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Perspective

Risk Management Solutions for Climate Change–Induced Disasters

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In honor of the 40th anniversary of *Risk Analysis*, this article suggests ways of linking risk assessment and risk perception in developing risk management strategies that have a good chance of being implemented, focusing on the problem of reducing losses from natural hazards in the face of climate change. Following a checklist for developing an implementable risk management strategy, Section 2 highlights the impact that exponential growth of CO_2 emissions is likely to have on future disaster losses as assessed by climate and social scientists. Section 3 then discusses how people perceive the risks of low-probability adverse events and the cognitive biases that lead them to underprepare for future losses. Based on this empirical evidence, Section 4 proposes a risk management strategy for reducing future losses using the principles of choice architecture to communicate the likelihood and consequences of disasters, coupled with economic incentives and well-enforced regulations.

KEY WORDS: climate change; natural disasters; cognitive biases; risk management

In honor of the 40th anniversary of *Risk Analysis*, this article focuses on reducing losses from natural disasters in the face of climate change. I begin with a checklist for developing an implementable risk management strategy that recognizes the importance of incorporating risk assessments by experts and taking into account risk perceptions of key interested parties. The article then discusses the impact that exponential growth of CO_2 emissions is likely to have on future disaster losses as assessed by climate scientists and social scientists, and how decisionmakers perceive the risks of low-probability adverse events and the cognitive biases that lead them to underprepare for future losses. To reduce future disaster losses, the article proposes using choice architecture to frame and communicate the likelihood and consequences of disasters in conjunction with economic incentives, well-enforced regulations, and insurance.

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1. A CHECKLIST FOR DEVELOPING A RISK MANAGEMENT STRATEGY

A risk management strategy to reduce losses from natural disasters in the face of climate change would consider these nine points:

1. *Listen to the experts*. Political leaders and key decisionmakers should turn to experts for advice on how to deal with the impacts of climate change and invest in protective measures for reducing losses from natural disasters.
2. *Involve interested parties in designing risk-management strategies*. Stakeholders include representatives from banks and financial institutions; the insurance industry; real estate brokers and developers; federal, state, and local officials; and property owners in hazard-prone areas.
3. *Characterize the values and goals of the interested parties*. Determine where there is general agreement on specific values and goals for

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designing a risk management strategy, and when and why there are differences that need to be addressed.

4. *Be aware of the behavioral biases and heuristics that cause misperceptions of the risk*. Recognize that intuitive thinking can lead decisionmakers to underestimate the probability of a disaster so they assume it will not happen to them and hence do not consider the damage and relate losses from future events.
5. *Use concepts from choice architecture and a behavioral risk audit to communicate the risks*. Reframe likelihoods of a disasters to overcome the biases and heuristics that characterize behavior with respect to low-probability events.
6. *Design short-term economic incentives for encouraging individuals at risk to invest in protective measures*. Provide long-term loans to spread upfront costs of loss reduction measures over time to address budget constraints.
7. *Recognize the importance of well-enforced regulations and standards*. Provide data on the reduction in damage to the community with well-enforced building codes and zoning restrictions.
8. *Protect against disasters through insurance via private-public partnerships*. Specify risk-based insurance premiums coupled with public sector involvement for covering catastrophic losses and dealing with affordability issues.

2. RISK ASSESSMENT OF CLIMATE CHANGE IMPACTS ON NATURAL DISASTERS

Climate scientists have long recognized that CO_2 emissions and their resulting effects have been increasing exponentially. Fig. 1 shows the monthly average CO_2 concentration at Mauna Loa Observatory in Hawaii—the longest record of direct measurements of CO_2 in the atmosphere. The volume of CO_2 stood at 315 parts per million (ppm) when first measured in 1958; by the end of May 2020, it had risen by 32% to 417 ppm (Fountain, 2020).

