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Addressing Catastrophic Risks: Disparate Anatomies Require Tailored Therapies[*]

by

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Abstract

Catastrophic risks differ in terms of their natural or human origins, their possible amplification by human behaviors, and the relationships between those who create the risks and those who suffer the losses. Given their disparate anatomies, catastrophic risks generally require tailored therapies, with each prescribed therapy employing a specific portfolio of policy strategies. Given that catastrophic risks occur rarely, and impose extreme losses, traditional mechanisms for controlling risks – bargaining, regulation, liability – often function poorly.

Commons catastrophes arise when a group of actors collectively impose such risks on themselves. When the commons is balanced, that is, when the parties are roughly symmetrically situated, a range of regulatory mechanisms can perform well. However, unbalanced commons – such as exist with climate change – will challenge any control mechanism with the disparate parties putting forth proposals to limit their own burdens.

When humans impose catastrophic risks predominantly on others – as with deepwater oil spills – the risks are external. For those risks, the analysis shows, a single responsible party should be identified. Primary emphasis should then be placed on a *two-tier liability system*. Parties engaged in activities posing such catastrophic risks would be subject to substantial minimum financial requirements, strict liability for all damages, and a risk-based tax for expected losses that would exceed the responsible party's ability to pay. Utilizing the financial incentives of this two-tier liability system would decrease the current reliance on regulatory policy, and would alter the role of regulators with a tilt toward financial oversight efforts and away from direct control.

Catastrophic risks will always be with us. But as rare, extreme events, society has little experience with them, and current mechanisms are poorly designed to control them. Only a tailored therapy approach offers promise of significant improvement.

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Introduction

Catastrophic risks are hazards that inflict substantial loss of life to large populations or cause tremendous property damage. Fortunately, catastrophic risks tend to be rare events. Unfortunately, their distributions tend to be fat-tailed, implying that when they do occur there may be extreme outliers. These two factors imply that the occurrence and consequences of catastrophes will be difficult to predict. Eliminating catastrophes is not possible, and in many cases should not be attempted. Moreover, even where some sources of catastrophes could be eliminated, such as by banning deepwater drilling, it will often be undesirable to do so. The objective should be to communicate risk levels adequately, allow risk-related bargains to be struck, and to impose liability, regulation, and risk-based taxes on a strategic basis to tamp risks down to efficient levels. When compensation is not likely, compensable losses should be covered by insurance.

While generic issues regarding the roles of different institutions in controlling risks have a long history in the literatures of law and economics, and in that of general jurisprudence, we know of no comprehensive assessment of how different institutions address the diverse challenges posed by catastrophic risks.[1] Those who prescribe policies for dealing with catastrophic risks often have their favorite instruments. Some embrace market solutions, with an appropriate nod to liability arrangements and the Coase Theorem. Others, at the opposite end of the political spectrum, posit that regulation and other government prescriptions can work effectively. Some champion insurance: risks that are spread, they observe, impose lesser utility losses. Still others focus on information provision, primarily to keep people out of harm's way.

Our analysis recognizes the disparate anatomies of various catastrophes and the limitations of relying on any single policy approach given the diversity of the threats and potential responses. The many fearsome possibilities that make up the spectrum of catastrophes differ substantially. A broad classification would look at the entities that cause them and at those that suffer from them. Appropriate policy instruments for different catastrophes will differ substantially in both objectives and modes of operation. Some policy instruments will seek to prevent the catastrophes, others to reduce their likelihood, others to minimize their consequences, and still others to spread and thus dissipate the impact of their costs.

Three principal considerations emerge from the analysis presented in this chapter. First, catastrophes – replete with disparate anatomies -- require therapies that differ across and

[1] Studies that address institutional coordination issues generally include, among others, Viscusi (1988, 2002), American Law Institute (1991a, b), Kessler (2011), Posner (2011), and Shleifer (2011).

sometimes within categories. That is, oil spills differ dramatically from hurricanes; within the categories of oil spills and of hurricanes, there are additional and significant differences; and such differences call for distinct policy measures. Second, given that catastrophes have complex social dimensions – what entities cause them, who or what suffers from them, the nature of the losses, the role of information provision, the compensability of the losses – a portfolio approach is required for effective control and response. Thus market processes, regulation, litigation, risk-based taxation, insurance, and information provision may all be part of the appropriate strategy for addressing a particular type of catastrophe. Third, the existing mix of policy instruments should be changed. We propose a liability system that bolsters the financial incentives to control risks and shifts much of the responsibility for safety from government regulators to the parties generating the risk.

The Causes of Catastrophes

Catastrophes can be caused or amplified both by humans and by non-human agents; the latter we call "nature." Even with catastrophes of natural origin, nature working alone rarely imposes losses so great as to make the front pages. Virtually all significant natural catastrophes involve some human actions that amplify the risks of the natural hazards. That is, nature is abetted by humans – for example, by choosing where to live or how to farm – in generating catastrophes out of nature's occasional, but inevitable, extreme expressions. Human behavior often leads to increased vulnerability to natural hazards. This is precisely what happened when an array of local and national American actors channeled the Mississippi and thereby removed existing protections against storms such as Katrina, or when Japanese entities designed and perched the Fukushima plant precariously in an earthquake zone. More generally, people all over the world have flocked to ocean coasts, where they have greater exposure to storms, and ultimately to any sea level rise accompanying global warming.

Nature usually needs a partner to wreak extreme damage on society. Hurricane Katrina decimated New Orleans because human action had wiped out protections afforded by the Mississippi River's delta. When a massive earthquake strikes Istanbul, as it is predicted to do, a great city will suffer extreme losses of life and property because of its location and lax building standards.[2]

[2] Andrew C. Revkin, "Disaster Awaits Cities in Earthquake Zones," *New York Times*, Feb. 24, 2010. The October 2011 earthquake in Eastern Turkey caused substantial loss of life, in part due to lax building codes. See Sebnem Arsu, "Amid Debris in Turkey, Survivors and Signs of Poor Construction," *New York Times*, Oct, 25, 2011.

Humans, however, can create catastrophes completely (or almost completely) on their own. So it was with the one monumental nuclear catastrophe experienced to date, the one at Chernobyl. Humans also get all the blame for the financial meltdown of 2008 and 2009, and the extreme recession that has followed.

Human-abetted or human-induced catastrophes come in many forms. Some are the products of decisions by multitudes of individuals, as are most financial crises, most current species extinctions, and the consequences of our accumulation of greenhouse gases. But in some cases, blame can be assigned to one or a few responsible parties, as with the BP *Deepwater Horizon* oil spill in the spring and summer of 2010. Though BP is a corporation employing tens of thousands of individuals, it has a unified structure. Thus, it had the potential to act in a unified manner, unlike the billions of individuals who contribute to global warming. And although Halliburton, Cameron International Corp., and Transocean Ltd. have been implicated in the catastrophe, BP was in charge and could have insisted on and paid for more prudent behavior by the others. BP has filed lawsuits against these three firms to recoup some of the damages it has paid or will pay.

In other instances, the human actions generating catastrophes may involve multitudes of individuals across many nations. So it has been with the depletion of the ozone layer. Billions of consumers may have sprayed chlorofluorocarbons, but the concerted action of just a few producers changed what could have been a worldwide catastrophe into a situation where relatively modest losses were incurred. Some finger-pointing analysts, or catastrophe analysts in love with the story of the butterfly flapping its wings in the Amazon, see giant cascades of events having been preventable if merely a few parties had behaved better. For example, John Taylor (2010) gives the Federal Reserve and its lax money policies the overwhelming blame for creating the financial meltdown. Other critics assign disproportionate blame to a few rogue private players. We find more compelling analyses that identify dozens of parties that behaved poorly or simply failed to do their jobs (Zeckhauser, 2011).

