomes large (diminishing marginal value of life saving). (In stated preference surveys, ability to pay may not be a strong constraint on responses.) These relationships are illustrated in Figure 3.

Surprisingly, Slovic recounts several studies finding that none of these depicts public attitudes; rather, in these studies, willingness to pay rises at first, but then as the number of people at risk grows, willingness to pay declines – not just marginally (as in the plateau relationship) but absolutely, to levels below the amount people were willing to pay to save one or two individuals. And the number of people at which the stated willingness to pay peaks and begins to decline is not very high – sometimes fewer than ten people at risk.

Slovic (2007) terms this 'psychic numbing' or 'mass numbing', and argues that it helps explain public neglect of genocide and other mass calamities (for further evidence, see Rheinberger and Treich, 2015). There is also evidence that it occurs for valuing nonhuman life (environmental conservation) (Markowitz et al., 2013). Hence the mass catastrophic impacts of uncommons risks may face undervaluation.

One reason for this response may be feelings of personal inefficacy (Vastfjall et al., 2015): as the number of lives rises, respondents may feel overwhelmed and doubt that their contribution can really make a difference to such a large problem. The 'end of the world' may be too much for people to act on; it may feel disabling rather than mobilizing. Relatedly, people may have a limited capacity to worry (Weber, 2006), and thus may deflect problems so large that they would consume all of that capacity.

A second reason for mass numbing may be the stronger public response to an identified individual – such as an identified victim or an identified villain. The public may be eager to save the baby who fell down the well, or the refugee child drowned on the beach, or the three whales stuck in the ice, but less willing to save a large and unidentified population of victims (Kogut and Ritov, 2005; Small and Loewenstein, 2005; Small, Loewenstein and Slovic, 2007). Kogut and Ritov (2005) and Slovic (2007) report that WTP to save a single victim also increases if the victim is described in more detail, and even more if the victim is given a face. Vastfjall et al. (2014) find that compassion is highest for a single child, and may decline after just one. Slovic (2007, p.79) quotes Mother Teresa: 'If I look at the mass I will never act. If I look at the one, I will.' These studies explain why charitable organizations try to feature a 'poster child' for a broader cause. But extreme mega-catastrophic risks typically lack a single

identified individual, unless rendered in fiction (e.g. a movie). The public may also be more eager to combat an identified villain than a faceless natural disaster or a ubiquitous social problem (Sunstein, 2007, p. 63, on the 'Goldstein effect'). This may help explain public outcry at villains highlighted in the news media, such as Osama Bin Laden and Saddam Hussein, compared with the apparently lesser public outcry regarding tsunamis (Indian Ocean 2006, killing 200,000 people; Japan 2011, killing 20,000 people), global climate change harming large populations, or large asteroids hitting the earth.

Underdeterrence

A third reason for neglect of uncommons risks is that traditional legal mechanisms may have weak or no deterrent effect. (This can be a problem of mismanagement, discussed below, but it also bears on ex ante neglect.) Rare mega-catastrophes may be literally 'too big to handle' by the traditional legal system.

One reason is that such extreme risks could destroy or disable the legal system. Consider civil liability (tort law), which is often cited as a key legal mechanism to deter risks that have not been adequately regulated by administrative bodies. But liability law seems unhelpful for extreme uncommons risks. First, any *ex post* legal remedy, such as liability, would be an empty prospect when the catastrophic risk itself would destroy the institutions meant to impose such an *ex post* remedy. The court system would not likely be operating after a large global catastrophe. Even if it were, money damage awards could likely be ignored or evaded in the impending chaos. Knowing this *ex ante,* potential tortfeasors would anticipate little prospect of liability awards and would be underdeterred. (This also explains why insurance is not an effective mechanism for dealing with catastrophic uncommons risks. Insurance with premiums reflecting full social costs may be helpful for managing extreme weather events such as hurricanes, which some scholars refer to as 'catastrophes' – see Kunreuther (2008) and Michel-Kerjan and Kunreuther (2012). But mega-catastrophic or existential risks that destroy all life, or civilization, or even major institutions, would render insurance moot. Policyholders would not pay premiums to insurers who probably would not exist to pay claims after the mega-catastrophe.)

Second, the magnitude of damages from a mega-catastrophe would often exceed the assets (including insurance) of any defendant. When expected damages exceed the firm's assets, the firm has an insufficient incentive to take precautions to prevent the damages (Faure, 2009).

Third, there might be no defendants to sue. Many of the causes of uncommons risks are not attributable to specific defendants, or only to defendants such as national governments who are very difficult to sue. A large asteroid hitting the earth, for example, would probably not be the fault of a corporate defendant. Suing the government for its alleged failure to prevent the collision would face hurdles of proving causation and sovereign immunity, among others.

For similar reasons, *ex post* criminal sanctions, or trade sanctions, or even threats of force and military reprisal, might also not be a strong deterrent against a mega-catastrophic risk that could destroy legal and political institutions. They would be perceived *ex ante* as unlikely to be applied *ex post*.

A different *ex post* remedy may undermine deterrence in a different way: disaster relief. If public institutions do survive the catastrophe, they may offer rescue or bailout or other relief. Anticipating this *ex ante*, potential recipients of such relief will have moral hazard incentives to engage in extra risk-taking. They may impose risk on others, or leave themselves exposed to greater risk by underinvesting in *ex ante* protective measures. But in a global catastrophe, the moral hazard incentive associated with *ex post* relief would likely be outweighed by the anticipation discussed above that institutions for *ex post* measures would be destroyed by the catastrophe.

