ISSUE BRIEF

# Adapting to Extreme Events: Managing Fat Tails

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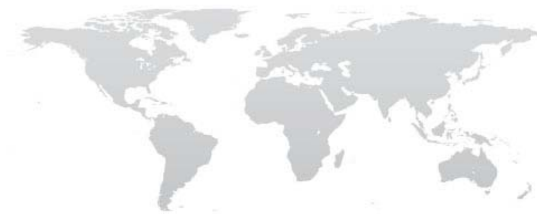
## Resources for the Future

Resources for the Future is an independent, nonpartisan think tank that, through its social science research, enables policymakers and stakeholders to make better, more informed decisions about energy, environmental, natural resource, and public health issues. Headquartered in Washington, DC, its research scope comprises programs in nations around the world.



# Adapting to Extreme Events: Managing Fat Tails

Carolyn Kousky and Roger Cooke[1]

*As defined by the Intergovernmental Panel on Climate Change, adaptation includes a set of actions to moderate harm or exploit beneficial opportunities in response to climate change. To date, little research has addressed public policy options to frame the nation's approach to adapt to a changing climate. In light of scientific evidence of extreme and unpredictable climate change, prudent policy requires consideration of what to do if markets and people fail to anticipate these changes, or are constrained in their ability to react. This issue brief is one in a series that results from the second phase of a domestic adaptation research project conducted by Resources for the Future. The briefs are primarily intended for use by decisionmakers in confronting the complex and difficult task of effectively adapting the United States to climate change impacts, but may also offer insight and value to scholars and the general public. This research was supported by a grant from the Smith-Richardson Foundation.*

## Summary


- Damages from natural disasters are characterized by fat tails, meaning the probability of ever more serious damage decreases slowly relative to the extent of the damage.
- Climate change may increase the frequency and/or magnitude of many extreme events, thus possibly fattening the tails of damage distributions.
- With fat tails, historical data can be a poor guide to the future.
- Fat-tailed risks are expensive to insure. Insurance-linked securities and tax-deferred catastrophe reserves could potentially increase the capital available to cover disaster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losses at a reasonable cost, increasing the availability and affordability of private insurance.

- The National Flood Insurance Program (NFIP) is not charging rates high enough to cover the fat-tailed nature of flood losses. Congress has been reluctant to have the program charge risk-based rates, but if the NFIP fails to do so, all taxpayers will shoulder catastrophic flooding costs.
- A more robust response to fat-tailed damage distributions is to reduce damages through cost-effective mitigation measures. Mitigation provides public as well as private benefits, and government could speed adoption through a variety of policy incentives.

## Fat-Tailed Damages from Disasters

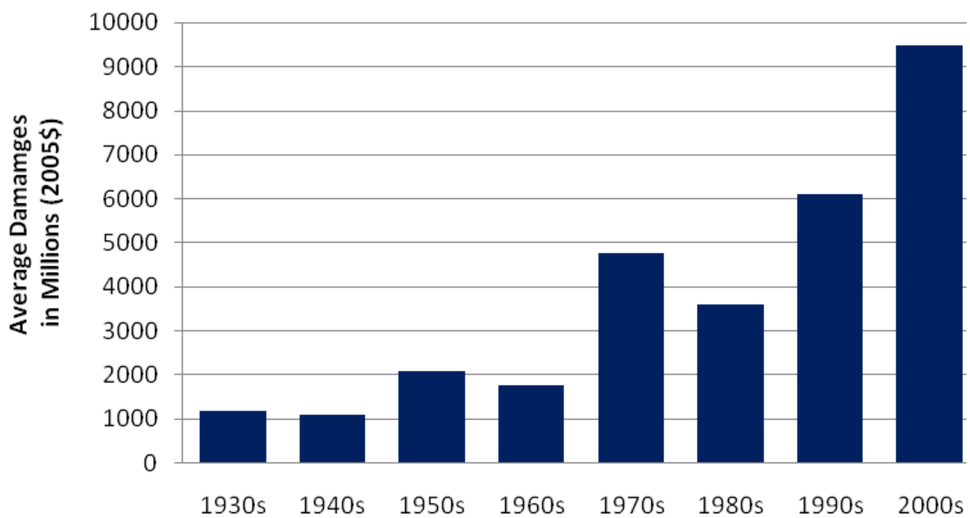
Many distributions we encounter in everyday life are thin tailed. Suppose the tallest person you have ever met was 7’1”. What do you expect will be the height of the next person you meet who is taller than 7’1”? If your distribution for human heights is thin tailed, you might say something like 7’3”. If it were very fat tailed, you might say 14’. Heights, weights, Olympic records—these all tend to be thin tailed. Damages from natural disasters, on the other hand, have been found to be fat tailed. Roughly this means that the expected size of an event larger than any event yet seen is much larger than the largest event experienced to date.