This exponential increase signals that CO_2 emissions and their resulting concentrations are likely to be considerably higher in the coming years, unless strong measures are taken to reduce them. The range of temperature increases considerably narrows from previous estimates, shifting it toward warmer outcomes. The research estimated that there was less than a 5% chance of a temperature shift below 2 °C but a 6% to 18% chance of a higher temperature change than 4.5 °C (Sherwood et al., 2020). With these new ranges of higher temperatures, one can expect more blistering heat waves, severe droughts, accelerating sea level rise (SLR), and unprecedented intensity of rainstorms and resulting flooding. Fig. 2 illustrates the impact of SLR on chronic flooding to an East Coast community in 30 or 45 years.

To illustrate, consider flood-related damage caused by climate change combined with population growth in hazard-prone areas. A 2013 analysis in 136

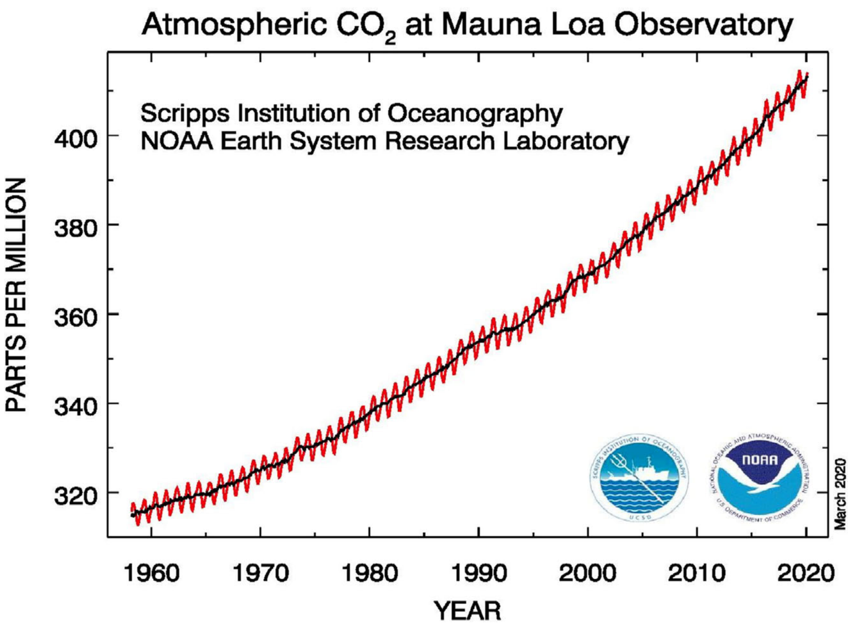

Fig 1. Mean carbon dioxide (CO_2) measured at Mauna Loa Observatory, Hawaii.
Source: NOAA ESRL Global Monitoring Division.

As sea level rise extends the zone of chronic inundation deeper into communities, chronic flooding may affect commercial, industrial, and residential areas, along with key infrastructure. The left panel shows the current zone of chronic inundation (light blue) in an East Coast community. The center panel shows the chronic inundation zone in 2045, when a densely developed neighborhood can expect to have to deal with twice monthly saltwater inundation. The right panel shows the chronic inundation zone in 2060, when much of the town's coastal area floods with regularity—a sobering challenge for local and state governments.

SOURCE: ESRI, DIGITALGLOBE, GEOEYE, EARTHSTAR GEOGRAPHICS, NCES/AIRBUS DS, USDA, USGS, AEROGRID, IGN, AND THE GIS USER COMMUNITY

Fig 2. Expanding the chronic inundation zone.

major coastal cities around the world reveals that SLR of 20 cm (7.9 inches) by 2050—an optimistic scenario—will cause the average annual flood losses in those cities to increase to $1.2 trillion that year from $52 billion in 2005. A more pessimistic scenario of SLR of 40 cm (15.7 inches) by 2050 will lead to average annual flood losses of $1.6 trillion (Hallegatte, Green, Nicholls, & Corfee-Morlot, 2013).

