Why We Fail to Learn from Disasters

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Abstract

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A puzzling feature of human response to catastrophes is that what we learn from them often seems short-lived. The occurrence of a disaster at one point in time is invariably followed rapid and aggressive protective responses, as measured both by public expenditures in mitigation and individuals' willingness to undertake protect measures on their own. But this willingness to invest in protection invariably fades with time—until it is provoked again by the next disaster. In this paper I explore some of the causes—and possible remedies—of such apparent failures to learn. The core thesis is that while such learning failures can sometime be explained as a natural outcome of learning by trial and error—that is, learning by repeating those behaviors that have produced attractive outcomes in the recent past—learning failures are often driven by other, overriding factors. The two most prominent are poor mental models of how hazards cause damage and the ability of mitigation to disrupt this process and beliefs in survivability—beliefs that encourage risk-taking as knowledge about hazards and mitigation grows.

Introduction

It has often been said that we are poor learners from experience about the value of hazard mitigation. In an empirical study of decisions to buy flood insurance, for example, Kunreuther (1984) found that the passage of several dry years was sufficient to convince residents of flood-prone areas that they faced limited future risk, something that dissuaded them from purchasing protection. Likewise, after the great San Francisco earthquake and fire in 1906 local authorities were at first to moved to enact stronger building codes—but they were quickly removed from the books when contractors complained that they were slowing the pace of the city's reconstruction (Hanson and Condon 1989). Finally, even in cases where investments *are* made after a disaster we often seem to quickly forget why we undertook them in the first place. The catastrophic flooding that New Orleans suffered in Hurricane Katrina in 2005, for example, has been widely attributed to a failure to invest in maintenance of the levees that were constructed in response to the floods of Hurricane Betsy in 1965 (Brinkley 2006). And while Galveston was widely commended for its efforts in building a protective sea wall around its city after the great hurricane in 1900, when Texans began to build residences on the Bolivar peninsula just to the north few saw the need to build similar protection there—protection that could have prevented the large losses of property that recently resulted from Hurricane Ike in 2008.

What causes these apparent failures to learn? A story that is often told is that it is an unavoidable consequence of what psychologists call stimulus-reinforcement (S-R) learning: the tendency we have to make decisions in life by repeating those behaviors that consistently yield positive rewards and avoiding those that do not (e.g., Kunreuther, Meyer, and Michel-Kerjan 2008; Meyer 2006). The story goes like this: while this S-R learning serves us quite well in many walks of life—it is helpful in teaching us how to play tennis and know what foods to enjoy versus avoid—when applied to low-probability negative events it can, in theory, produce patterns of behavior that are potentially dysfunctional. We are bad at seeing the value in investing in protecting against rare events because, by definition, the occasions on which we would have the opportunity to see a tangible positive reward from such investments will be few. As such, in the absence of disastrous events protective behaviors are invariably prone to extinction. In the quiet years that have elapsed since the Northridge earthquake in 1994, for example, the state of California has witness just a decline in interest in among residents in buying earthquake insurance; whereas 30% of homeowners held the insurance in 1994, by 2007 the percentage had dropped to less than 12% in 2007 (Kunreuther, Meyer, and Michel-Kerjan 2008).

But there is a problem with this explanation of learning failures: while compelling in its simplicity, it fails to explain all the data. In many cases communities *do* eventually learn the value of mitigation (e.g., by adopting and enforcing building codes), and one can point to examples where people seem to *over*-learn the value of mitigation, such as by repeatedly engaging in acts of protection that are of limited real effectiveness, or mitigating against hazards that are unlikely to ever occur. For generations farmers in the Henan province of China, for example, have followed the custom of avoiding consuming steamed bean soup (a dietary staple) for five days at the start of each year in the belief that it helps prevent floods (Li, 1990), and Europeans once sprinkled mustard seeds on the roof of their houses as a means of mitigating against the hazard of vampire attacks (Mappin 2003). One could, of course, still try to explain such superstitious behaviors in S-R terms by pointing out that the adopters of such precautions would have observed them to be effective (however spuriously) more often than not. The rarity of floods implies that a practice of soup abstinence would produce the desired result more often than not, and one must assume that houses with mustard seeds on their roofs were rarely victimized by vampires. But what is puzzling is why such folk beliefs about prevention seem to have no difficulty arising and persisting, while other, more scientifically-based, beliefs have less staying power, such as the wisdom of maintaining levees around major cities built below sea level.