In addressing causality, we distinguish between situations where one or a few persons or groups could have prevented a catastrophe, as opposed to those where only the actions of a multitude – numbers stretching from dozens to billions – could have made a difference. If a few parties could have controlled the actions of the multitude, we assign responsibility to those few. We thus classify catastrophes according to whether there are few causal agents or many. To be clear, sometimes these “causal agents” are in effect “firemen” who did not do their job effectively and let a conflagration start or spread. While many would not accuse regulators of creating the excesses, misrepresentations, and foolhardiness that produced the financial catastrophe of 2008-2009, some critics would argue that if just a few regulatory agencies had done their jobs effectively, the crisis could have been avoided. It remains unclear whether it would have been feasible for the regulators to have been as effective as these critics specify, after the fact. Following most catastrophes, particularly those where humans were major contributors, hindsight readily identifies the warning signs that were not heeded.

The Victims of Catastrophes

The catastrophes that concern us here are only those that cause suffering to *many*. Personal catastrophes, such as having lightning mangle one's house, as happened to one of this paper's authors the night before the conference for this volume, may impose substantial costs on a household but hardly impose significant costs at a societal level. They involve different issues from the broad catastrophes that we study. They are not the types of catastrophes that concern us here: catastrophes that involve major losses to significant numbers of people.

One basic difference within catastrophes that affect significant numbers of people is whether the causers and the sufferers are the same or distinct. Some but not all catastrophes result from human actions in a group bringing harm onto itself. If those generating the catastrophe and those suffering the harm are predominantly the same, we have the risk-related variant of a *commons problem*. We refer to this as a *commons catastrophe.* The preeminent example of a potential commons catastrophe today is climate change; most humans are spewing greenhouse gases, and the potential losses will affect all of us, some directly, and all due to our concern for future generations.

We make an important distinction between two types of commons problems: those that are balanced, where all participants are in roughly symmetric positions, and those that are unbalanced, where the parties are significantly unequal in size or otherwise asymmetrically situated, therefore imposing and suffering different risks. Climate change is an unbalanced commons problem because some nations and individuals are responsible for far more greenhouse emissions than others, some nations and individuals are suffering disproportionately now, and future generations will potentially suffer much more than those living now.

There are many potential catastrophes where the potential sufferers play little or no role in creating the conditions for catastrophe, as was the case with the BP oil spill. We label such a situation in which injurers are imposing losses on others as an *external catastrophe.* The appropriate policy instruments for dealing with commons and external catastrophes are often far different. Note that commons problems inevitably involve externalities, but we do not refer to them as external catastrophes because the group is inflicting harm onto itself rather than on others who are not part of the group.

<u>Classification of Catastrophes and the Policy Portfolio</u>

Our basic assertion is that the accurate classification of the anatomy of a catastrophe helps enormously in identifying what policy instruments should be employed in dealing with it. Three social institutions will get our major attention: markets and Coasean bargains, civil liability, and governmental regulations and taxation. Within these broad categories, there are specific policy instruments, such as insurance and risk communication. Additionally, each of these instruments comes in a variety of forms. Thus, for example, insurance can be provided by the government or by the private sector, or the private sector can provide it with the government offering reinsurance. Often, these instruments should be used in tandem.

Therapies and Criteria for Catastrophic Risk Policies

Catastrophes will always be with us. Some catastrophes can be avoided, most can be minimized, and virtually all can have their risks spread more effectively. To these ends, society has developed a range of policy instruments to address various circumstances. Our overall conclusion is that there is no single institution and no single set of policies across institutions that will always be the most effective choice, even within a single type of catastrophe. Given this, the task should be to design and coordinate portfolios of policies that will address the catastrophic risks under study.

These policies have three principal objectives: i) providing for an efficient level of risks and protection from catastrophic risks, ii) providing for an efficient level of compensation for harm, hence optimal liability payments and insurance, and iii) providing an adequate level of risk communication so that people and institutions can protect and insure themselves appropriately. Consider first the task of achieving efficient risk levels. Efficient policies set risk levels where the costs of further risk reduction just equal the benefits such reduction would provide – that is where marginal costs equal marginal benefits. In the case of risks caused by nature, nature’s trajectories cannot be readily altered, except perhaps in the long term, such as through carbon taxes if climate change is the driver. The principal task in efficiently ameliorating nature-induced risks is to invest in avoiding them and to engage in protective actions such as flood control projects, hurricane warning systems, and structural requirements in earthquake-prone areas. Catastrophic risks due predominantly to human behavior offer opportunities both to reduce the risk and to reduce the exposure to the risk by, for example, having effective nuclear safety regulation. For both risk prevention and risk protection, the efficient level of risk reduction should strike an appropriate balance between benefits and costs. The challenge regarding catastrophic risks is that the probabilities associated with various levels of damage are very difficult to assess. Because the probabilities are small, society will have little or no experience with any particular category of catastrophic risk. Moreover, many risks, such as climate change, arise from previously unseen conditions, or from innovative technologies, such as deepwater drilling.

Similarly, the standard principles for optimal levels of insurance also carry over to coverage for catastrophic risk. People who are risk-averse, as most of us are, would prefer full insurance coverage of financial or otherwise compensable losses (e.g., loss of earnings) if insurance is offered at actuarially fair or close to actuarially fair rates. Such insurance will make the victim whole after the catastrophe and is efficient despite its costs. Matters, however, are quite different for nonmonetary losses, such as bodily injury or loss of life. The optimal insurance amounts are similar to the values for economic loss in tort liability for wrongful death and personal injury. Lost earnings, medical costs, rehabilitation expenses, and other financial losses are valued compensation components. Generally, it would not be optimal and often would not be possible to obtain insurance that makes the individual whole for such outcomes from disasters. For example, no amount of money can compensate an individual for being killed. The efficiency goal of insurance is to equate the marginal utility of money across various states of the world.[3] Compensating for injuries and deaths is quite different from paying for compensable losses because the former losses are nonmonetary and cannot be replaced by money.

Make whole compensation equates utility across states; it does not equate marginal utility. In a first-best world, an individual's own health, life, and disability insurance would provide appropriate compensation. In the second-best world in which we reside, insurance is under-purchased, in part due to behavioral mistakes, and in part due to the lack of roughly actuarially fair insurance. In this world, compensation for lost income and other financial consequences makes sense, and is a desirable component of a policy portfolio. But

[3] Interestingly, equating marginal utilities in this fashion sometimes leads to insuring against bad events, as with life insurance, and sometimes to insuring against good outcomes. For example, annuities and Social Security protect one against living for a long time.

compensation for the welfare loss associated with suffering chronic pain does not.[4] These principles are borne out in patterns of private insurance purchase. People buy insurance for financial losses, but not for grief or pain and suffering.

Likewise it would not be desirable to provide financial compensation to the citizenry to restore their welfare after the destruction of rare archaeological sites by floods, or to cover them for the loss of 1.6 million acres of forest in Yellowstone National Park due to the fire in 1988,[5] or to compensate them for the extensive wildlife deaths after the *Exxon Valdez* spill. Such losses are not equivalent to monetary harms, and money is not a capable substitute.