This characteristic of fat tails means that the most extreme event observed could be orders of magnitude greater than the second-most extreme event, which could be orders of magnitude greater than the third, and so on. Take hurricanes. The most costly hurricane to hit the United States was Hurricane Katrina, which caused more than $100 billion in damages. The second-costliest hurricane was Hurricane Andrew, which the National Oceanic and Atmospheric Administration (NOAA) estimates caused “only” $35.6 billion. The frightening implication of fat tails is that the next hurricane we observe that is *at least as bad* as Katrina could be much, much worse.

Damages from disasters are not just the result of the severity of the hazard—such as the wind speeds in a hurricane or the height of floodwaters—but also the development decisions that communities have made. A Category 5 hurricane that hits undeveloped land will not cause property damage or lives lost. Similarly, a hurricane that passes over a community that has invested heavily in mitigation will have lower damages than if the same hurricane passed over a community that had not undertaken any mitigation.

Damages from many natural disasters have been rising in inflation-adjusted terms over the last several decades, largely because we are building more in hazardous areas and not investing enough in mitigation. For instance, Figure 1 shows decade averages of inflation-adjusted yearly flood damages in the United States based on National Weather Service data.[2] While variation exists, an upward trend is apparent.

**Figure 1. Average U.S. Flood Damages by Decade**




Damage per unit GDP for many disasters, however, shows much less of an upward trend. Figure 2 shows damages from all weather-related events taken from the SHELDUS database[3] (which are conservative estimates), as total dollars per year and per unit of U.S. GDP per year. The 2005 spike shows the nature of fat-tailed losses.

Climate change might be increasing the frequency and/or the magnitude of many extreme events. Heavy rainfall events are predicted to increase in a warmed world (Allen and Soden 2008), and models specific to the United States have found that certain regions are likely to see an increase in severe thunderstorms (Trapp et al. 2007). Some areas of North America are expected to see more droughts, and the wind speeds and rainfall intensity from hurricanes are predicted to increase along with storm surge levels (U.S. Climate Change Science Program 2008). Not only may averages become more severe with climate change, but variability may increase as well. Both impacts would lead to an increase in extreme events and could effectively thicken the tail of damage distributions.