People are actually moving *into* harm's way, not realizing the potential for severe damage they might suffer in the coming years due to climate change. From 1980 to 2018, the population of hurricane-prone counties in Florida increased by 163%, from 3.7 million people to 9.8 million, compared with a 61% increase in the population of the United States during this period. These Florida residents might not recognize that they are likely to experience increased damage from more intense hurricanes coupled with SLR due to climate change (Union of Concerned Scientists, 2019).

If carbon emissions continue to grow exponentially, most of the United States could experience 20 to 30 more days annually with maximum temperatures higher than 90°, with the Southeast potentially enduring 40 to 50 more such days. This extreme heat poses serious health risks, especially to the very young and elderly, construction and agricultural workers, and those living in urban areas (Union of Concerned Scientists, 2018). A July 2019 study by researchers at the Earth Institute of Columbia University reveals that wildfires could continue to grow exponentially in California in the next 40 years as temperatures rise due to climate change (Williams et al., 2019).

3. RISK PERCEPTION OF NATURAL DISASTER LOSSES

Risk perception relates to the psychological and emotional factors that have been shown to have an enormous impact on behavior. In a set of path-breaking studies begun in the 1970s, psychologists began measuring laypersons' perceptions of different

System 1 operates automatically and quickly with little or no effort

- Individuals use simple associations including emotional reactions
- Highlight importance of recent past experience
- Basis for systematic judgmental biases and simplified decision rules

System 2 allocates attention to effortful and intentional mental activities

- Individuals undertake trade-offs implicit in benefit-cost analysis
- Recognizes relevant interconnectedness and need for coordination
- Focuses on long-term strategies for coping with extreme events

Fig 3. Intuitive and deliberative thinking.

types of risks. These studies revealed that hazards about which the person had little knowledge were also highly feared and perceived as being the riskiest ones (Slovic, 2000).

The general finding that laypersons see the world differently from the scientific community also raised a set of questions as to the nature of the decision-making process for dealing with risks. For a long time, experts ignored the public's risk perceptions since most laypersons did not focus on the likelihood and consequences of these hazards but were motivated by factors such as dread and catastrophic potential.

Experts now recognize the need to include psychological and emotional factors in developing risk management strategies to address public concerns. Recent studies have confirmed this view by showing that many individuals will oppose certain technologies such as nuclear power or would not want to reside near a landfill or waste facility because they perceive them to be hazardous. This attitude may create significant indirect effects due to social amplification and stigma (Kasperson et al., 1988). On the other hand, with respect to natural disasters, the general public is often unconcerned about the risks associated with living in a hazard-prone area prior to experiencing a loss from an earthquake, flood, or hurricane.

3.1. Intuitive and Deliberative Thinking

In his thought-provoking book *Thinking, Fast and Slow*, Nobel Laureate Daniel Kahneman highlighted two modes of thinking based on research in psychology and behavioral economics over the past 50 years. *Intuitive thinking* (System 1) operates automatically and quickly with little or no effort and no voluntary control. It is often guided by emotional reactions and rules of thumb that have been acquired by personal experience. *Deliberative thinking* (System 2) allocates attention to effortful and intentional mental activities where individuals undertake trade-offs, recognize relevant interdependencies and the need for coordination (Kahneman, 2011). Fig. 3 depicts the factors influencing decision making based on these two modes of behavior.

With respect to low-probability, high-consequence (LP-HC) events, such as natural disasters where decisionmakers have had limited experience, there is a tendency to rely too heavily on intuitive thinking. More specifically, those at risk who have had limited personal experience often rely on their emotions and exhibit cognitive biases in choosing between different alternatives. There is thus a tendency to ignore a hazard until after a disaster occurs and then overreact to the event, often because of worry and anxiety about a future catastrophe. As the memory of the disaster fades, the motivation to prepare for another one subsides.