That such nonmonetary losses should not be fully compensated in no way diminishes their importance. For example, even though money will do nothing to restore your welfare if you are killed by a disaster, preventing each expected death has an economic value on the order of $9 million, as judged by decisions in other domains (Viscusi, 2011). As a result, for nonmonetary harms for which money cannot effectively restore one's welfare, the emphasis should be on preventing those harms from occurring, usually by deterring the party or parties that create the risk. Simply transferring money to those who have suffered a loss will be an inadequate response, as it will not restore the victim's welfare. It will also be an inappropriate response because it will exceed the insurance amount the person would have chosen if free to do so.

If private risk decisions with respect to self-protection and insurance are to be efficient, people must have a reasonable understanding of the risk involved. Information provision through risk-communication efforts can play a key role in fostering such understanding. Market prices for insurance often convey appropriate information, but sometimes not. Thus, insurance prices in a locale may provide some information about the level of the risk but will not indicate whether there is a current crisis or if the risk level has changed from the historic level used to set insurance rates.[6] The risk-communication task is often complicated by the fact that even the

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[4] It is not evident such losses even raise the marginal utility of income so that people would not choose to structure insurance policies to provide additional income after such adverse events.

[5] National Interagency Fire Center, Historically Significant Wildland Fires, http://www.nifc.gov/fireInfo/fireInfo_stats_histSigFires.html.

[6] In the 1990 Berkshire Hathaway Inc. Shareholder Letter, Warren Buffett explained to shareholders why his firm wrote relatively little insurance in the prior year. "The picture would change quickly if a major physical or financial catastrophe were to occur. Absent such a shock, one to two years will likely pass before underwriting losses become large enough to raise management fear to a level that would spur major price increases. When that moment arrives, Berkshire will be ready - both financially and psychologically - to write huge amounts of business." Subsequently, he observes "…we will [write insurance] only at prices we believe to be commensurate with risk. If competitors become optimistic, our volume will fall. This insurance has, in fact, tended in recent years to be woefully underpriced; most sellers have left the field on stretchers."

government or private party that is most knowledgeable about the risk may not fully understand it. Even in situations where we have a substantial scientific basis for making risk judgments, as with hurricane warning systems, the magnitude of the risk may not be widely known until the emergency has passed.

If the government offers shrill warnings that lead people to evacuate needlessly when the damage turns out to be modest, it runs the risk of people's dismissing the warnings in the future. Maintaining the credibility of the warnings effort is an essential but knotty task when dealing with ambiguous risks that are rare or evolving occurrences. Telling people on a barrier island to evacuate because a disastrous hurricane risk is 5% likely, as would seem prudent, will have them evacuating 10 times on average before a disastrous hurricane hits. Over time, residents may level charges of excessive wolf-crying and become complacent when future warnings are received.

Because of the scale of the harms produced and the multiplicity of causes of catastrophic events, societal efforts to foster efficient risk and insurance responses to catastrophic risks will require that multiple social institutions be involved and coordinated. Below, we consider in illustrative contexts these different institutional mechanisms and the particular roles that they might play. Identifying the respective roles that might be served by different institutions is a useful starting point for conceptualizing the appropriate policy design. However, these institutions are not subject to centralized control in the United States. There is not, for example, a single administrator who can dictate the roles of market forces, common law doctrine, and regulatory policies. Nor would we propose such. Despite the virtue of unity for dealing with catastrophes, most government agencies concerned with catastrophes have many other roles to play, roles that should be kept separate. To further the challenge, in the case of catastrophes with an international dimension, such as climate change, even coordinated actions by a single country will be far from sufficient, given the global dimensions of the problems.

Our proposed framework distinguishes three broad sets of social institutions: the market and Coasean bargains, civil liability, and government regulation through rulemaking, legislation, and taxation. Within each of these three sets, there are different mechanisms that could play a role with respect to catastrophic risks, such as insurance and information. Effective policy making consequently requires that different institutions be engaged, and that within them, choices be made regarding the most appropriate forms of intervention. The optimal policy mix will differ substantially as the efficacy of the institutions varies according to the source of the risk and whether the catastrophe is self-imposed, commons, or external. For example, the annual occurrence of 400,000 smoking-attributable American deaths from a series of individual risk-taking behaviors is a self-imposed loss to a large number of smokers. However, it would not be categorized as a catastrophe, as this loss is the aggregation of a series of isolated risks. In contrast, 400,000 people being killed by a natural disaster would be categorized as a monumental catastrophe.

The Scale of Catastrophic Risks

What are the characteristics of catastrophic risks and how do those characteristics affect the ability of the market, political processes, and other institutions to deal with them? The scale of catastrophic risks greatly affects the ability of conventional decentralized institutions to address them. Figure 1 indicates the number of fatalities per year and the associated cumulative number of events involving different levels of fatalities for earthquakes, floods, tornadoes, and hurricanes. Each of the scales in the diagram is logarithmic; thus the figure represents what are called power laws. A variable $p(x)$ has a power law distribution if it can be characterized as $p(x) = cx^d$, where c and d are constants, so that $\log p(x) = \log c + d \log x$. Thus, moving from 10 fatalities to 100 fatalities on the horizontal axis doubles the distance along the horizontal axis but increases the number of fatalities by a factor of 10. After transforming the scale in this manner, the pattern of catastrophes appears well-behaved, but note that this happens only after the scale has, in effect, been compressed more strongly for higher values, thus letting substantial outliers to be shown. Scientists have used power functions to characterize the distribution of catastrophic events, because familiar well-behaved distributions, such as the normal distribution, do not come close to characterizing the pattern of catastrophic risks. Catastrophes have too many extreme outliers. For example, a normal distribution, or even a lognormal distribution, would not fully capture the potential for truly extreme catastrophic outcomes that differ markedly from less severe catastrophes. The distributions for such catastrophic risks are called fat-tailed, reflecting the fact that extreme outliers are much more likely than they are with well-known distributions, such as the normal or lognormal. Such extreme outliers cause inordinately severe harm and account for a substantial percentage of expected losses from catastrophes.

One encounters outliers for a variety of catastrophic risks. The Japanese earthquake in 2011 – merely one of the four largest earthquakes since 1990[7] – merits outlier status due to the extreme damage it caused to the Japanese economy. The BP *Deepwater Horizon* oil spill in

[7] U.S. Geological Survey, Largest Earthquakes in the World Since 1900, http://earthquake.usgs.gov/earthquakes/world/10_largest_world.php.

2010, which is the largest oil spill ever in North American waters, dumped 4.9 million barrels of oil into the Gulf of Mexico.[8] The *Exxon Valdez* oil spill, which riveted the nation in 1989, was the second largest oil spill in U.S. waters.[9] That spill dumped 257,000 barrels of oil into Prince William Sound, but that catastrophic spill provided little clue that there might be a BP disaster that would involve much more spillage, as the BP *Deepwater Horizon* disaster dumped nearly 20 times as much oil, though fortunately warm water tamed its consequences.[10] The only greater spill anywhere in North America happened over a century ago, in 1910, when 9 million barrels of oil were spilled by the Lakeview Gusher in California.[11] However, that inland spill did little damage because the affected area was inland and was barren.[12] The 9/11 terrorist attack took almost 3,000 lives, far more than the worst previous domestic terrorist loss, the 168 deaths due to the Oklahoma City bombing.[13] As these examples show, the potential for extreme outliers consequently involves a scale that may pose insurmountable challenges to conventional institutional responses, such as private insurance arrangements. Moreover, the scale associated with catastrophes is difficult to predict because such harms are unprecedented.