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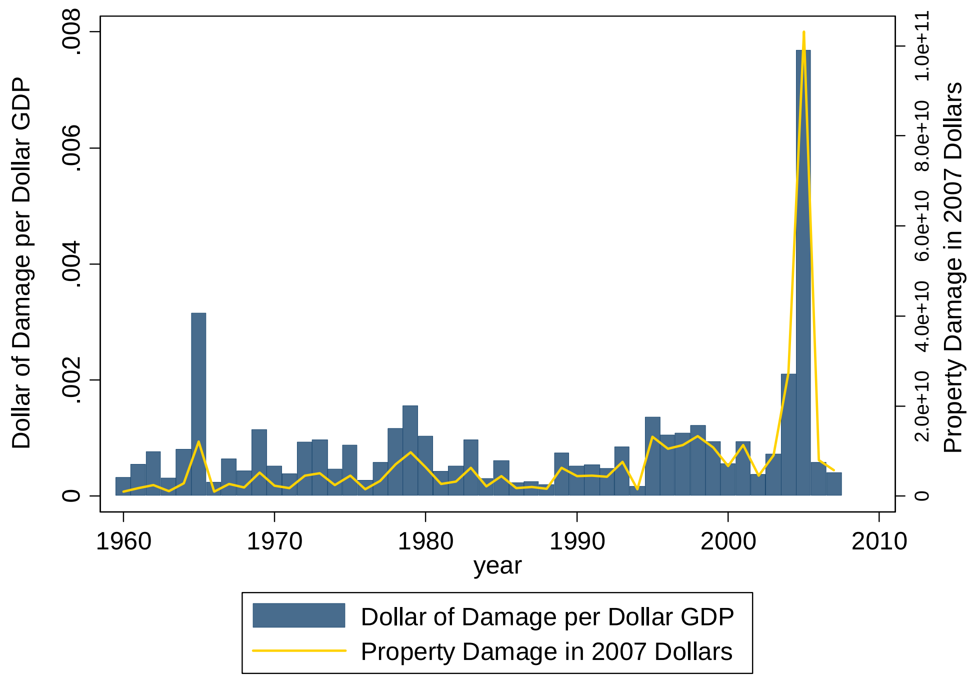
[2] Data is based on reassessments of National Weather Service data by Pielke et al. (2002), as well as raw National Weather Service data for those years not in the Pielke at al. dataset. The data is available at http://www.nws.noaa.gov/oh/hic/flood_stats/Flood_loss_time_series.shtml and http://www.flooddamagedata.org/ (accessed May 25, 2010).

[3] Information on SHELDUS is available online at http://webra.cas.sc.edu/hvri/products/SHELDUS.aspx (accessed May 25, 2010). The damage and fatality estimates in SHELDUS represent the minimum, as the approach to compiling the data always takes the most conservative estimates (for further discussion, see Cutter et al. 2008).