An illustration: 'back contamination' from outer space

It is (happily) difficult to find historical examples of rare extreme mega-catastrophic uncommons risks, and policy responses, that can be evaluated in retrospect. Their rarity makes it difficult to test the above hypotheses about public neglect. Occasional forecasts of asteroid collisions are often quickly revised, which may unintentionally foster public complacency (the crying wolf syndrome: repeated false alarms yield subsequent inattention to a true alarm, i.e. a mistaken complacency or false negative).

One example that may nonetheless be instructive occurred in the 1960s. The history is complicated and detailed; what follows is an abridged account (drawn from Robinson, 1971; Compton, 1989; Robinson, 2005). As humans began sending rockets into space, they began to worry about two types of biological contamination. One is 'forward' contamination, bringing life from the earth to the moon or planets or other bodies. This could both harm those outer space ecosystems, if any, and also mislead human scientists' efforts to detect extraterrestrial life by introducing terrestrial life forms that might be mistaken for indigenous extraterrestrial life forms. A second type is 'back' contamination, bringing extraterrestrial life forms back to earth and unintentionally releasing this life on earth where it might harm terrestrial ecosystems. The Outer Space Treaty of 1967, in Article IX, calls on parties to adopt appropriate measures to avoid both forward and back contamination.

In the 1960s, as the National Aeronautics and Space Administration (NASA) prepared to send humans to walk on the earth's moon and bring these humans back again, the US Public Health Service (PHS) raised concerns about back contamination. They conceded that the probability of finding microbial organisms, or any life, on the moon was close to zero, but they worried that if microbes were on the moon, they might return to earth inside the astronauts' capsule, which was after all built to sustain life.[4] They envisioned scenarios in which such microbes consume all the earth's oxygen or otherwise end much of life on earth. PHS asked NASA to build a quarantine facility on the ship that would fetch the space capsule from its splashdown at sea. NASA worried about the high cost of such a quarantine facility. PHS apparently hinted at its authority to keep the astronauts from re-entering the US, based on a statute giving PHS the power to deny visas to persons suspected of carrying communicable diseases (although the statutory provision, 42 U.S.C. 264, referred to persons coming from 'foreign countries', possibly inapplicable to persons coming from the moon or the high seas). Congressional hearings addressed the quarantine question and its cost.[5] NASA agreed to build the quarantine facility on the ship that would retrieve the space capsule.

When the Apollo 11 capsule returned to earth from landing on the moon in 1969, it splashed down at sea and the ship approached to retrieve it. While the original quarantine protocol had called for the astronauts to remain inside the sealed spacecraft until it was lifted onto the ship's deck and into the quarantine facility, 'NASA officials began to have second thoughts about the discomforts the astronauts would endure if they were confined too long in a hot spacecraft buffeted by ocean waves... Deciding to trade one risk for another, NASA, without fanfare, changed its recovery plan.'[6] About two months before the mission, NASA decided that it would open the capsule as it floated at sea, let the astronauts exit, and take the astronauts to the ship by raft and helicopter. Then the astronauts and the capsule were later placed inside the ship's quarantine facility.[7] One report called the brief opening of the capsule at sea 'a major gap in the quarantine defenses', and quoted Carl Sagan remarking that, 'Maybe it's sure to 99 per cent that Apollo 11 will not bring back lunar organisms, but even that one per cent of uncertainty is too large to be complacent about.'[8]

This historical example illustrates several aspects of uncommons risks, although these inferences are partly conjecture, unless we can find public opinion surveys on these questions from the 1960s. The public was apparently unconcerned about microbial back contamination from the moon; there was no 'available' event, and the public presumably trusted the experts. Public enthusiasm for landing on the moon may have eclipsed any concern about extraterrestrial microbial contamination. (Michael Crichton's book *The Andromeda Strain* was published in 1969, and the film was released in 1971.) The experts were divided, with PHS more concerned about back contamination and NASA less so. The mass impact (potential end of much life on earth) may have been 'numbing', though it is hard to know if the public even heard or thought about it. Civil or criminal sanctions probably did not worry NASA, because apart from legal immunities, NASA no doubt deduced that such sanctions would be moot if life on earth ended. (Perhaps future commercial space flights would not be legally immune from liability, but the catastrophe could still destroy legal institutions, or at least exceed the commercial firm's assets, thereby undermining *ex ante* incentives for deterrence.)

Meanwhile, NASA's action to pop open the capsule at sea, before it was put into the quarantine facility, illustrates the preference for saving identified individuals over averting mass catastrophic risks. NASA saved the three astronauts from overheating and ignominy inside the capsule, at the risk of some (miniscule) probability of releasing microbes into the air or ocean that could (possibly) destroy terrestrial ecosystems. This is consistent with the view that the public and governments are more concerned about experienced events and identified individuals than about ultra-low-frequency scenarios of mass catastrophe.

Today, NASA and other space agencies have elaborate agreements and technical plans for 'Planetary Protection' to prevent back contamination. These were evidently developed over time by experts, not due to public concern or pressure. Future space travel by public or private enterprises, such as the Mars One trip planned for 2024, may raise these risks anew.

3. The tragedy of mismanagement

Neglect of rare catastrophic risks warrants greater attention to such 'uncommons' problems, but remedying such neglect does not by itself indicate which policy measures are warranted to prevent uncommons risks. Policy options must be assessed and compared to avoid perverse outcomes. Policy recommendations cannot assume that they will overcome the psychological and positive political obstacles discussed above, but must find ways to navigate these obstacles (Posner and Vermeule, 2013). Normatively, if policy evaluation is based on current public preferences, then the neglect of rare catastrophic risks (due to unavailability and mass numbing) could seem to express the public's willingness to accept such risks (Salanié and Treich, 2009); but if these expressions are the result of cognitive heuristics and biases, then an informed and de-biased public outlook, and an expert appraisal of these risks coupled with public valuations of the harms, could favor greater attention to such extreme

uncommons risks. Extra weight could be added to benefit-cost analysis to account for catastrophic losses (Sunstein, 2007), and a corrective could be added to counter the psychological and institutional failures of political systems to anticipate and prepare for rare extreme uncommons risks.