Insurance companies base their rates on the history of premiums and losses for a particular line of insurance. Doing so in a meaningful way requires that there be sufficient data to assess the riskiness of particular policies. The government often assists in providing risk assessments, particularly with respect to weather patterns and natural hazards. For a firm to remain solvent, the premiums plus the returns earned on the policies must be sufficient to cover the firm's losses when they occur, plus its capital costs and administrative expenses. Random modest losses that are not anticipated cause little difficulty. However, if there are catastrophic events generating a scale of damages that is unprecedented, as is the case with many record setting catastrophic events, it will be difficult to provide appropriate and viable insurance coverage.

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[8] National Commission on the BP *Deepwater Horizon* Oil Spill and Offshore Drilling (2011), at 55, 167. [hereinafter BP Commission Report]. The second largest spill was Ixtoc I in the Bay of Campeche in the Gulf of Mexico, off the cost of Mexico, which was 3.3 million barrels. See http://www.nytimes.com/2010/08/03/us/03flow.html and http://www.timesonline.co.uk/tol/news/environment/article7113061.ece (before *Deepwater Horizon* surpassed Ixtoc I).

[9] See King (2010), http://www.cnie.org/NLE/CRSreports/10Aug/R41320.pdf.

[10] *Exxon Valdez* Oil Spill Trustee Council, Questions and Answers, http://www.evostc.state.ak.us/facts/qanda.cfm.

[11] World's Largest Oil Spills Map, http://geology.com/articles/largest-oil-spills-map/.

[12] See http://articles.latimes.com/2010/jun/13/locl/la-me-then-20100613 and http://www.kpmg.com/Global/en/IssuesAndInsights/ArticlesPublications/Documents/gulf-of-mexico-oil-spillv2.pdf.

[13] U.S. Department of Homeland Security, Federal Emergency Management Agency, Oklahoma City Bombing, 1995, http://www.fema.gov/emergency/usr/usrok95.shtm.

These catastrophic events could involve a single concentrated loss or could involve a multitude of highly correlated losses. The home mortgage financing crisis was not due to a single bad mortgage but rather was due to many hundreds of thousands of mortgages that fell into default in a single year. Banks' portfolios included very large numbers of mortgages, but these numbers did not provide diversification, since all mortgages were vulnerable to the common risk of plummeting housing prices.

Despite the bailouts, the recent financial meltdown showed the tremendous spillover effects that catastrophes often generate. Three years later, most of the developed world's economy was still reeling from this financial collapse. Similarly, the harm to Japan from the earthquake and its accompaniments of a tsunami and the Fukushima Daiichi nuclear crisis, reverberated throughout the Japanese economy, which in turn affected Japan's trading partners.

At a most fundamental level, the scale and associated probabilities of catastrophic events are poorly understood because small probabilities are often coupled with comparatively little relative experience with the risk. To the extent that the risks result from human actions, those responsible for generating the risks may not fully understand either the levels of the risks or how these risk levels might be altered by precautionary behavior by potential sufferers. For risks due to nature, the only possible effective responses are precautionary actions and the provision of insurance. Offering insurance to homeowners for potential damage from fires – excluding massive fires from single events, such as an earthquake or terrorist attack – will generate a portfolio of independent risks, thus making risk pooling is feasible.[14] However, for catastrophic risks that kill hundreds of thousands, as did the Tangshan, China earthquake in 1976, or produce vast damage, as did the 1906 San Francisco earthquake, which destroyed 80% of the city, the risks are strongly dependent.[15] For correlated risks affecting very large groups, the scale of the harm, and the interdependence of the risks, often undermines the potential role of insurance.[16]

The difficulties posed by low-probability severe-loss events affect all catastrophic risks, whether generated by human action, by nature, or by the two jointly. Where human action

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[14] The fires caused by the San Francisco earthquake destroyed 28,000 structures, or three-fourths of the developed areas in San Francisco. See Canton (2006), p. S159.

[15] While the official death toll from the Chinese earthquake is 255,000, estimates range as high as 655,000. U.S. Geological Survey, Earthquakes with 50,000 or More Deaths, http://earthquake.usgs.gov/earthquakes/world/most_destructive.php. For the damage caused by the San Francisco earthquake, see http://mceer.buffalo.edu/1906_Earthquake/cit_destroyed/city-destroyed.asp.

[16] That is because traditional insurance is provided by insurance companies and reinsurance companies, whose assets may be large, but are small relative to the losses from some catastrophic risks. Financial markets have far greater asset levels, and it is possible that catastrophe bonds offer an attractive insurance arrangement. Such bonds pay a premium over regular bonds, but do not pay off at all if a specified form of catastrophe occurs.

precipitates the event, dimly understood risks lend themselves neither to fostering adequate risk controls by the injurer nor to self-protective actions by the potential victims. Whatever the cause of a harm, insurance approaches through market forces will be impeded by the substantial scale and/or by the inability to predict the distribution of potential harm.

The limits of markets in dealing with catastrophic risks caused by nature are exemplified by considering a doomsday-rock scenario, whereby a large asteroid threatens to collide with the Earth and wipe out much, if not all, of its population.[17] Averting such a disaster is not feasible given available technologies, though humans could attempt to develop weapons to blow the rock off course if a real threat were anticipated with sufficient lead time. If efforts to divert the on-course rock were unsuccessful, potential insurance responses would, at best, be woefully inadequate and probably irrelevant.

Many less draconian catastrophes present the doomsday-rock difficulties, albeit on a smaller scale. For example, no insurance arrangements could have protected widely against the 2008 financial meltdown. Risk assessment and risk communication could help address the political challenges of dealing with catastrophes. Unfortunately, it is often difficult to determine when preventive measures did avert a catastrophe and, therefore, to give due political credit. Because disastrous outcomes are unlikely to occur during any particular politician's watch, the natural political response is to do little to avoid or ameliorate low-probability risks, even though such measures would be quite worthwhile on an expected-value basis. Nonetheless, provision of good risk assessments would help the public understand current risk levels. Equally important, it would help voters assess the contributions of government policies in reducing risks. Although policies are sometimes undertaken for symbolic reasons and have no demonstrable effects, concrete evidence of policy impact often helps bolster public support. In the political realm, accomplishments that cannot be measured are often accomplishments that are not pursued. If anti-terrorism measures reduced the risk of another 9/11 from 10% to 5% in the decade following 9/11/2001, that was a major accomplishment. But with present technologies, reporting systems, and media practices, no one would know the magnitude of the accomplishment, or even whether there had been any accomplishment.

[17] An earlier "doomsday rock," the Chicxulub asteroid, is believed to have led to the extinction of the dinosaurs. See http://impact.arc.nasa.gov/intro_faq.cfm. Future threats also exist. "A massive asteroid, meteor or comet threatens to destroy life on Earth as we know it. Only this scenario is not relegated only to movie theaters and science-fiction novels. There is a real possibility that a large object could one day be on a collision course with Earth." See John P. Millis, "Killer Asteroids and Comets: How Will We Stop Armageddon?" http://sapce.about.com/od/frequentlyaskedquestions/a/KillerAsteroids.htm. The doomsday rock serves as a principal case study in Posner's (2004) exploration of policies toward catastrophic risks.