The earthquake hazard in California highlights this behavior. In the 1970s, fewer than 10% of the homes in the state were insured against the earthquake damage. Between 1983 and 1994, six moderate-scale earthquakes occurred in the state, the last one being the Northridge earthquake that caused total losses exceeding $50 billion. By 1995, over 40% of the homes in many areas affected by these disasters had purchased earthquake insurance (Palm, 1998). There have been no severe earthquakes in California since Northridge and today, only 10% of homes in the state have earthquake insurance. If a severe quake hits San Francisco in the near future, the damage could be as high as $200 billion, and it is likely that most victims will be financially unprotected (Risk Management Solutions, 2014).

Seismologists have undertaken many studies indicating that if there has not been a severe earthquake in an area for a number of years the likelihood of one occurring is much higher in the future.[1] If homeowners in California utilized more deliberative thinking, they would pay attention to experts' assessment of the earthquake risk and focus on the likelihood of disasters of different intensities and magnitudes occurring and the resulting impacts on their property and belongings.

Wildfires highlight property owners' tendency to ignore the interdependent nature of the risk. More specifically, the damage faced by homeowners depends not only on their own decisions as to whether to invest in fire protection measures, but also on the risk reduction investments of their neighbors. An article in the Los Angeles Times characterizes this interdependency, noting:

> Fires that spread from house to house generate a force of their own. Embers, broadcast by the wind, find dry leaves, igniting one structure then another, and the cycle is perpetuated block after block. Break that cycle and the fire quits, and destruction can be minimized. (Curwen & Serna, 2018)

3.2. Cognitive Biases in Underpreparing for Natural Disasters

As noted above, many residents in hazard-prone areas ignore or underestimate natural disaster losses and similarly do not recognize the impact that climate change will have on their future property damage and well-being. This failure stems from a combination of the following biases and heuristics (Meyer & Kunreuther, 2017).

3.2.1. Myopia

One of our greatest weaknesses as decisionmakers is that our planning horizons are typically shorter than those necessary to appreciate the value of protective investments. For example, people routinely engage in *hyperbolic discounting*, where they demand far more compensation for short-term delays of gratification than could be explained by the opportunity cost of money that is defined by interest rates (Laibson, 1997). If individuals considered the expected discounted benefits of the measure over a time horizon reflecting the life of the house, investments in many protective measures would then be viewed as financially attractive (Kunreuther, Pauly, & McMorrow, 2013).

3.2.2. Optimism

People tend to believe that they are more immune than others from LP-HC events and thus perceive that the disaster will *not happen to them*. A principal reason for their optimism is that they have not previously experienced a disaster. Estimating the likelihood of a specific event based on personal experience, termed the *availability bias*, has been observed and tested in a large number of controlled experiments and field studies (e.g., Kahneman, Slovic & Tversky, 1982; Tversky & Kahneman, 1973). Another reason for the optimism bias is our tendency to construct positive scenarios that we hope will happen. Rather than imagining the impact that climate change will have on SLR so that our living room would be under water should a flood or hurricane occur, we prefer to think about the scenario of not experiencing any damage from a flood or hurricane. This behavior is termed *motivated reasoning* (Kunda, 1990).

3.2.3. Simplification

Individuals have a tendency to consider only the likelihood of a disaster when determining whether to protect themselves against a future disaster. If the perceived probability of a flood or hurricane is very low, a person is likely to treat it as below their threshold level of concern and not focus on potential losses. In a controlled experiment on insurance decision making with money at stake, McClelland, Schulze, and Coursey (1993) found that more than 25% of the subjects bid zero dollars when asked the maximum they were willing to pay for insurance protection against a specific loss, suggesting they were making their decision without reflecting on its financial consequences to them.