The goal of this essay to explore in greater detail what we know about the ability of communities to learn to invest in mitigation against low-probability, high-consequence, hazards, and to offer an expanded view of the factors and processes that drive adoption and forgetting. The core thesis is that while stimulus-reinforcement mechanisms often play a role in how decisions are made to take protective action, the role is only partial, and in many cases its effects are offset—or amplified—by two additional influences on decision making: the decision maker's mental models of the physical mechanics of hazards and their preventability through mitigation, and the decision maker's core emotional beliefs about the mortal threat posed by a hazard. A case is made that the most vivid instances of learning failure—such as decisions made about investing maintaining levees around New Orleans—are due not just to the extinguishing effects of non-reinforcement, but rather its effect combined with two other necessary forces: poor mental models, and a fundamental belief that a disaster, no matter how severe, will be survivable.

The discussion will be partitioned into four phases. We begin by reviewing in greater detail the arguments behind S-R-learning explanations of mitigation behavior, and then discuss, in turn, how the predictions made by S-R models would be colored by the nature of decision makers' mental models of hazards and beliefs about the lethalness of the hazard. We then conclude with a discussion of the implications of these ideas for efforts to improve the speed and accuracy of learning.

S-R learning and mitigation

Decisions about whether it is worthwhile to invest in mitigation against low-probability, high-consequence, hazards are not east to make. Consider, for example, the dilemma of a homeowner who is mulling over whether it is worthwhile retrofit his or her roof to make it more hurricane-resilient, such as by installing additional tie-down straps and a stronger bed under the roofing shingles. From the perspective of classic decision theory the decision *should* be straightforward: the homeowner should make this investment if the long-term expected benefits of the mitigation exceed its costs. How would this be done? Here is the rub; while the advice is easy to offer, implementing it in a rigorous matter would, in most cases, be virtually impossible. Specifically, to implement the advice the homeowner would have to possess well-developed beliefs about at least two probability distributions: one over the severity of wind events likely to be experienced by a home in a given year (let's call it f(x)), and another over the savings in foregone repairs provided by mitigation conditional on a certain wind event ($g(r|x)$). If the homeowner knew these distributions and believed that he or she would be living in the home for T years, he or she should invest in mitigation if

$$C<\left[\sum_{t=0}^{T} \beta^{t} \int_{x} \int_{r} r f(x) g(r|x) d_x d_r\right], \qquad (1)$$

where β is the consumer's inter-temporal discount rate and C is the cost of that is. In words, equation (1) describes that the simple idea that mitigation should be undertaken if its cost is less than the discounted stream of expected benefits.

But there is an obvious problem with this analysis: in natural settings the decision maker would never know what these key hazard and mitigation-value distributions are. The historical record of hurricanes in the Atlantic Basin, for example, goes back only 150 years, and it is superimposed by periodicities in frequency whose properties are largely unknown. Likewise, the probability distribution over the damage likely to be experienced by a given structure given a certain wind event—and how that would be reduced by mitigation is also highly ambiguous.

But note that this specification problem is by no means unique to natural hazards. In fact, a case can be made that we almost *never* know enough about our environment for standard decision analysis to provide us with useful guidance as to the actions we should take when faced with most risky decisions. Few of us, for example, would consider trying to undertake such a complex (and ultimately indeterminate) expected-value analysis to decide, say, whether to try an unfamiliar item on a menu, get married, or retire. So how are these decisions made? A widely-hypothesized view we more typically make such decisions using comparatively little analytic reasoning; they are, rather, guided by simple trial-and-error learning heuristics that value actions simply based on how well they have been observed to produce pleasing outcomes in the past.