A prominent challenge for smart management of uncommons risks is priority-setting. The challenge is not only triage between rare catastrophic risks and higher-probability risks (such as those we face every day – air pollution, tobacco, automobile accidents, etc.), but also triage among the numerous scenarios of rare catastrophic risks (Calabresi and Bobbitt (1978) dubbed such triage 'tragic choices'). As we confront risks that are rarer, the number of conceivable scenarios expands. In addition to large asteroid collisions, back contamination from outer space, and extreme climate change, experts have worried about many other scenarios, such as the Large Hadron Collider consuming the earth, bioterrorism overcoming all human immune systems, nuclear winter, artificial intelligence surpassing and dominating human intelligence, the Search for Extra Terrestrial Intelligence (SETI) attracting malicious aliens, and others (Posner, 2004; Bostrom and Cirkovic, 2008; Wells, 2009). It may be that as the cognizable probability becomes infinitesimally small, the number of cognizable scenarios approaches infinity. It may be difficult to judge which low-probability theories are plausible (Cirkovic, 2012). Thus, careful assessment is needed of which uncommons risks warrant attention and action. Public deliberation may be useful to see which of several scenarios the public (once informed) finds most troubling. But assessing and sorting among these risks is mainly a job for experts.

Second is the challenge of optimal precaution. Precaution against some uncommons risks may be warranted, but precaution can take many forms and can be effective or not, desirable or perverse (Wiener, 2007). Most formal versions of the 'Precautionary Principle' (PP) are not satisfactory because they say nothing about which risks to be precautionary about (Bodansky, 2004; Sunstein, 2005). Indeed, combining advocacy of the PP with public's tendency to neglect rare mega-catastrophic risks could lead to precautionary measures that are applied to more mundane risks, such as chemicals and food safety, which is what we observe in practice. Precaution in practice has hardly been applied aggressively to mega-risks such as extreme climate change (Wiener, 2016), partly for collective action reasons and partly for cognitive neglect reasons (and partly due to the cost of abatement) (on the combination, see Campbell and Kay, 2014). On the other hand, some steps have been taken by experts to detect asteroids (e.g. the Spaceguard Survey) and to prevent back contamination (the Planetary Protection protocols). Moreover, the PP, even if applied to mega-catastrophic risks, does not say which actions to take (Wiener, 2002; Bodansky, 2004; Sunstein, 2005). We would still need analysis of the cost-effectiveness of different options for preventing, say, human extinction (Matheny, 2007).

Third, efforts to prevent uncommons risks could turn out to yield unintended risk–risk trade-offs (Graham and Wiener, 1995; Wiener, 2002). These could be catastrophe–catastrophe trade-offs: preventing one uncommons risk might invite another. For example, preventing climate change by shifting from coal to natural gas might reduce CO_2 but increase CH_4 (Graham and Wiener, 1995, ch. 10, pp. 193-225); by shifting from coal to nuclear power might replace long-term carbon loadings with long-term radioactive waste storage; or by deploying geoengineering (solar radiation management) might make the planet too cold, or accelerate stratospheric ozone depletion, or pose other problems. Preventing stratospheric ozone depletion by phasing out chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) and replacing them with hydrofluorocarbons (HFCs) might turn out to increase global warming (WMO, 2014; also forecast in Graham and Wiener, 1995: ch. 10, pp. 200-202). It is not a sufficient argument that these countervailing risks may be unlikely or remote: if the target risk is low-probability or uncertain, then countervailing risks that are low-probability or uncertain also deserve evenhanded attention (Wiener, 1998). Some such risk–risk trade-offs will be worth tolerating because reducing the target risk is more urgent than the less harmful increase in the countervailing risk; other risk–risk trade-offs may yield net increases in overall risk and should be avoided. Ideally, policy makers should seek 'risk-superior moves' that reduce multiple risks in concert (Graham and Wiener, 1995, ch. 1, pp. 36-41). Indeed, some policies to reduce global catastrophic risks in the far future may also offer near-term co-benefits that make them attractive to current policy makers (Baum, 2015; Shindell et al., 2016).

A core difficulty, as noted above, is that uncommons risks offer little opportunity for adaptive management – for learning and updating policies. Collective action is often driven by a crisis event (Percival, 1998; Birkland, 2006; Repetto, 2006; Wiener and Richman, 2010), which enables policy advocates to overcome interest group opposition, and enables learning from the crisis to revise regulatory policies and institutions (Balleisen et al., 2016). But for extreme mega-catastrophes, we cannot wait to act after the crisis, nor to learn from the crisis. The extreme catastrophic event may be only one-shot, with no precursor events to trigger the availability heuristic and help us learn to prepare. And the mega-catastrophic impact may be too big, wiping out life or institutions. There may be no chance for repeat players to learn insights and build confidence in cooperation. Indeed, it is this lack of opportunity for adaptive policy learning after a global mega-catastrophe that presents the strongest

case for precaution. The prospect of catastrophic losses strengthens the case for precaution (Sunstein, 2006; Farber, 2003, 2010), but the special feature of mega-catastrophes that they may not offer a chance to learn and revise policies after the event bolsters the case for precaution even further. Tragedies of the uncommons may be 'too big to learn'. Indeed, the typical basis for invoking precaution – uncertainty – actually points more toward experimentation and learning to gain knowledge and reduce those uncertainties (Listokin, 2008). It is the absence of the chance for adaptive learning from 'uncommons' mega-catastrophes that especially counsels anticipatory prevention, while also making it difficult. As noted above, policies to prevent uncommons mega-catastrophes still face the challenges of priority-setting, optimal stringency and risk–risk trade-offs.