External Harms

If risks are self-imposed, people have an incentive for self-protection, to the extent that they understand those risks and how they respond to the ways people might change their behavior. If human action imposes external harms, then self-interested behavior alone will lead to inadequate control of the risk. In the case of risks generated through market contexts, such as the manufacture of a prescription drug that could cause thousands of birth defects, there will be market incentives to produce safer products if consumers are cognizant of the risks. But if the prospect of harm is not recognized, the potential losses to the firm will be limited by the firm's available financial resources. In the case of externalities not in a market context, which are sometimes referred to in the law and economics literature as "harm to strangers," the market will exert little or no incentive to exercise caution. This is equivalent to the classic problem of excess pollution when the source cannot be traced.

In theory, externalities caused by human action can be addressed through application of the Coase Theorem (Coase, 1960). The many well-known limitations of such voluntary agreements to control risks affecting broad population groups – most notably high transactions costs for reaching an efficient agreement – are applicable to catastrophic risks. But with catastrophic risks, the challenges facing potential application of the Coase Theorem are magnified. Consider the case in which the injurer has the property rights to engage in the risky activity. The potential injured parties collectively may suffer enormous damage from a catastrophe; but, not being aware of the risk levels and the potential harms, they will have little basis to propose such Coasean bargains, much less to organize themselves effectively to avoid free-rider problems.

However, if the risks are reasonably well understood and the potential victims own the property rights, then it is likely that the risky activity can be shut down through, for example, an injunction, as the injurer will not have adequate resources to compensate the victims for the expected losses.

Internal Harms

One-to-One or Many-to-Many

It would seem that if parties are imposing risks on only themselves, effective policy would not be a major challenge. That is true if the predominant costs incurred by each party are due to its own actions, if good and intelligible information is provided on risks, and if parties respond rationally. Alas, the second and third conditions are rarely satisfied for catastrophic risks. The field of behavioral decision has amply demonstrated that humans are poor at dealing with low-probability events (Berger et al., 2011).

We label as a "commons catastrophe" the loss that results when people impose harm on their shared resource. Although commons problems represent merely a subset of externalities, they are an important subset. The commons name is borrowed from Garrett Hardin's (1968) "The Tragedy of the Commons," an essay examining the process by which farmers raising sheep on a village commons, which was available to the community for free, caused the commons to be severely overgrazed. To achieve an efficient outcome in such a situation, some regulatory regime, in the broadest sense of that term, must be created.

<u>Balanced Versus Unbalanced Commons</u>

In a balanced commons, symmetric agents impose risks on each other. Given their balance, the prospects for a successful regulatory regime brighten considerably. The sheep farmers would surely note the overgrazed commons and their scrawny sheep with their lusterless wool. They would be likely to get together and formulate a scheme of taxation or a regulation limiting the number of sheep per farmer. None would expect to be allowed to graze six sheep to the neighbor's four. Given the symmetry among the parties, the achievable outcomes would inevitably be symmetric as well. The tragedy of this commons would become merely an episode of minor loss, as the farmers worked out appropriate impositions on each to the benefit of all, thereby demonstrating the compatibility of a balanced commons with Coase Theorem success.

A similar outcome could be expected when symmetric agents create a hazard by using the commons as a dump. For example, equal-sized metal plating firms could be dumping toxic wastes into their joint "backyard." They might mutually agree to limit or eliminate such dumping, accepting equal restraints on their access to the commons.

In an unbalanced commons, asymmetric agents, perhaps some big and others small, might find a compromise much more elusive. The potential gains from an efficient regulatory regime would be no less, but each agent would have a logical argument in favor of a preferred distribution of impositions. Many would believe the normative strength of their own proposals. This, of course, is the situation the world confronts with global warming.[18] The two biggest

[18] We leave aside the fact that, while emitters are around today, the majority of sufferers are as yet unborn; we effectively assume that nations represent their citizens, present and future. Were the present/future divide acknowledged, the problem would become one of external impositions.

emitters of greenhouse gases, China and the United States, see the world very differently. China argues that it is poor, that most gases dumped to date have come from highly developed countries, and that those countries bore no restrictions on their emissions while they were passing through China's current state of development. The United States, by contrast, argues that emissions should be tied to amounts produced at some prior date, that China should refrain from building lots of new coal-fired power plants that threaten the world's climate, that China is prospering even as the U.S. struggles, and that China should certainly bear a significant share of the burden of reducing gases, etc. Given this stark clash of policy views, optimism on reaching an effective agreement is hardly merited. On the brighter side, if the major players in this unbalanced commons situation can reach an agreement, the prospects for other nations following are favorable.

To see the challenge of the unbalanced commons, consider two dissimilar chemical companies, A and B: the sole residents around a small lake, each reliant on its water as an input for its production and as an outlet for its filtered effluent. Company A, the larger firm, has been there for decades. Company B, the smaller but much faster-growing firm, is a new arrival. Both firms are adhering to EPA effluent regulations, but those are insufficiently strict. The toxic buildup in the lake water from both companies' discharges has raised production costs for both companies significantly.

There is a bigger concern for these agents than escalating production costs. The lake may pass a point of no return, a risk that would shutter both the plants. Unfortunately, the science on dealing with such toxic accumulations is unclear. The firms may not know if they are approaching the "point of no return."

Company A proposes that the total toxic content of effluents be reduced 20% below 2011 levels and held there. Faster-growing Company B points out that much of the toxic buildup in the lake is due to A's dumping over decades, including dumping at high levels in the old days when EPA restrictions were much laxer. It proposes that until its cumulative contribution to the buildup reaches the cumulative contribution of A, that A cut back by 40% from its 2011 levels, with no cutbacks imposed on B. Once cumulative contributions are equal, B expects that its output will be greater than that of A. It proposes that then both firms adhere to a per-unit-of-output standard, one that would have to be tightened over time so as to hold the toxic level in the lake as fixed.

The prospects for reaching voluntary agreement in this situation are poor. Both firms have a negotiating position that can be supported with good arguments and moral claims.

Moreover, they are not close to agreement. An unbalanced commons is likely to be a heavily overburdened commons. If a commons catastrophe is a possibility, its risk is likely to rise with little restraint until the commons is on the verge of collapse. To return to our prior metaphor, if the doomsday rock were five years away, given the world's impending demise, the nations of the world would likely pitch in wholeheartedly to mount a diversion effort, quite unlike their behavior for the control of greenhouse gases, where the danger is both less and more distant. But if the doomsday rock would not hit for another 50 years, we could expect fierce debate on who should pay what, with valuable time wasted before agreement was reached, possibly too late.

Our principal argument about commons catastrophes brings both good and bad news. The good news, contrary to much that has been written about commons problems (which are usually presented with symmetric players), is that solutions to the balanced commons are readily available and plausibly achievable. The bad news is that most of the world's salient commons problems, many of which bring risks of commons catastrophes, have players in quite asymmetric positions. These problems are much harder to solve than those that are usually presented in scholarly articles and textbooks. Climate change is a salient case. With major agents as dissimilarly situated as are the U.S. and China, the task of dealing effectively with this commons problem is almost insoluble.