To illustrate, consider the simple case of a homeowner who must decide, at the start of each hurricane season, whether it is worthwhile to make some investment c to mitigate losses from storms. The homeowner learns the value of making these investments through a simple trial-and-error learning process that updates beliefs about the value of mitigation based on recent experienced losses and conjectures about what those losses might have been with or without mitigation. Formally, as time evolves the homeowner's beliefs about the subjective value of mitigation ($V(m)_t$) evolve as

$$V(m)_t = aV(m)_{t-1}) + \beta\, d|m_{t-1} + \gamma\, (d|0_t - d|m_{t-1}) \qquad (2)$$

$$\alpha + \beta + \gamma = 1$$

where $d|m_{t-1}$ is the damage experienced by the homeowner given the mitigation decision that was made in the previous year ($t-1$),
$d|0_t - d|m_{t-1}$ is the homeowner's conjecture about the damage that would have occurred in the absence of mitigation (or, if mitigation was not undertaken, what the precluded losses would have been), and a, β and γ are updating parameters.

Note that if the damaging storm events are frequent and the decision maker focuses only on the conjectured benefit of mitigation in each year—that is, the case where $\beta=0$—equation (2) could be seen as a Bayesian updating model that would allow beliefs about the conditional benefits of mitigation converge to the true expected value with time. In particular, if the decision maker concluded that mitigation was worthwhile at some early point in time t (i.e., $V(m)_t > c$) he or she would continue to make the investment in all future points in time.

But what about the case where storm events are comparatively rare, and the homeowner is sensitive to the amount of damage actually experienced rather than just conjectures about the benefits of mitigation—i.e., the case where $\beta > 0$? Here is where the trouble starts. When applied to such cases equation (2) predicts the possibility of an oscillating sequence of on-again, off again decisions to invest. Specifically, a decision to invest in mitigation in year t decreases the likelihood of investing again the next because of one of two forces:

1. the absence of a storm event precludes the ability to observe any conjectured benefit (i.e., $d|0_t - d|m_{t-1} = 0$); or
2. the presence of previous mitigation precludes the ability to observe any damage (i.e., $d|m_{t-1} \rightarrow 0$).

The degree to which such oscillation would actually occur would depend, of course, on such factors as the absolute severity of damage ($d|m_{t-1}$) and the amount that could be precluded by mitigation (the difference ($d|0_t - d|m_{t-1}$), and the degree to which the decision maker attends just to the different drivers of beliefs (the parameters α, β, and γ). Likewise, one could consider variations on this basic model that assume more sophisticated learning abilities, such as those that assume that individuals have a much better ability to recall past damage instances. But across a broad range of similar structures the same the core property would hold: as long as an individual's decision about the value of mitigation is motivated by losses observed in the recent past, positive decisions to invest in mitigation will be prone to periodic extinction.

The Amplifying Role of Inappropriate Mental Models

While stimulus-reinforcement models provide a simple mechanism that could be used to explain historical myopia, it is important to emphasize that forgetting is not a necessary outcome of all *S-R* learning models. If one is willing to assume that individuals respond to periods in which there are no hazards by *imagining* them—triggering *fictitious* reinforcement (see, e.g., Camerer and Ho 1999)—then, in theory these same models would predict sustained investments in mitigation.

How likely are individuals and communities to engage in fictitious learning? One assumes that such influences abound; societies are quite good, after all at developing means for helping its members recall catastrophic events which they have had no direct experience. Travelers along the Overseas Highway in the Florida Keys, for example, pass by a monument commemorating the loss of life that occurred during the great hurricane of 1935—a monument designed to serve as a reminder of the omnipresent threat that such storms pose in that area. Likewise, even societies that lack the means of formal record-keeping often keep memories of past catastrophes alive through story-telling and folklore. A ubiquitous part of the folk mythologies of almost all cultures, for example, are stories of great deluges or floods—mythical descriptions of caused them (invariably angered gods), how they were survived, and how they might be avoided in the future (e.g., Dundes, 1988). The fact that people routinely gain knowledge about low-probability events without ever actually experiencing them would thus seem to pose a formidable problem for *S-R* explanations of why we often under-invest in mitigation.