Solving collective action obstacles (as for more familiar 'tragedies of the commons') can be helpful to addressing uncommons risks, indeed maybe necessary, but may not be sufficient to solve tragedies of the uncommons. Some uncommons risks do not require collective action by multiple actors – just one actor could solve them. And there remains the triage question of which extreme catastrophic risks to make a top priority for action (by collective or individual actors), as well as the dilemma of risk–risk trade-offs. If we mobilize collective action, but aim it at more obvious commons problems, or solve those problems while inducing countervailing catastrophic risks, we will still be neglecting the possible tragedies of the uncommons.

Nor would using a zero discount rate solve tragedies of the uncommons. Giving future impacts equal weight with present impacts could help address long-term uncommons risks by increasing the estimated benefits of long-term risk reduction in cost-benefit analysis. But some extreme catastrophic risks are soon, not long-term. The asteroid nicknamed Apophis is slated to pass close to the earth in 2029 and 2036, sooner than much climate change. Back contamination could arrive on a near-term space mission (perhaps more likely on those returning from other planets). Moreover, a truly zero discount rate would in a sense go too far, by putting ultra-long-term risks (thousands or millions of years into the future) on equal weighting with medium-term and short-term risks. Among such ultra-long-term risks are the next global ice age thousands of years from now, a large asteroid collision millions of years from now, and the expansion of the Sun to consume the earth billions of years from now, all of which could be weighted as if they occurred today. A truly zero discount rate could shift current investments toward addressing those ultra-long-term scenarios (e.g., researching how to save the earth, or how to move humans off the earth), without necessarily addressing nearer-term catastrophic risks.

4. Toward uncommon foresight

As we continue to surmount tragedies of the commons around the world, we also need to pay greater attention to oft-neglected tragedies of the uncommons. This paper has offered a set of conjectures, drawing on research in psychology and political economy, indicating that extreme catastrophic risks are systematically neglected in public perception, due to unavailability, mass numbing, anchoring on the individual, underdeterrence and related phenomena. If so, tragedies of the uncommons reveal a twist in the old debate over public vs expert perceptions of risk: the conventional view that the public demands more risk protection while experts urge less turns out to apply to unusual but experienced (available) risks, whereas for both familiar routine risks, and ultra-low-frequency (unexperienced) catastrophic risks, it is not the public demanding more protection, but experts.

To deal with uncommons risks, we may need greater public awareness. Perhaps this could be achieved by 'synthesizing availability' through films or virtual reality (although these may not be effective in raising public concern about the most important uncommons risks or the best policy responses). Precursor events and 'near misses' could be cited, such as smaller asteroid impacts (e.g. Chelyabinsk), or transcontinental invasive species as an analogy for interplanetary pathogens. But near misses pose their own risks of misinforming, misleading, inducing complacency, or inducing misguided action (Dillon et al., 2014). Public attention to uncommons risks should be raised (as it may already via prosperity and longevity), with careful emphasis on the important scenarios and the attractive policy responses. Yet the public will likely remain focused on present and unusual (experienced) risks. Experts are not infallible, but they can try to correct the cognitive failure of neglect of uncommons risks by engaging in the foresight that the public would favor – and would delegate to experts – if the public were judging fully informed, or *ex post* rather than *ex ante*.

Hence an important approach is to support experts who are studying the range of rare catastrophic risks. Expert analysis is crucial not only because of public neglect of uncommons risks, but also because, as noted at the outset, the case for increasing attention to rare extreme uncommons risks does not necessarily mean that these risks outweigh or deserve greater priority than other serious current and chronic risks, nor does it directly point to optimal policy responses. Careful analysis of these questions is needed. Posner (2004, p. 213) advocated creation of research centers on catastrophic risk assessment and response. Several such university-based centers are now operating. Perhaps several National Academies of Science, especially in prosperous

countries that are dealing relatively well with tragedies of the commons, should assemble expert committees on rare catastrophic risks. The World Bank has recently urged every country to establish its own 'National Risk Board' (World Bank, 2014, pp. 278–279), which could have as one of its functions examining the underappreciated uncommons risks faced by that country. Singapore, for example, has created a Risk Assessment and Horizon Scanning office to enhance its foresight across all risks facing the country. An international panel of experts on global catastrophic risks could issue periodic assessment reports. Experts need to sort out the best ways to evaluate scenarios, warning signs and near misses, triage/priorities, optimal precaution, cost-effectiveness, risk–risk trade-offs and related issues of risk management for uncommons risks. To be sure, experts themselves may make mistakes, and experts will still confront political systems leaning toward public opinion. Cases of expert success – perhaps including the funding and execution of the Spaceguard surveys of near-earth objects – could be used as models for future efforts.

Precaution and regulatory impact assessment need not be adversaries – in general, and especially for uncommons risks. Not only can some versions of precaution and cost-benefit analysis be compatible or combined (Graham, 2001; DeKay et al., 2002; Wiener, 2002; Gollier and Treich, 2003; Driesen, 2013), but, more fundamentally, both precaution and impact assessment are expressing a demand for policy foresight – for better ways to foresee the future consequences of our current choices (Wiener, 2013). Precaution against tragedies of the uncommons must confront the challenges of triage or priority-setting (choosing which of numerous extreme scenarios to address) and risk–risk trade-offs (because measures to prevent one catastrophic risk might induce another). Thus, even in cases where precaution is strongly warranted against rare extreme mega-catastrophic 'uncommons' risks, a full portfolio impact assessment remains crucial to choose the best policy responses.