3.2.4. Inertia

A principal reason why we do not undertake protective measures to reduce future losses is that we often prefer to not change our current behavior (Samuelson & Zeckhauser, 1988). This tendency to maintain the *status quo* saves us time and energy

[1] The U.S. Geological Survey estimates that there is a 72% probability of at least one earthquake of magnitude 6.7 or greater striking somewhere in the San Francisco Bay region before 2043 and the probability increases each year that a quake has not occurred. https://pubs.usgs.gov/fs/2016/3020/fs20163020.pdf

by not having to collect information on the costs and benefits of new alternatives. This behavior is defended in proverbs and aphorisms ("better the devil you know than the devil you don't" and "when in doubt, do nothing"). One reason for not examining new options when there is uncertainty in the outcomes is *loss aversion*. People prefer avoiding losses than acquiring equivalent gains: It is better to not lose \$5 than to find \$5 (Kahneman & Tversky, 1979).

3.2.5. *Herding*

Individuals' choices are often influenced by other people's behavior, especially under conditions of uncertainty. Imitating what friends and neighbors do is problematic when the collective crowd is no better informed than the least informed of its individual members. In a survey of homeowners residing in flood- and earthquake-prone areas, one of the most important factors determining whether they purchased earthquake or flood insurance was discussions with friends and neighbors rather than considering the perceived likelihood and consequences of a future disaster (Kunreuther et al., 1978). A 2013 study of the factors that caused Queenslanders to buy flood insurance found that purchase was unrelated to perceptions of the probability of floods, but highly correlated with whether residents believed there was a social norm for the insurance (Lo, 2013). With respect to investing in mitigation measures, if a homeowner is the only one in the community elevating his house to reduce future flood damage, it may stick out like a sore thumb, thus reducing its appeal and property value. To avoid this stigma, the homeowner may decide not to invest in this protective measure (Gregory, Flynn, & Slovic, 1995).

3.2.6. *Psychic Numbing and Pseudoinefficacy*

Statistical data—for example, on potential damage due to climate change—are unlikely to create feelings of concern. One factor explaining the absence of fear and dread is *psychic numbing*, where numerical projections of CO_2 concentrations do not stimulate the emotional reactions necessary to motivate action. This lack of concern is exacerbated by *pseudoinefficacy*, where individuals feel that any personal contribution that they make to reduce a catastrophic threat associated with climate change will be unimportant and thus ineffective (Slovic & Västfjäll, 2019).

4. DESIGNING A RISK MANAGEMENT STRATEGY FOR REDUCING NATURAL DISASTER LOSSES

A successful strategy for reducing losses from future natural disasters should take into account the cognitive biases and heuristics that lead decisionmakers to underestimate the risk of LP-HC events. In addition to communicating the nature of the risk that individuals are likely to face today and in the future, it may also be necessary to utilize economic incentives coupled with well-enforced regulations and insurance so those at risk decide to adopt measures to reduce negative impacts.

4.1. Risk Communication Strategies

With respect to helping individuals pay attention to risks, it may be useful to employ a behavioral risk audit (Meyer & Kunreuther, 2017). The audit characterizes the biases and heuristics that influence how individuals are likely to perceive risks and why they tend to ignore the probability and consequences of adverse events. Next, strategies are proposed that work *with* rather than *against* people's natural decision biases by drawing on the principles of choice architecture (Thaler & Sunstein, 2008). Examples of strategies that are likely to lead individuals to consider whether or not to protect themselves against these risks are illustrated below.

4.1.1. *Stretching the Time Horizon*

As noted above, individuals have a tendency to treat the probability of a disaster as below their threshold level of concern. One way to overcome this heuristic when presenting probability information is to stretch the time horizon over which the next disaster is likely to occur. Most people do not realize that a 1% annual risk of an event that is independent and constant over time implies a 26% chance of at least one occurrence of that event over 30 years.