To be sure, if the commons were privatized, that is, if a single party owned the lake where the two chemical companies reside, dumping would be controlled to maintain the lake's quality. A reasonable outcome would be achieved regarding an unbalanced commons. Unfortunately, most unbalanced commons are not owned in this manner, the Earth's atmosphere being the best example. In theory, many other unbalanced commons, including local air quality and lakes, are under the control of a government, which could act like a private owner. Any poor outcomes then would be due to inappropriate regulatory policies, stemming in turn from such factors as information shortcomings, inflexible options, and political distortions. Such factors would probably be much more in evidence with an unbalanced commons, since agents in a balanced commons would gladly assist the government in developing regulations. Our ability and the methods to fix such political economy concerns are beyond the scope of this paper.[19]

[19] Kishore Mahbubani, in a forthcoming book, argues that the vastly increased interdependence of the world calls for greatly enhanced schemes of global governance. He observes that in former times the nations of the world might be thought of as 193 separate boats. However, a metaphor more appropriate for today's world is that they are residents of 193 cabins on a single boat. If so, that would create a balanced commons, and effective global governance might be feasible. (Private communication, October 2011.) Following Mahbubani's boat image, we think of the nations of the world as being on a 10,000 cabin boat, with some nations, such as the United States and China, occupying many hundreds of cabins, but other nations having only one or a few. And some nations are giving up cabins and others

We now turn to the analysis of a variety of mechanisms, each of which helps in dealing with catastrophic risks in some contexts.

Tort Liability

When human activity imposes external risks, liability for torts can be an effective mechanism for controlling those risks and providing compensation to the injured. Tort liability generally deals with physical and monetary harms such as auto accidents, medical malpractice injuries, and product risks. They rarely involve a "commons" situation. When nature creates the risk, liability is not a factor, since nature cannot be sued or otherwise incentivized. Therefore, we examine here only human-created external harms when examining the tort system's role in fostering safety incentives and providing compensation. If all losses are financial or, more generally, compensable, then liability rules that require the injurer to make any injured party whole produce both efficient outcomes and optimal insurance. In addition, for many contexts, tort liability establishes requirements that the potential injurer provide adequate information, thereby enabling those at risk either to avoid the hazard or to take precautions against it. However, because tort liability is generally limited to foreseeable harms, catastrophic events may be so rare that they could not be anticipated.

However, if the losses involve harms for which money is not a viable substitute, such as the loss of a scenic view or the loss of life or limb, it will often not be feasible to make the injured party whole. To adequately deter risky imposing actions, institutions beyond the market and its partner liability arrangements, such as government regulations, will be required. Liability rules have other shortcomings, such as difficulty parsing the causal influences in situations involving multiple contributing parties. As part of our two-tier liability proposal below, we suggest that joint and several liability not be applied, and that a single party be subject to strict liability for all catastrophic risk damages. The expectation is that the responsible firm will contract with other participants on a contingent basis for their share of the liability.

The shortcomings of the current tort liability system are well known. Catastrophic risks, which can involve large-scale losses, present severe additional challenges to the tort system. Legal limits restrict the amount of liability to a firm's financial resources; this prevents the liability system from providing either adequate safety incentives or sufficient compensation for

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are taking them over. Moreover, some nations have their cabins on top decks, whereas others are in steerage. To reach agreement on how the boat should proceed, and who should pay for its operation would represent an immense challenge.

catastrophic risks. This is not to say that liability rules are irrelevant. Rather, they are insufficient. The potential benefit of liability rules in controlling risks is in forcing external harms to be internalized by the injurer. However, to be truly effective for catastrophic risks, society must address the fact that liability has no effect beyond a certain scale of loss. If such beyond-scale losses are significant in expectation, as they usually are with the fat tails of catastrophic risks, then risk imposers lack the incentive to be sufficiently cautious.

A Two-Tier Liability Solution

To overcome these limits of liability in addressing catastrophic risks posed by human action, we have proposed a two-tier liability system.[20] While we developed this proposal in the context of oil firms such as BP undertaking deepwater drilling, the structure is broadly applicable to a wide range of human activities posing catastrophic risks. Our proposal is targeted at the demonstrably high stakes situations of deepwater drilling and nuclear power, but can be readily extended to a broad array of contexts, including many where the stakes are far lower. Use of the two-tier liability approach is best suited to potential catastrophic risk situations in which there is a single party that can be identified as being in control of the risky activity. Adopting our proposal anywhere would require legislation to replace the current legal regimes, and there would need to be a change in regulatory functions as well.

The first tier of our proposal makes a firm that is engaged in potentially risky activities subject to strict liability for all damages. Moreover, the firm must provide evidence that it has the financial resources, including insurance, commensurate to meet potential harms in most circumstances. The second tier of the proposal is that a firm should be taxed for the expected value of harms it imposes beyond its demonstrated financial capabilities. This assures that the firm will internalize the full costs it is creating in its risk-related behavior. In addition to serving as a safety-incentive mechanism, this tax can be used to establish a compensation fund that, across firms, will cover losses beyond the established resources of the perpetrators.

Before detailing these principal tiers of the proposal, it is useful to summarize all the proposal's various main features, which we elaborate on elsewhere. Our overall objective is to create a set of economic incentive mechanisms to generate efficient levels of risk-taking even in situations in which adverse outcomes may be catastrophic. The policy emphasis would shift from the current regulation-oriented approach to a decentralized financial incentive system.

[20] A fuller version of this proposal is presented in Viscusi and Zeckhauser (2011).

Experience with past catastrophes, such as the Valdez and BP spills and the Fukushima disaster, points to the inadequacy of using regulation as the primary control mechanism. Government regulators, at least in the United States, are woefully underpaid relative to the market, and hence are likely underskilled. Also, political pressures or regulatory capture often leads them to be under vigilant. Finally, regulators usually have much less information than the parties imposing risks have; therefore, they are not the most effective decision makers about how to control risks.

To establish financial incentives, we propose a financially meaningful structure in which full responsibility is placed on the lead firm in the risky activity. As just mentioned, this firm is better situated than government regulators to have the requisite technical expertise and ability to monitor contractor and worker behavior to ensure that it meets appropriate standards of care.

Our proposal will make the responsible party for the risky behavior subject to strict liability. There will be no joint and several liability. Instead, the lead firm can contract with other firms involved in the risky operation to share in liability on a contingent basis. To provide appropriate incentives, any existing damages caps will be eliminated, and the lead firm must demonstrate adequate financial capacity either through its assets or insurance to cover most levels of catastrophic loss. Damage payments will be limited to compensatory damages, as there is no deterrence rationale for punitive damages when the probability of detection is 1.0, as it is with the types of catastrophic situations we are discussing. The second tier of the liability structure establishes a risk tax for expected losses in excess of the firm's demonstrated resources. Regulators will continue to have their traditional role in terms of safety inspections, but the policy approach would recognize regulators' likely inability to ensure safe operations. There would be a shift in regulators' main responsibility to setting the financial requirements for firms engaged in the risky activity and establishing the amount of the risk tax.

Implementation of the first liability tier of this proposal requires that a minimum level of financial resources be set, presumably in light of the scale of potential catastrophic harms. Of course, it is not possible to predict the worst-case scenarios, given the fat-tailed nature of catastrophic risks. But a convenient starting point might be the worst harm that has been experienced to date in that activity. Thus, for deepwater drilling in the Gulf, firms might be required to demonstrate a level of financial resources and insurance that is adequate to cover losses of the magnitude of the fund that BP set up after the spill, which was $20 billion.[21] A high financial threshold will restrict operations to firms with resources sufficient to cover major

[21] BP Commission Report, *supra* note 4, at 185. As of August, 23, 2011, BP had paid out $5 billion to victims of the oil spill. See http://www.reuters.com/article/2011/08/23/bp-oilspill-fund-idUSN1E77MOW520110823.

losses, thereby restricting competition and possibly turning away the most efficient producers. But the alternative of opening up operations to firms with limited financial resources will dilute safety incentives and create an influx of small firms that have little financial stake in potentially high payoff – catastrophic loss ventures. The threshold should be set not too high and not too low, so as to balance these two sources of disadvantage.