Notes

The author is grateful for helpful comments from Matt Adler, Alberto Alemanno, Ed Balleisen, Scott Barrett, Seth Baum, Lori Bennear, Nick Bostrom, James Hammitt, Shi-Ling Hsu, Philip Kitcher, David Markell, Deirdre McCloskey, Richard Newell, William Pizer, Richard Posner, Margaret Race, Christoph Rheinberger, Lisa Robinson, Erin Ryan, Paul Slovic, Nicolas Treich, Anne van Aaken, Elke Weber and Hannah Wiseman; from two anonymous referees; and from participants in workshops at the Wissenschaftskolleg Berlin, the Toulouse School of Economics, the Society for Risk Analysis (SRA), SRA-New England, the Harvard T.H. Chan School of Public Health, HEC Paris, Oxford University, Florida State University, and the University of Pennsylvania. Kim Lott and Juliana Soic provided excellent research assistance.

1. The tragedy of the commons, in which too much access yields too much use, has been contrasted with a converse phenomenon, the tragedy of the 'anticommons', in which too many restrictions on access yield too little use. Whereas 'commons' problems involve too few property rights and thus excessive access to the resource with shared losses from overuse, 'anticommons' problems involve too many property rights (each with a right to block other users) inhibiting multiple owners from collaborating to make productive use of the resource, such as patent thickets that prevent borrowing and further innovation. See Heller (1998). My concept of tragedies of the 'uncommons' is thus different from Heller's concept of the 'anticommons'.
2. Another factor – and heuristic error – may be perceived less control as the passenger vs perceived greater control as the driver.
3. Perhaps the function of expert study in this context is to retrain the brain to overcome this tendency to rely on availability, and to draw on other kinds of theory and evidence to inform foresight. See Gilbert and Wilson (2007).
4. In recent decades, terrestrial microbes have been found living inside the International Space Station (ISS) – an example of forward contamination, but also evidence hinting that potential extraterrestrial microbes (if there are any) might inhabit spacecraft as well. See NASA, 'Microbial Stowaways on the ISS', 26 November 2000 [online]. Available from: http://science.nasa.gov/science-news/science-at-nasa/2000/ast26nov_1/ [Accessed 21 March 2016]; NASA, 'Microbial Creatures in Space', 21 June 2013 [online]. Available from: http://www.nasa.gov/mission_pages/station/research/news/microbial_ecosystems.html [Accessed 21 March 2016]. Perhaps microbes could also have lived on the outside of the Apollo capsule – as unlikely as this sounds, terrestrial sea microbes were allegedly discovered living on the outside of the ISS in August 2014, see Miriam Kramer, 'Sea Plankton on Space Station, Russian Official Claims', *Discovery Channel News,* 21 August 2014 [online]. Available from: http//news.discovery.com/space/private-spaceflight/sea-plankton-on-space-station-russian-official-claims-140821.htm [Accessed 21 March 2016].
5. *1967 NASA Authorization, Part 2: Hearings on H.R. 12718 Before the House Subcomm. on Manned Space Flight*, 89th Cong. 419 (1966).
6. 'Science: Lowering the Guard against the Invaders', *TIME Magazine,* 16 May 1969 [online]. Available from: http://content.time.com/time/magazine/article/0,9171,902579,00.html [Accessed 21 March 2016].
7. 'They had to don protective biological isolation garments (BIGs) in case they were infected by some unknown and potentially hazardous "moon germs". Of course there were no pathogens, but this was not definitely known at the time. After their return to Earth, the trio was scrubbed with a disinfect solution of sodium hypochlorite and had to remain in quarantine for 21 days inside a 30 feet (9.1 m) long quarantine facility known as the Lunar Receiving Laboratory (LRL).' Ken Kremer, Apollo 11 Splashdown 45 Years Ago on July 24, 1969 Concludes 1st Moon Landing Mission – Gallery, 24 July 2014 [online]. Available from: http://www.universetoday.com/113428/apollo-11-splashdown-45-years-ago-on-july-24-1969-concludes-1st-moon-landing-mission-gallery/ [Accessed 21 March 2016].
8. 'Space: Is the Earth Safe from Lunar Contamination?', *TIME magazine*, 13 June 1969 [online]. Available from: www.time.com/time/magazine/article/0,9171,942095,00.html [Accessed 21 March 2016].

References

Balleisen, E., Bennear, L., Krawiec, K., and Wiener, J. B. (eds) (2016). *Policy Shock: Regulatory Responses to Oil Spills, Nuclear Accidents and Financial Crises* (forthcoming). Cambridge: Cambridge University Press.

Barrett, S. (2007) *Why Cooperate? The Incentive to Supply Global Public Goods*. Oxford: Oxford University Press.

Barrett, S. (2016) 'Collective Action to Avoid Catastrophe: When Countries Succeed, When They Fail, and Why', *Global Policy* (forthcoming).

Birkland, T. A. (2006) *Lessons of Disaster: Policy Change after Catastrophic Events*. Washington DC: Georgetown University Press.

Baum, S. D. (2015) 'The far future argument for confronting catastrophic threats to humanity: Practical significance and alternatives', *Futures*, 72, pp. 86–96.

Baum, S. D. and Tonn, B. E. (2015) 'Introduction: Confronting future catastrophic threats to humanity', *Futures*, 72, pp. 1–3.

Bodansky, D. (2004) 'Deconstructing the Precautionary Principle', in D. D. Caron and H. N. Scheiber (eds), *Bringing New Law to Ocean Water*. Leiden: Koninklijke Brill NV, pp. 381–391.