Recent web-based lab experiments found that stretching the time horizon from 1 year to 5, 10, 30, or even 100 years in presenting the probability of a future flood occurring increased individuals' demand for flood insurance (Chaudhry, Hand, & Kunreuther, 2020). The Federal Emergency Management Agency (FEMA) has recently recognized the importance of communicating the flood risk in this manner by indicating that the chances of a homeowner experiencing a flood with a 100-year return period some time during a 30-year mortgage is greater than 1 in 4.

4.1.2. Use of Default Options

The tendency to rely on the status quo provides a rationale for using default options to convince individuals to protect themselves against future losses from disasters. Field and controlled experiments reveal that consumers are more likely to stick with the default option rather than going to the trouble of opting out in favor of an alternative. Many examples of this behavior are detailed in Thaler and Sunstein (2008). To date, this framing technique has been applied to situations where the outcome is either known with certainty, or when the chosen option (such as a recommended 401(k) plan), has a higher expected return than the other options (Madrian & Shea, 2001; Thaler & Benartzi, 2004).

The use of a default option may increase demand for insurance protection against flood and earthquake damage when homeowners do not voluntary protect themselves against these risks. One way to do this is for insurers to incorporate flood and/or earthquake coverage with risk-based premiums in a standard homeowners policy, normally required as a condition for a mortgage. Policyholders would then be offered the opportunity to opt out of either or both of these coverages and receive a reduction in their premium. Given the tendency to maintain the status quo, making coverage for these risks as the default option would likely increase the percentage of homeowners who maintain this protection. The current insurance arrangement of offering separate policies for flood and earthquake protection (so that individuals have to decide whether they want to purchase this additional coverage) has not been successful.

4.1.3. Constructing Worst Case Scenarios

One way to counteract the tendency to view the probability of a disaster as below one's threshold level of concern, is providing individuals with graphic data on the financial impact of experiencing severe damage from a hurricane or flood if uninsured. Images that simulate the impact of SLR on cities like Miami or New Orleans, coastal areas, and island nations may stir up emotions and concerns that demand action to protect their home, and also to reduce CO_2 emissions.

Due to the *availability bias*, people's receptiveness to change is likely to be highest following a damaging hurricane, flood, wildfire, or heat wave. These natural disasters are likely to become more frequent and more severe in the future due to climate change. Political leaders might then have the opportunity to pass legislation, such as a carbon tax, to reduce CO_2 emissions now.

4.2. Role of Incentives and Well-Enforced Regulations

Utilizing choice architecture to address cognitive biases may help the general public and key decisionmakers in the private and public sectors pay attention to the risks associated with future natural disasters and how they will be exacerbated by climate change if CO_2 emissions are not reduced now. Even so, individuals may be reluctant to invest in specific actions to address these risks because they will view the costs as too high given budget constraints. Thus, short-run financial incentives, coupled with well-enforced regulations or standards may be necessary in developing strategies that spur decisionmakers to mitigate the losses from future natural disasters.

In this regard, banks and financial institutions can provide low-interest loans to enable homeowners to invest in cost-effective protective measures. If insurance prices are risk based, homeowners will then receive a premium reduction due to their lower expected claims should a disaster occur. This proposal provides net economic benefits to homeowners annually and should overcome their budget concerns and address the perception that the upfront cost of investing in mitigation is not yielding sufficient short-term benefits to justify the measure.

To illustrate this point, consider a family who could not afford $5,000 to flood-proof their house to reduce storm surge damage from hurricanes. Suppose their annual risk-based flood insurance premium would decrease by $600 after undertaking this loss reduction measure. A 15-year home improvement loan for $5,000 at an annual interest rate of 5% would require yearly payments of approximately $480, so the savings to the homeowner each year would be $120.

A similar strategy is likely to lead homeowners to invest in clean energy technologies like wind and solar power to avoid burning fossil fuels. Suppose a household is considering investing in solar panels that would cost $15,000 to install and would result in a reduction in their average annual energy bill by $3,000. If the annual discount rate is 5% or less, the expected discounted savings will be greater than $15,000 after six years (Gerarden, Newell, & Stavins, 2017).