**Figure 2. Weather-Related Damages**

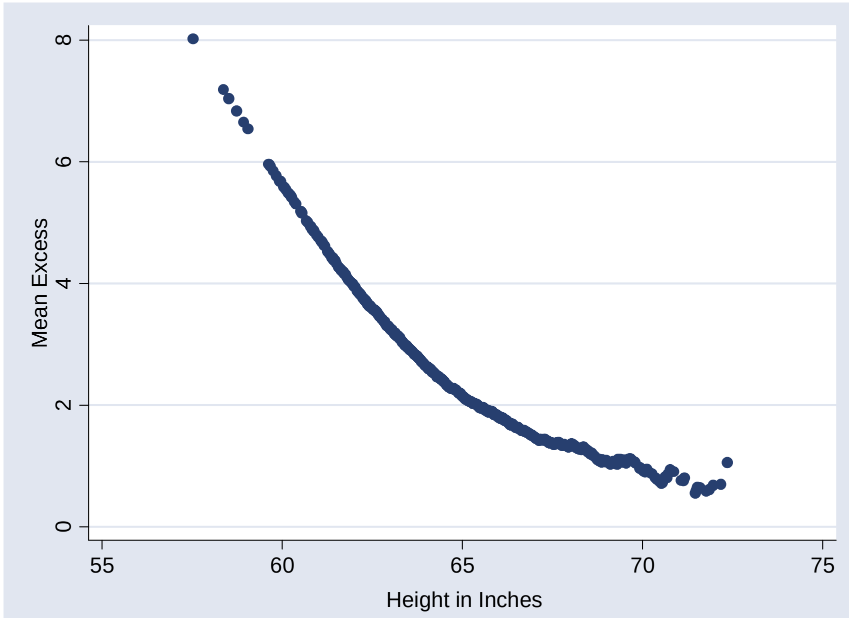



## Measuring Fat Tails

An intuitive way to observe whether data is fat tailed is to look at mean-excess plots. To understand these plots, first consider a thin-tailed distribution—for example, women's heights. For any given height, x, the mean-excess plot shows how much taller we can expect a woman to be on average, given that she is at least x inches tall. For instance, assume women's heights in the United States can be approximated by a normal distribution with a mean of 65" (5'5.5") and a standard deviation of 2.5".[4] If we consider a woman who is at least 68" (5'8"), we expect, on average, for her to be an extra 1.4", or about 70.4" (5'10.4"). 1.4" is called the mean excess. Now consider a woman who is at least 72" (6'). We would expect her to be, on average, an extra 0.7". As we increase the height, the mean excess is decreasing for thin-tailed distributions. A mean-excess plot of a random sample of 1,000 heights based on this distribution is shown in Figure 3.

[4] This distribution has been used to approximate women's heights in the United States on many web pages, (e.g. http://www-stat.stanford.edu/~naras/jsm/NormalDensity/NormalDensity.html, accessed May 25, 2010]). McDowell et al. (2008), in a National Health Statistics report, put the true mean of women's heights in the United States (for those over 20) between 2000 and 2003 at 63.8."

**Figure 3. Mean-Excess Plot for Random Sample of Normal Variables**




Mean-excess plots of fat-tailed distributions are not decreasing. This is seen in Figure 4, which shows the mean-excess plot for income- and exposure-adjusted flood claims from the NFIP by county and year from 1980 to 2006. Since exposure to flood hazard has been growing over time, we divide inflation-adjusted flood claims by total personal income by county per year. Most years, claims are a vanishingly small percentage of total income. In disaster years—like 2005—however, they can be many times personal income.[5]

Interestingly, despite the advance in warning systems, fatalities in the United States are also fat tailed. This is shown in Figure 5, which plots fatalities per county and month from natural hazards for the years 1960–2007, from the SHELDUS database.[6] If Katrina deaths were included, it would further fatten the tail.

[5] The few observations in which claims are tens, hundreds, or even (in two observations) thousands of times total income may be due in part to the inclusion in flood claims for businesses, which can be much larger than residential claims.

[6] This data does not include fatality estimates from Katrina. Other estimates seem to be underestimates of deaths reported in other sources.

**Figure 4: Mean-Excess Plot for Flood Claims per Dollar Personal Income**

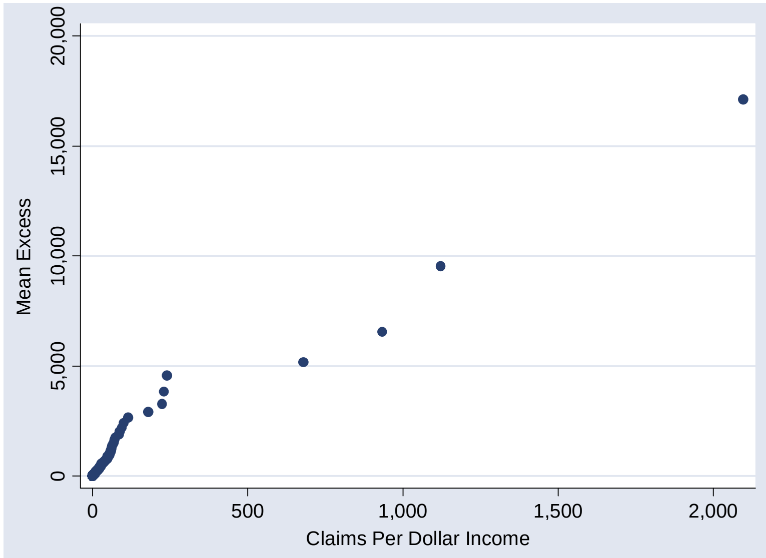
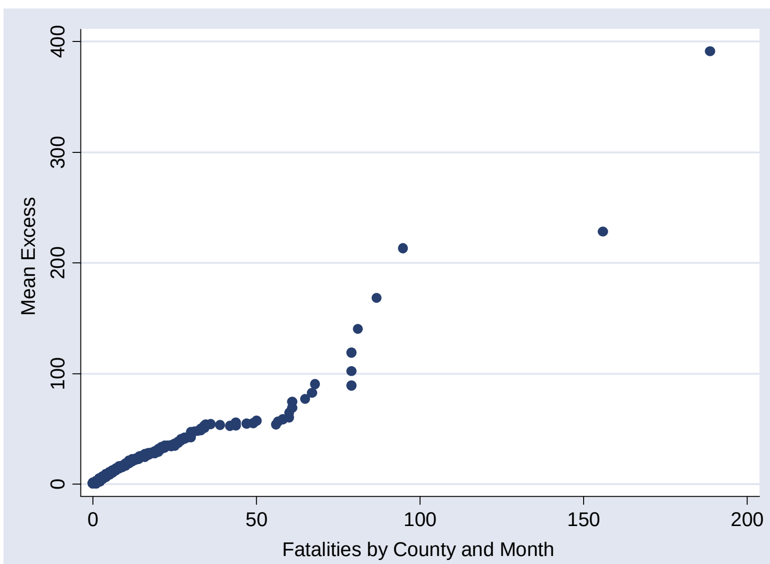