Ensuring adequate financial resources at a very high level does not guarantee that there would be sufficient resources to compensate for all possible losses. In addition to financial losses that might not be compensated, there could be irremediable harms, including losses of life and of natural resources. However, by providing much stronger safety incentives than those the tort liability system can impose alone, this proposal would increase the degree to which the potential injurers internalize the costs imposed by their activities for losses both below and above their financial resources.

A complementary component of our proposal is that one firm should be identified as the responsible party for the two-tier liability regime. In the case of deepwater drilling, this party would be the operator. The principal impetus for making the responsible firm the linchpin of the proposal, rather than government regulators, is that the firm is more likely to have technical expertise and private knowledge about the risky activity. There are few enough situations where catastrophic risks are created that identifying such parties in advance should not be burdensome. The responsible firm then can make arrangements with its contractors to monitor their activities and to share possible financial responsibility with these firms.

In the case of the BP oil spill, BP purchased the rights to drill in that location and for legal purposes became the operator of the well.[22] BP then hired Transocean to be its drilling contractor, which in turn hired Smit Salvage Americas to salvage the rig.[23] BP also hired Halliburton to cement the production casing into the place at the bottom of the well, and a Halliburton subsidiary (Sperry Sun) did the "mud logging" (examination of the rock or sediment dislodged during drilling).[24] BP also hired other contractors for specialized jobs, such as "mud engineers from I-I SWACO (a subsidiary of Schlumberger, a major international oilfield services provider), remotely operated vehicle technicians from Oceaneering, [and] tank cleaners from the OCS Group."[25] Under our proposal, BP would have full liability but could make arrangements with its many contractors to be reimbursed for part of its liability costs depending on the nature

[22] BP Commission Report, p. 92.
[23] Ibid, p. 130.
[24] Ibid, p. 3, 100, 224.
[25] Ibid, p. 3.

of the damage, the role of the contractor in relation to the harm, and whatever other provisions are mutually agreed upon. Similarly, contractors such as Transocean and Halliburton could make independent arrangements with any subcontractors that they employ, but irrespective of these arrangements and whether their subcontractors can pay for the damages, they will nevertheless be liable for any damages specified in the agreement that they have with BP.

Regulation, Legislation, and Taxation

Our two-tier liability proposal for addressing external catastrophic risks caused by human actions requires government action. In the case of oil spills resulting from deepwater drilling, there already is an initial tier administered on a case-by-case basis. The threshold financial resources amount for offshore drilling can be set at a level ranging from $35 million to $150 million, but the amount is set more typically in the $10 million to $35 million range.[26] Liability for oil spills is capped at a level of $75 million except when firms are shown to have been grossly negligent or otherwise reckless.[27] Similarly, operators of nuclear reactors are required to obtain private insurance for only $375 million.[28] All these levels are ridiculously low relative to the magnitudes of possible losses from accidents. Our proposal would remove all caps and would impose much more substantial financial requirements.

The second tier of our liability proposal would involve government taxation of the residual risk. The level of this tax should be set to reflect the risk level of the particular firm's activities. It should be set to equal the expected cost of damages beyond the demonstrated financial resources. This is the level just sufficient to provide appropriate safety incentives to the firm. There are similar kinds of fee systems in place at present. However, those are not the safety-incentive tax that we propose, but instead are more modest fees designed to establish victim-compensation funds. The tax would serve a second purpose. It should be sufficient in expectation to pay for the cost of accidents beyond the responsible firm's ability to pay.

The appropriate tax level for any project, such as a deepwater well, would depend on the risk involved, which would involve difficult assessments of the likelihood and size of possible accidents. The government may be poorly equipped to make such an assessment. One possible

[26] BP Commission Report, *supra* note 4, 283.
[27] Oil Pollution Act, 33 U.S.C. § 2704(a)(3). Thus, unless gross negligence could have been demonstrated, BP's financial responsibility was limited to $75 million. It agreed to establish a compensation fund of $20 billion due to intense political pressures created by President Obama. Such retrospective impositions are hardly the way to run a risk-control regime. Fortunately, BP had the resources to cover the losses it imposed.
[28] 42 U.S.C. § 2210(s). The Price-Anderson Act also established a separate fund to provide for compensation of up to $12.975 billion. However, such group contributions do not establish private safety incentives.

approach would involve knowledgeable private parties, such as other oil firms or insurance companies. They would bid to assume a sliver, say 5%, of the damages above the responsible firm's total of demonstrated resources plus insurance. This would establish the appropriate tax rate, which in this case would be 20 times the low bid for assuming the 5% sliver of responsibility.

The sliver amount plus the tax collected for the remaining 95% of excess risk would simultaneously provide efficient incentives for safety as well as funds that in expectation would cover losses beyond the responsible firm's ability to pay.

Safety Regulation

Our proposal does not, it should be stressed, rely substantially on government regulation, the usual mechanism for fostering safety incentives involving major risks. We do not propose that regulation be abandoned. For example, there should continue to be regulation of nuclear safety and other highly dangerous activities. The assessments by these regulators also can play a role in evaluating the riskiness of the firm's activities. However, as the BP *Deepwater Horizon* oil spill demonstrated, regulation as the principal instrument for assuring safety fails for two principal reasons.[29] First, there is substantial inequality of information. The firm undertaking the risky behavior has significant private knowledge of the risks and precautions that is not generally available to regulators. Second, the activities involved often are highly technical and require specialized expertise that government officials with broad regulatory responsibilities may not possess. Corporate engineers who have substantial relevant expertise often can earn salaries well above the government pay scale, suggesting the government will continue to be unable to secure sufficient talent to deal with many classes of risks (Donahue, 2008).[30]

For risks generated by nature, regulation can play a much more constructive role than any liability system to achieve proper safety, since nature is not deterred by potential financial penalties. Although it is not feasible to regulate nature, it is possible to regulate the human behaviors that could amplify the losses inflicted by nature. A relatively unobtrusive form of regulatory intervention is the provision of information. Sirens and media announcements alerting citizens to an approaching tornado can enable people to take shelter, and weather

[29] The inadequacies of government regulation in addressing the hazards from deepwater drilling, including a lack of technical expertise and institutional failures, are documented in the BP Commission Report, *supra* note 4, at 250-291.
[30] This theme was echoed by the BP Commission Report as well. Industry experts are paid salaries far above the government pay range.

warnings can limit the harms caused by major hurricanes. In some instances, this informational intervention can be bolstered with either recommendations or requirements that an area be evacuated, as in the cases of Hurricanes Katrina and Irene. More generally, the government can require that houses meet building codes pertinent to the risks in the region, or that no residential or commercial construction occur on a fault line or in a flood-prone area.