Borovicka, J., Spurny, P., Brown, P., Wiegert, P., Kalenda, P., Clark, D., and Shrbeny, L. (2013) 'The trajectory, structure and origin of the Chelyabinsk asteroidal impactor', *Nature*, 503, pp. 235–237.

Bostrom, N. and Cirkovic, M. M. (eds) (2008) *Global Catastrophic Risks*. Oxford: Oxford University Press.

Breyer, S. G. (1993) *Breaking the Vicious Circle: Toward Effective Risk Regulation*. Cambridge, MA: Harvard University Press.

Calabresi, G. and Bobbitt, P. (1978) *Tragic Choices*. New York, NY: W.W. Norton.

Campbell, T. H. and Kay, A. C. (2014) 'Solution aversion: On the relation between ideology and motivated disbelief', *Journal of Personal and Social Psychology*, 107, 809–24.

Cirković, M. M. (2012) 'Small Theories and Large Risks – Is Risk Analysis Relevant for Epistemology?', *Risk Analysis*, 32, pp. 1994–2004.

Compton, W. D. (1989) 'Where No Man Has Gone Before: A History of Apollo Lunar Exploration Missions', NASA [online]. Available from: http://history.nasa.gov/SP-4214/cover.html [Accessed 21 March 2016].

Crichton, M. (1969) *The Andromeda Strain*. New York, NY: Knopf.

Cross, F. (1997) 'The Subtle Vices Behind Environmental Values', *Duke Environmental Law & Policy Forum*, 8, pp. 151–172.

DeKay, M., Small, M., Fischbeck, P., Farrow, S., Cullen, A., Kadane, J. B., Lave, L., et al. (2002) 'Risk-Based Decision Analysis in Support of Precautionary Policies', *Journal of Risk Research*, 5, pp. 391–417.

Deonandan, R. and Backwell, A. (2011) 'Driving deaths and injuries post9/11', *International Journal of General Medicine*, 4, pp. 803–807.

Diamond, J. (2005) *Collapse: how societies choose to fail or succeed*. New York, NY: Viking Penguin.

Dietz, T., Ostrom, E. and Stern, P. (2003) 'The Struggle to Govern the Commons', *Science*, 302, pp. 1907–1912.

Dillon, R. L., Tinsley, C. H. and Burns, W. J. (2014) 'Near-Misses and Future Disaster Preparedness', *Risk Analysis*' 34, pp. 1907-1922.

Driesen, D. (2013) 'Cost-Benefit Analysis and the Precautionary Principle: Can They Be Reconciled?', *Michigan State Law Review*, 2013, pp. 771–826.

Efron, E. (1984) *The Apocalyptics*. New York, NY: Simon and Schuster.

EPA (US Environmental Protection Agency) (1987) 'Unfinished Business'. Washington DC: US EPA.

EPA (US Environmental Protection Agency) (1990) 'Reducing Risk'. Washington DC: US EPA.

Farber, D. A. (2003) ''Probabilities Behaving Badly: Complexity Theory and Environmental Uncertainty', *U.C. Davis Law Review*, 27, pp. 145–173.

Farber, D. A. (2010) 'Uncertainty', *Georgetown Law Journal*, 99, pp. 901–959.

Faure, M. (ed.) (2009) *Tort Law and Economics*. Cheltenham UK and Northampton MA: Edward Elgar.

Gaissmaier, W. and Gigerenzer, G. (2012) '9/11, Act II: A Fine-Grained Analysis of Regional Variations in Traffic Fatalities in the Aftermath of the Terrorist Attacks', *Psychological Science*, 23, pp. 1449–1454.

Gilbert, D. T. and Wilson, T. D. (2007) 'Prospection: Experiencing the Future', *Science*, 317, pp. 1351–1354.

Gollier, C. and Treich, N. (2003) 'Decision Making under Uncertainty: The Economics of the Precautionary Principle', *Journal of Risk and Uncertainty*, 27, 77.

Graham, J. D. (2001) 'Decision-Analytic Refinements of the Precautionary Principle', *Journal of Risk Research*, 4, 127.

Graham, J. D. and Wiener, J. B. (1995) *Risk vs risk: Tradeoffs in protecting health and the environment*. Cambridge, MA: Harvard University Press.

Hardin, G. (1968) 'The tragedy of the commons', *Science*, 162, pp. 1243–1248.

Heller, M. A. (1998) 'The Tragedy of the Anticommons: Property in the Transition from Marx to Markets', *Harvard Law Review*, 111, pp. 621–688.

Kahan, D. (2010) 'Fixing the communications failure', *Nature*, 463, pp. 296–297.

Kahneman, D. (2011) 'Thinking, Fast and Slow', New York, NY: Farrar Strauss Giroux.

Kahneman, D., Slovic, P. and Tversky, A. (1982) *Judgment under Uncertainty: Heuristics and Biases*. Cambridge: Cambridge University Press.

Keohane, R. O. and Ostrom, E (eds) (1995) *Local Commons and Global Interdependence*. London: SAGE Publications.

Kogut, T. and Ritov, I. (2005) 'The "Identified Victim" Effect: An Identified Group, or Just a Single Individual?', *Journal of Behavioral Decision Making*, 18, pp. 157–167.

Kunreuther, H. (2008) 'Reducing Losses from Catastrophic Risks through Long-Term Insurance and Mitigation', *Social Research: An International Quarterly*, 75, pp. 905–930.

Kuran, T. and Sunstein, C. R. (1999) 'Availability Cascades and Risk Regulation', *Stanford Law Review*, 51, 683–768.