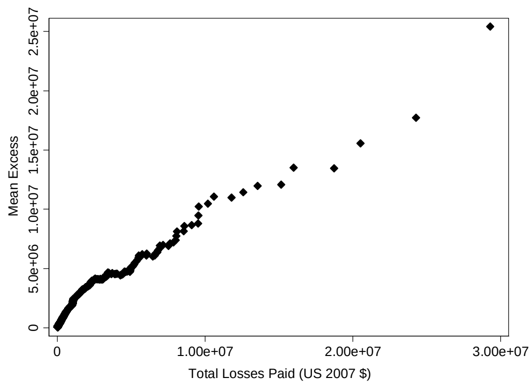

**Figure 5: Mean-Excess Plot for Fatalities**



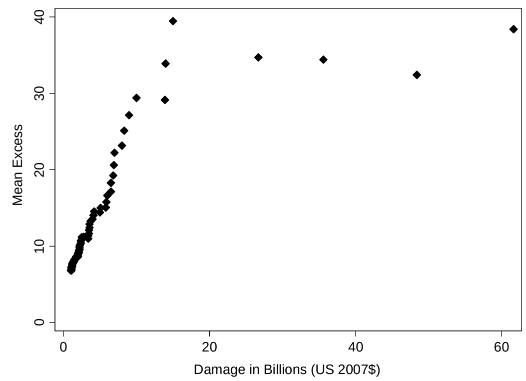

Other loss distributions from natural hazards have fat tails, suggesting fat-tailed loss distributions may not be the exception, but the rule. Figure 6 shows mean-excess plots for (a) wind-only claims payments by Citizens Property Insurance Corporation, the state insurer in Florida, for the years

2002–2008 in 2007 dollars,[7] (b) billion-dollar-plus U.S. weather disasters between 1980 and 2005 as reported by NOAA's National Climatic Data Center in 2007 dollars, and (c) crop indemnities paid per county from 1980 to 2008 through the U.S. Department of Agriculture's Risk Management Agency in year 2000 dollars.

**Figure 6: Mean-Excess Plots: (a) Wind Claims from Citizens Property Insurance Corporation in Florida, (b) Billion-Dollar Weather Event in the United States, and (c) Crop Indemnities Paid**




**(a)**

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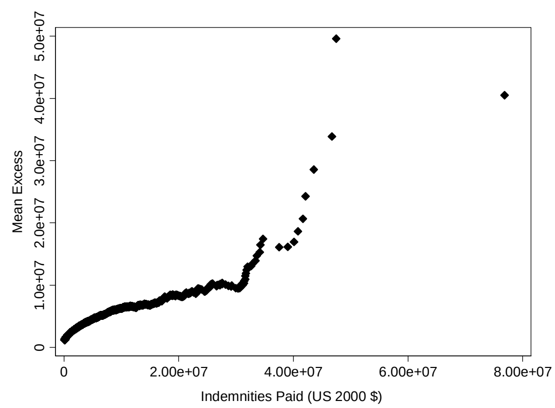