California has recognized the long-term economic benefits to homeowners of solar energy and requires new single-family homes and new multifamily residences to be constructed with solar panels on their roofs as of January 1, 2020. The California Energy Commission, which approved this new regulation, estimates that the monthly mortgage payment on the house would increase by $40 a month but the homeowner would save $80 a month in electricity costs on average (Rogers, 2019). By incorporating the upfront cost of the solar panels into the mortgage, the household incurs lower total costs from the time they purchase the house. Not only is the myopia bias addressed by stretching the time horizon for paying for the solar panels, but households considering buying a new house should now be less concerned with its impact on their budget.

Well-enforced building codes reduce the negative externalities associated with natural disasters due to the interdependency of the risks. California requires homeowners to brace their water heaters so as to prevent them from tipping over and creating fires that could cause additional damage to the property as well as to neighboring homes.[2] The town of Montecito, CA, requires homes to put screens over vents and replace siding and roofs with non-flammable materials to reduce the likelihood that embers will ignite a wildfire. A case study of the 2017 Thomas Fire reveals how these measures significantly reduced the damage to homes in the community (Kolden & Henson, 2019).

4.3. Role of Insurance and Public–Private Partnerships

Risk-based insurance premiums can provide individuals with accurate signals as to the nature of the hazards they face and encourage them to engage in cost-effective mitigation measures to reduce the vulnerability of their property to future disasters. Catastrophe models have been developed and improved over the past 25 years to more accurately assess the likelihood and damages resulting from disasters of different magnitudes and intensities (Grossi & Kunreuther, 2005). Today, insurers and reinsurers utilize the estimates from these models to determine risk-based premiums and how much coverage to offer in hazard-prone areas.

A principal reason insurers have sometimes withdrawn from providing coverage against LP-HC risks is their concern with future catastrophic losses that could deplete their surplus and lead to insolvency. The lack of sufficient private reinsurance capacity and other risk transfer instruments (e.g., catastrophe bonds) led to the establishment of government-backed programs such as the California Earthquake Authority, the National Flood Insurance Program, and the Terrorism Risk Insurance Act. These government backstops allow private insurers to continue to provide coverage against these extreme events (Kunreuther, 2015).

The public sector also needs to address affordability issues for low- and middle-income residents in high hazard areas who, due to budget constraints, cannot afford insurance if premiums are risk based. Several studies have recommended a federal means–tested assistance program for disaster insurance, but such programs have not yet been adopted (Dixon et al., 2017; FEMA, 2018; National Research Council, 2015). If financial assistance were tied to cost-effective loss reduction measures (e.g., floodproofing, home elevation) through long-term loans and mitigation grants, insurance premiums could be reduced to reflect lower future claims payments, thus reducing the necessary financial assistance from the public sector. Insurance will then be more affordable and future flood-related costs to the nation will be reduced (Kousky & Kunreuther, 2014).

5. CONCLUDING COMMENTS

A principal purpose of the Society for Risk Analysis (SRA) from its inception in 1975 has been to bring together experts in risk assessment, social scientists focusing on risk perception and decision making, and policy analysts with an interest in designing implementable risk management strategies.

As a founder of the Wharton Risk Management and Decision Processes Center of the University of Pennsylvania in 1984, I sought to emulate the SRA's principles with a focus on understanding how consumers, firms and public sector organizations make choices as a basis for proposing policies and programs for reducing the adverse impacts of LP-HC events. By appreciating the need for long-term deliberative strategies, effective risk communication, and strategies to overcome cognitive biases using a behavioral risk audit coupled with short-term incentives and well-enforced regulations, we can improve

[2]https://www.cityofberkeley.info/uploadedFiles/Online_Service_Center/Planning/Guideline%20for%20Water%20Heater%20Bracing.pdf

the likelihood of implementing a risk management strategy for reducing LP-HC losses.

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