But there is a complication: the ability to engage in fictitious learning about hazards is a good thing only to the degree that the knowledge conveyed in these simulated memories is objectively helpful. If individuals and/or societies we have poor mental models of how and why natural hazards arise, then processes that reinforce these beliefs through story-telling would be decidedly counter-productive. False beliefs would be constantly self-reinforcing, and a society might find itself engaging in protective behaviors conceivably exacerbate rather than mitigate the risks they face from hazards.

One example of the perpetuation of erroneous mitigation beliefs due to poor mental models is the long-held belief among residents in tornado-prone areas that the best way to prevent a house from being destroyed if a tornado passes overhead was to open windows, particularly on the northeast side of the structure. This practice had its origins in a mistaken—but long perpetuated--belief about what caused houses to be destroyed by cyclonic winds. The traditional view was that extreme pressure differences inside versus outside a house as a tornado passes overhead causes the house to "explode", much like a balloon might pop if were allowed to over-inflate. This, logically, could then be prevented by equalizing the pressure by opening windows. Later engineering studies of house performance during wind events, however, revealed that this structural theory was fundamentally flawed; open windows were more to be the *cause* of building collapse rather than the cure (Pendergrass 1999).. Houses were found not "explode" as tornados passed overhead, but rather collapse because of wind entering the house through broken (or open) windows, which, in turn, would exert upward pressure on roofs, whose subsequent removal would cause a collapse of supporting walls.

This same misunderstanding of the effect of wind on structures may also be a factor in the reluctance of residents in hurricane-prone areas to invest in storm shutters (e.g., Peacock 2003). For the reasons stated above the real value of storm shutters lies in protecting a home's roof and resulting structural integrity, not the windows themselves. A resident who lacks this knowledge might thus fail to see the how the benefits of shutters (or wind-resistant glass) justify the cost; the preventive cost of the shutters is obviously much more than that of replacing a broken window and maybe a bit of wet carpet once every decade or so. But a resident who understands that it is the house itself, not just the window glass that the shutters are there to protect would likely reach a quite different conclusion.

Another well-known example where poor mental models degrade the ability of people to learn from experience about hazards is misunderstanding of the time-series properties of hazardous events. The likelihood that a specific location will be impacted by a natural disaster at a given point in time is usually governed by what statisticians call a zero-order probabilistic process; while there may indeed be aggregate cycles in the frequency of hazards (e.g., stresses on faults are released by ruptures, and hurricanes in the Atlantic Basin are marked by multi-decadal frequency cycles), for any given location it is difficult to reject a hypothesis that the probability that it will be subject to a disaster in a given year is best described by a constant, small, value. Yet, residents and communities are notorious for believing that low-probability events are highly temporally correlated. To some degree these beliefs are exacerbated by misguided attempts to make low probabilities more understandable by conveying them in "1 every *N*-years" terms. Hence, it is not uncommon to hear residents of a 100-year flood plain (for which there is a 1% chance of experiencing a flood in a given year) to rationalize their quick resettlement after experiencing a flood by expressing the view that they are safe because they have already "had" their 100-year flood; i.e., another one should not be due for another 99 years.

At the other extreme are residents and communities who might *over*-invest in mitigation because of a belief that the occurrence of recent hazard suggests that they will be more likely in the future. A good example of this is the inflated premia that reinsurers began charging for coverage after the active 2004 and 2005 hurricane seasons (Wharton Risk Center 2008). Although there was no reliable statistical evidence to support a hypothesis that the extreme activity of 2004 and 2005 was anything more than a statistical blip not dissimilar to those that have been observed in the past (e.g., the 1933-34 was a similar two-year period of high activity), the two seasons prompted widespread beliefs that such seasons would now be typical going forward, fueled by global warming. Not surprisingly the seasons since have been comparatively quiet as measured by storm landfalls.