LeDoux, J. (2007) 'The amygdala', *Current Biology*, 17, pp. R868–874.

Leiserowitz, A. (2004) 'Before and after The Day After Tomorrow: A US study of climate change risk perception', *Environment*, 46(9), pp. 22–37.

Lerbekmo, J. F. (2014) 'The Chicxulub-Shiva extraterrestrial one-two killer punches to Earth 65 million years ago', *Marine and Petroleum Geology*, 49, pp. 203–207.

Lisboa, M. M. (2011) *The End of the World: Apocalypse and its Aftermath in western Culture*. Cambridge: Open Book Publishers.

Listokin, Y. (2008) 'Learning through Policy Variation', *Yale Law Journal*, 118, pp. 480–553.

Markowitz, E. M., Slovic, P., Västfjäll, D. and Hodges, S. D. (2013) 'Compassion Fade and the Challenge of Environmental Conservation', *Judgment and Decision Making*, 8, pp. 397–406.

Matheny, J. G. (2007) 'Reducing the Risk of Human Extinction', *Risk Analysis*, 27, pp. 1335–1344.

Mazur, A. (2004) *True Warnings and False Alarms: Evaluating Fears about the Health Risks of Technology, 1948–1971*. Washington, DC: Resources for the Future.

Michel-Kerjan, E. and Kunreuther, H. (2012) 'Paying for Future Catastrophes', *NY Times*, 25 November, p.SR 7 [online]. Available from: http://www.nytimes.com/2012/11/25/opinion/sunday/paying-for-future-catastrophes.html [Accessed 21 March 2016].

Ostrom, E. (1990) *Governing the Commons*. Cambridge: Cambridge University Press.

Ostrom, E., Dietz, T., Dolšak, N., Stern, P. C., Stovich, S. and Weber, E. U. (eds) (2002) *'The Drama of the Commons', Committee on the Human Dimensions of Global Change, Division of Behavioral and Social Sciences and Education, National Research Council*. Washington, DC: National Academy Press.

Percival, R. V. (1998) 'Environmental Legislation and the Problem of Collective Action', *Duke Environmental Law & Policy Forum*, 9, pp. 9–28.

Pinker, S. (2011) *The Better Angels of Our Nature: Why Violence Has Declined*. New York, NY: Viking.

Posner, E. A. and Vermeule, A. (2013) 'Inside or Outside the System?', *University of Chicago Law Review*, 80, pp. 1743–1797.

Posner, R. A. (2004) *Catastrophe: Risk and Response*. Oxford and New York: Oxford University Press.

Randle, M. and Eckersley, R. (2015) 'Public perceptions of future threats to humanity and different societal responses: A cross-national study', *Futures*, 72, pp. 4–16.

Rees, M. (2003) *Our final hour: A scientist's warning: How terror, error, and environmental disaster threaten humankind's future in this century – on Earth and beyond*. New York, NY: Basic Books.

Reinhardt, J. C., Chen, X., Liu, W., Manchev, P. and Paté-Cornell, M. E. (2016) 'Asteroid Risk Assessment: A Probabilistic Approach', *Risk Analysis*, 36, pp. 244–261.

Repetto, R. (ed.) (2006) *Punctuated Equilibrium and the Dynamics of US Environmental Policy*. New Haven, CT: Yale University Press.

Rheinberger, C. M. and Treich, N. (2015) 'Attitudes Toward Catastrophe', draft, Toulouse School of Economics', Toulouse France, 6 December.

Robinson, G. S. (1971) 'Earth Exposure to Extraterrestrial Trial Matter: NASA's Quarantine Regulations', *International Lawyer*, 5, pp. 219–248.

Robinson, G. S. (2005) 'Interplanetary Contamination: The Ultimate Challenge for Environmental and Constitutional Lawyers?', *Journal of Space Law*, 31, pp. 117–163.

Rose, C. M. (1986) 'The Comedy of the Commons', *University of Chicago Law Review*, 53, 711–781.

Salanié, F. and Treich, N. (2009) 'Regulation in Happyville', *The Economic Journal*, 119, pp. 665–679.

Sandler, T. (2016) 'Strategic Aspects of Difficult-to-Handle Global Challenges', *Global Policy* (forthcoming).

Schachter, D. L., Addis, D. R. and Buckner, R. L. (2008) ''Episodic Simulation of Future Events: Concepts', *Data, and Applications', Annals of the New York Academy of Sciences*, 1124, pp. 39–60.

Shindell, D. T., Lee , Y., and Faluvegi, G. (2016) 'Climate and health impacts of US emissions reductions consistent with 2 °C', *Nature Climate Change*, doi:10.1038/nclimate2935. Available at http://www.nature.com/nclimate/journal/vaop/ncurrent/full/nclimate2935.html [Accessed 21 March 2016].

Shrader-Frechette, K. (1991) *Risk and Rationality*. Berkeley, CA: University of California Press.

Slovic, P. (1987) 'Perception of Risk', *Science*, 236(4799), pp. 280–285.

Slovic, P. (2007) '"If I Look at the Mass I Will Never Act": Psychic Numbing and Genocide', *Judgment and Decision Making*, 2(2), pp. 79–95.

Slovic, P., Zionts, D., Woods, A. K., Goodman, R. and Jinks, D. (2013) 'Psychic Numbing and Mass Atrocity', in Shafir, E. (ed.), *The behavioral foundations of policy*. Princeton, NJ: Princeton University Press, pp. 126–142.

Small, D. A. and Loewenstein, G. (2005) 'The Devil you Know: The Effects of Identifiability on Punishment', *Journal of Behavioral Decision Making*, 18, pp. 311–318.