The Government Role with Respect to Insurance

The government also has actively imposed requirements for purchasing insurance and providing government-subsidized insurance for disasters, most notably for floods. One rationale for government provision of catastrophic-risk insurance, or reinsurance beyond normal coverage, is that the scale of the losses is so great that private markets are not up to the task. But perhaps an even stronger rationale is that, after a catastrophe, there will be huge numbers of people who have suffered major harm or firms whose collapse would cause major suffering in the economy. The pressures for the government to mitigate these harms with post-disaster relief are generally strong and at times are irresistible. By requiring that people or firms buy insurance when exposed to catastrophic risks, the government in effect provides for some of the funding that will ultimately be needed after disaster strikes.

That government-mandated insurance can serve constructive roles does not imply that current insurance arrangements are ideal. Most government mandates for insurance tend to be accompanied by heavy government subsidies, as we see in such areas as flood insurance, pension insurance, or terrorism reinsurance for real estate.[31] Unfortunately, a government-subsidized catastrophic-risk insurance program would adversely affect behavior. People and corporations would have an unintended inducement to build in flood- or hurricane-prone areas, or in high-risk terrorism locales, since they would be undercharged for their expected risks. The classic problem of insurance is that of moral hazard, in which the insured feel less need to exercise sufficient care. If natural disasters or terrorism were the source of losses, the covered party would not control the risk, as they would be caused by nature or terrorists. However, the extent of the harm caused by such disasters is very strongly related to the siting of construction and to the efforts that are made to protect it. Should catastrophe insurance be subsidized, people would

[31] An interesting case involving many forms of government subsidy is that of a development of high-end homes constructed in a known flood plain in South Dakota adjacent to the Missouri River. Some homeowners dropped their insurance, but 172 did not. To fund barriers against current flooding, the community financed much of the cost with a no-interest loan from the state, and they are seeking to obtain reimbursement of 75% of the cost from the federal government and 10% from the state. A. G. Sulzberger, “In Flood Zone, But Astonished By High Water,” *New York Times*, July 31, 2011, p. 1.

relocate inappropriately and would make insufficient efforts to protect themselves or reduce their losses. To the extent that people anticipate a government bailout after a disaster affected by humans and consequently do not take protective actions, the problems are similar, although probably less severe, since there is less assurance of a bailout than there would be of compensation from a subsidized disaster-insurance program, whether run by the government or by private companies.

Allocating Institutional Responsibilities

We have described the anatomy of catastrophic losses, focusing on the identity and incentives of those who impose the risk, and on the relationship of the risk imposers to the parties suffering losses. We have argued that different anatomies call for different policies, sometimes for significantly different policies. Table 1 summarizes the institutional responsibilities we identify as appropriate to each type of catastrophe. Note that in every instance at least one of the institutions has no significant constructive role to play. This categorization highlights the diversity of catastrophic risks and the need to develop and deploy a portfolio of risk policies. Different policy tools are useful with respect to different kinds of risk situations. Generally, it will be fruitful to employ a mix of policy instruments tailored to the particular situation.

Civil liability has a critical but restricted area of application, namely when humans impose risks externally (or internal risk impositions are severely unbalanced). But even in that area, the current liability system falls far short when dealing with catastrophic risks. It cannot cover the largest losses, which given the fat tails of disaster losses, constitute a significant portion of overall expected losses. We have proposed that where a responsible party can be identified prior to any accident, liability approaches be augmented with a two-tier liability structure designed to cope with this problem. The tax-tier aspect of the two-tier liability system would be part of the regulatory mechanism. The two-tier liability structure would greatly enhance the current efficacy of government regulation, which is not suited to provide adequate risk incentives for many high-risk activities.

Predominant market approaches play a limited but useful role in dealing with catastrophes. In almost all contexts, there are at least some opportunities for self-protection and for private insurance. Appropriate information can provide the right incentives for controlling self-imposed catastrophes. A variety of approaches, such as agreed-upon self-regulation or taxation of risky activities, can work for balanced-commons catastrophes, that is, for situations in which symmetrically situated parties have imposed risks upon themselves. Unfortunately, where catastrophes are concerned, a balanced commons is an unlikely situation.

Greater challenges arise with external catastrophes, such as deepwater oil spills, and those arising in an unbalanced commons, such as climate change. As we show in Table 1, markets and Coasean bargains are far from adequate for dealing with such problems. Indeed, the general category of one-to-many externalities serves as a paradigmatic example of market failure in economic textbooks. To achieve the best feasible outcomes in such situations, individual actions must be combined with an array of liability and regulatory interventions.

Catastrophic risks will always be with us. But the judicious choice of policies from the entire portfolio of public and private institutional mechanisms can significantly reduce their frequency, magnitude, and consequences.

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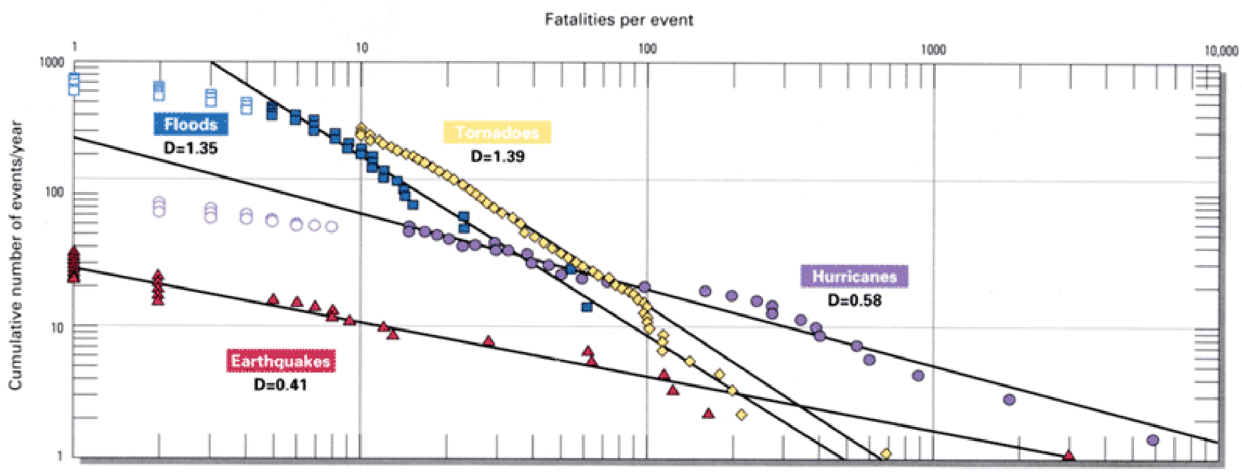
Table 1

Allocation of Responsibility for Catastrophic Risks

	External Risks Caused by Nature	External Risks Caused by Humans	Internal Risks Caused by Humans
Markets and Coasean Bargains	Yes, but limited for catastrophes due to scale and correlation of risks.	Yes, but limited by bargaining impediments.	Information, insurance, and personal self-protection.
Civil Liability	No.	Yes, but liability limits for catastrophes. Need first tier of two-tier liability system.	Not generally, but sometimes possible for unbalanced internal risks.
Regulation, Legislation, and Taxation	Yes, to provide information, foster self-protection, mandatory or subsidized insurance, and post-disaster relief.	Yes, regulate externalities in many ways, but need second tier of two-tier liability for complex risks.	Yes, but often barriers to policy adoption for unbalanced risks.

Figure 1

Fat tails for Catastrophic Events



Source: U.S. Geological Service Fact Sheet, "Natural Disasters – Forecasting Economic and Life Losses," http://pubs.usgs.gov/fs/natural-disasters/index.html.