The Survivability Effect

The above accounts still leave us with one remaining puzzle. In principle, the better we are at recalling the past and the advanced our scientific knowledge is about hazards and mitigation, the lower our losses should be from them. But the reality seems to be the opposite. The data suggest that as rapidly as we have seen increases in the science of mitigation, we have witnessed even faster increases in material losses from disasters. As an example, while hurricanes have plagued communities along the United States Atlantic and Gulf coasts for decades—often with greater frequency and severity than we are seeing today—the inflation-adjusted losses imposed by recent storms dwarf those imposed by past storms. Seven of the hurricanes that made landfall in 2004 and 2005, for example, were among the 20 most costly insurance disasters of all time (Wharton Risk and Decision Processes Center 2009). The typical explanation for this is that the more that we know about hazards and how to survive them, paradoxically the more we are to expose ourselves and our property to risk. In other words, when it comes to protecting against hazards, more knowledge can be a dangerous thing.

A good example of this paradox of knowledge is the fate of the town of Indianola, Texas. In the 1875 Indianola was a thriving Gulf-coast town of 5,000 that was home to the second most important port in Texas, behind Galveston. In September of that year, however, Indianola was destroyed by a major hurricane and accompanying tidal surge. Not to be dissuaded, the community rapidly recovered from this disaster and rebuilt--only to see the town destroyed yet again by a hurricane in 1886. Lacking any knowledge of hurricane climatology, and knowing little about how one might prevent such a disaster from happening yet again, the surviving residents reached the only sensible conclusion they could: this was simply not a good spot to build a town, and the residents moved elsewhere. What remains of Indianola still exists, but as a ghost town that serves as rare monument to sensible prudent decision making under uncertainty.

In contrast, the far more advanced knowledge that we have today about hurricane risks and mitigation tends to produce something of the opposite reaction among communities and individuals: the belief that storms and other hazards are both survivable and predictable has induced aggregate risk taking, with the dominant migration pattern being to coastal zones that would have been deemed too unsafe for sensible development in earlier, less knowledgeable, times. In short, we suffer more from hazards today because of inflated beliefs about the degree to which we can survive them.

What explains this effect? Past research on risk-taking and learning in other domains suggests three complementary mechanisms. The first is that the tendency for knowledge to foster risk-taking can be seen as the mirror image of the well-known tendency for individuals to *avoid* risky decisions when the odds of different outcomes are unknown or ambiguous. For example, while a decision maker may be willing to take a bet for which there is an 50% chance of winning $10 and a 50% chance of losing $2, he or she will be less likely to take that same bet if the odds of the two outcomes are either unknown, or are randomly drawn from a uniform distribution with a mean of 50% (Camerer andWeber 1992). Hence, by reverse implication, the more precisely one can express the odds of a gamble, the more likely a person will be to play it.

The second mechanism is the widespread finding that individuals are less dissuaded by risks whose odds are perceived as controllable. For individuals who engage in risky health behaviors (such as cigarette smoking and exposure to AIDS) have been found to do so, in part, because they feel that their personal odds of suffering ill effects are simply less than that faced by others; while others are at risk, they are less so because their superior ability to control it (e.g., Menon, Block, and Ramanathan 2002). Hence, the more easily it is for a coastal resident to envision how they might survive a hurricane through stronger windows, better roofing, government aid after the storm, etc., the more likely they are to believe that damage is something that will happen to other residents, not them.

The final mechanism might be termed the mortality effect; individuals will be less inclined to want to experiment with risky actions if there is a perceived real possibility—no matter how small--of a fatal outcome. Even if one suspected that a certain belief may not be factually well-grounded—such as a belief that a certain coastal location was "cursed" to receive a disproportionate share of hurricanes, or that abstaining from bean soup might prevent floods---if the consequences of being wrong are sufficiently catastrophic the experiment needed to reject the belief would never be conducted. As an extreme example, the ancient Aztecs routinely conducted human sacrifices in the belief that they were necessary to prevent the end of the world[1]. This custom, clearly, had little evolutionary basis in objective reinforcement learning; presumably no one had any direct evidence that the world would end without the sacrifices. But it nevertheless persisted due to the joint effects of fictitious reinforcement via the re-telling of myths, and, most importantly, the understandable reluctance of the Aztecs to undertake the experiment necessary to find out whether the myth was true or not.