Small, D. A., Loewenstein, G. and Slovic, P. (2007) 'Sympathy and callousness: The impact of deliberative thought on donations to identifiable and statistical victims', *Organizational Behavior and Human Decision Processes*, 102, pp. 143–153.

Stern, J. and Wiener, J. B. (2008) 'Precaution against Terrorism', in Paul Bracken, Ian Bremmer and David Gordon (eds), *Managing Strategic Surprise: Lessons from Risk Management and Risk Assessment*. Cambridge: Cambridge University Press.

Sunstein, C. R. (2005) *The Laws of Fear: Beyond the Precautionary Principle*. Cambridge: Cambridge University Press.

Sunstein, C. R. (2006) 'Irreversible and Catastrophic', *Cornell Law Review*, 91, pp. 841–897.

Sunstein, C. R. (2007) *Worst-Case Scenarios*. Cambridge, MA: Harvard University Press.

Tetlock, P. E. and Gardner, D. (2015) *Superforecasting: The Art and Science of Prediction*. New York: Crown.

Tonn, B. E. (2009) 'Beliefs about human extinction', *Futures*, 41, pp. 766–773.

Turner, B. A. (1976) 'The organizational and inter-organizational development of disasters', *Administrative Science Quarterly*, 21, pp. 378–397.

Västfjäll, D., Slovic, P. and Mayorga, M. (2015) 'Pseudoinefficacy: Negative feelings from children who cannot be helped reduce warm glow for children who can be helped', *Frontiers in Psychology*, 6, pp. 1–12.

Västfjäll, D., Slovic, P., Mayorga, M. and Peters, E. (2014) 'Compassion Fade: Affect and Charity Are Greatest for a Single Child in Need', *PLOS One*, 18 June [online]. Available http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0100115 [Accessed 21 March 2016].

Walker, B. and Barrett, S. Polasky, S., Galaz, V., Folke, C., Engström, G. et al. (2009) 'Looming Global-Scale Failures and Missing Institutions', *Science*, 325, pp. 1345–1346 (11 September).

Weber, E. U. (2006) 'Experience-Based and Description-Based Perceptions of Long-Term Risk: Why Global Warming does not Scare us (Yet)'. *Climatic Change*, 77, pp. 103–120 (21 July).

Weitzman, M. L. (2009) 'On modeling and interpreting the economics of catastrophic climate change', *The Review of Economics and Statistics*, 91, pp. 1–19.

Wells, W. (2009) *Apocalypse when? Calculating how long the human race will survive*. New York, NY: Springer Verlag.

Wiener, J. B. (1998) 'Managing the Iatrogenic Risks of Risk Management', *Risk: Health Safety and Environment*, 9, pp. 39–82.

Wiener, J. B. (1999) 'Global Environmental Regulation: Instrument Choice in Legal Context', *Yale Law Journal*, 108, pp. 677–800.

Wiener, J. B. (2002) 'Precaution in a Multirisk World', in Dennis D. Paustenbach (ed.) *Human and Ecological Risk Assessment: Theory and Practice*. New York, NY: Wiley and Sons, pp. 1509–1531.

Wiener, J. B. (2005) 'Reviews of Catastrophe by Richard Posner and Collapse by Jared Diamond', *Journal of Policy Analysis and Management*, 24, pp. 885–890.

Wiener, J. B. (2007) 'Precaution', in Daniel Bodansky, Jutta Brunnee, and Ellen Hey (eds), *Oxford Handbook of International Environmental Law*. Oxford: Oxford University Press, pp. 597–612.

Wiener, J. B. (2008) 'The Tragedy of the Uncommons', remarks at the Conference on Global Catastrophic Risks, 16–20 July, Oxford University.

Wiener, J. B. (2011) ''The Real Pattern of Precaution' (chapter 20)', in Jonathan B. Wiener, Michael D. Rogers, James K. Hammitt and Peter H. Sand (eds), *The Reality of Precaution: Comparing Risk Regulation in the US and Europe*. Washington, DC and London: RFF Press/Earthscan/Routledge, pp. 519–565.

Wiener, J. B. (2013) 'The Diffusion of Regulatory Oversight', in Michael A. Livermore and Richard L. Revesz (eds), *The Globalization of Cost-Benefit Analysis in Environmental Policy*. Oxford and New York: Oxford University Press, pp. 123–141.

Wiener, J. B. (2016). 'Precaution and Climate Change', in Cinnamon Carlarne, Kevin R. Gray and Richard Tarasofsky (eds), *The Oxford Handbook of International Climate Change Law* (forthcoming). Oxford and New York: Oxford University Press.

Wiener, J. B. and Richman, B. D. (2010) 'Mechanism Choice', in Daniel Farber and Anne Joseph O'Connell (eds), *Public Choice and Public Law*. Northampton, MA: Edward Elgar, pp. 363–396.

Wildavsky, A. (1997) *But Is It True? A Citizen's Guide to Environmental Health and Safety Issues*. Cambridge, MA: Harvard University Press.

WMO (World Meteorological Organization) (2014) *Assessment for Decision-Makers: Scientific Assessment of Ozone Depletion: 2014*. World Meteorological Organization, Global Ozone Research and Monitoring Project – Report No. 56. Preprint 10 September. Geneva [online]. Available from: http://www.wmo.int/pages/prog/arep/gaw/ozone_2014/ozone_asst_report.html [Accessed 21 March 2016].

World Bank (2014) *World Development Report 2014: Risk and Opportunity – Managing Risk for Development*. Washington DC: World Bank Group.

Wuthnow, R. (2010) *Be Very Afraid: The Cultural Response to Terror, Pandemics, Environmental Devastation, Nuclear Annihilation, and Other Threats*. Oxford: Oxford University Press.

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