In contrast, the less lethal hazards are perceived to be, the more willing individuals and communities may be to experimentally push the boundaries of survivability. At long as there is uncertainty about the likelihood that a given location will be subject to a disaster, the possibility exists that forecasts of doom will go unfulfilled, particularly in the short time horizon of expected residence--and the only way to find for sure is to undertake the experiment of living there.

Discussion

One of the greatest challenges facing modern communities is that of persuading residents to voluntarily engage in protective behaviors that would reduce losses from low-probability, high-consequence events. Although mitigation *is* widely practiced, it is also seen as not enough. The seven billion dollars that are currently being invested in restoring the levees around New Orleans, for example, dwarfed by the almost one-hundred billion in losses that the original failure to maintain them induced. Likewise, and analysis conducted by the Wharton Risk Center in 2008 estimated that rudimentary investments in windstorm mitigation could reduce losses from hurricanes by 60%--an amount that would greatly reduced required insurance premiums (Wharton Risk Center in 2008). What is perplexing about these examples is that they arise in a domain where one might think that individuals and communities would have long-learned the value of mitigation. To the degree that learning has occurred, it has often appeared to be painfully slow, with good-meaning attempts to upgrade investments in mitigation following one disaster losing steam, only to be taken up again when the next disaster arises.

What causes this slow learning? This paper examined in detail one of the most common arguments for learning failures: in the absence of clear knowledge about the risk posed by hazards and how best to mitigate against them, communities and individuals turn to trial-and error learning heuristics that repeat those behaviors that have worked well in the recent past and avoid those that have not. Under such a process instincts to mitigate against low-probability events are inherently prone to extinction simply because decisions *not* to invest in mitigation are financially rewarded far more often than decisions *to* invest.

The core thesis of this essay, however, was that the reasons people under invest in mitigation are more complex than this. As an example, problematic to this account is that the world is filled with a wide range of mechanisms designed to keep memories of past disasters and the benefits of mitigation alive, be it through monuments, story-telling, or folklore. Indeed, we noted that a trial-and-error learner need only bring up frequent *fictitious* memories of the benefits of mitigation to persist in making protective investments, even against hazards he or she has never actually seen. In light of this, why is under-investment in mitigation is widely observed given the numerous mechanisms that exist that help us recall the past? The reason, we suggested, is that for trial-and-error learning to be effective the accuracy of *what* is imagined about the benefits of mitigation is just as important as *how often* it is imagined. And here is where as decision makers we often falter; in many cases failures to mitigate have as much to do

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[1] This belief arose from the Aztec cosmology which held that the universe operated in 52-year cycles. The current cycle could be extended, but only with the help of gods who drew their strength from human sacrifice (Townsend 2000).

with forgetting the past as with possessing poor mental models of how hazards function and how best to protect against them. Likewise, there is also the complicating factor of beliefs about the survivability of disasters encouraging people to take risks. Hence the paradox of mitigation knowledge: the more advanced the science of mitigation and the more people see the risk as small and controllable, the more willing they will be to make decisions that put them in harm's way.

Can learning be enhanced? The answer here is somewhat uncertain. On one hand, the above analysis suggests that we have all the tools at our disposal needed to support efficient learning paths, both through communication programs designed to remind residents and communities of the threats posed by hazards and, even more critically, education programs designed to correct mental models of how hazards cause damage and the benefits of mitigation. On the other hand, the fact that we *do* know so much more about hazards and mitigation has the counter-productive effect of making these events seem less lethal than they once were. In the 1800s residents of Indianola, Texas lacked warning advice by the National Hurricane Center, lacked building codes, and lacked FEMA to help with recovery after a storm. But they had one thing that modern coastal residents in the Bolivar peninsula to the north lack: a fearful respect for nature that led to learn the most efficient possible method of mitigation, that of moving to where one has the least *need* to mitigate.

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