**(c)**

## THE WORST COULD BE MUCH WORSE

The logic of fat tails is that the next event at least as bad as the worst experienced to date could be much, much worse. We can pick a county-month-year off the plot in Figure 4, say Bay County, Florida, in October of 1995. That month, the county was hit by Hurricane Opal, and flood-related claims were 54 times greater than total personal income in the county that year. But the mean excess—the amount of damage that can be expected for a county with a year at least as bad as

[7] Citizens offers five types of policies; the ones shown here are the "high risk accounts," which include wind-only residential, commercial-residential, and commercial policies.

Bay County in 1995—is almost 920 per dollar of income! That is more than an order of magnitude larger.

### INFINITE AVERAGES?

The average of a finite set of numbers is always finite. With very fat tails, however, as we collect more and more numbers, the average just keeps going up. The phenomenon is well known in theory but sometimes startling when it arises in practice. Consider a collection of random numbers drawn independently from the interval [0, 1]. Their average will converge nicely to ½. Now take the average of the inverses of these numbers; that average will not converge but will keep growing. Even if the theoretical average is finite, the "spread" or variance (average square deviation from the mean) may be infinite. If the spread is infinite, then the spread of the sum of N such variables is also infinite, and dividing infinity by N gives again infinity. Hence, even if the theoretical average is finite, we may be unable to estimate the value by averaging any finite number of samples.

When tails are so fat that the variance, or spread, is infinite, then as the sample size increases, the average square deviation from the true average keeps growing. This means that historical data can be a poor predictor of damages from fat-tailed distributions. A few years of data are not enough to accurately estimate fat-tailed losses, and estimates of the average damage can jump back and forth. For example, using the data shown in Figure 1, average yearly flood damages for the years 2000–2003 were just a little more than $3,000 million (in 2005 dollars). When 2004 and 2005 are added, however, the yearly average jumps to $11,600 million.

Infinite variance can be particularly troublesome for insurance companies. Companies hold many policies and are thus interested in how their risk changes as they aggregate policies. For independent, fat-tailed policies with a finite variance, as more and more policies are bundled together, the tails thin. When distributions are so fat that the variance is infinite, however, the tails stay fat. In these cases, aggregating policies does not bring down the risk of catastrophic losses, undermining common diversification strategies.

## Insuring Fat-Tailed Risks: Tackling Availability and Affordability

Insurance regulations often require companies to keep the probability of insolvency below a certain level (so-called Value-at-Risk requirements, as have been proposed for the Solvency II regulations in Europe). With fat tails, the expected losses beyond the solvency probability can be quite substantial, however, and firms have no incentive to manage this risk. Once a firm is insolvent, it does not care *by how much* it is insolvent. There is no pressure from consumers for insurers to manage risks beyond the point of insolvency either, since policyholders are protected by consumer guarantee funds—state programs that pay the claims of insolvent insurers. The tail risk is essentially transferred to the public.

For sufficiently stringent solvency probabilities, an insurance company will need access to more capital to cover claims for a fat-tailed line than a thin-tailed one. Whether companies hold capital themselves, seek reinsurance, or look to the financial markets, fat-tailed risk will require higher premiums. This makes insuring fat-tailed risks expensive. State insurance commissioners have authority over insurance prices. Insurance scholars have noted that U.S. insurance commissioners tend to weight low prices and availability of policies more heavily than solvency considerations or management of catastrophe risk (Klein and Wang 2007). This has led to rate suppression—keeping rates lower than they would be otherwise—and rate compression—decreasing the spatial variability in rates from those that would be truly risk based.

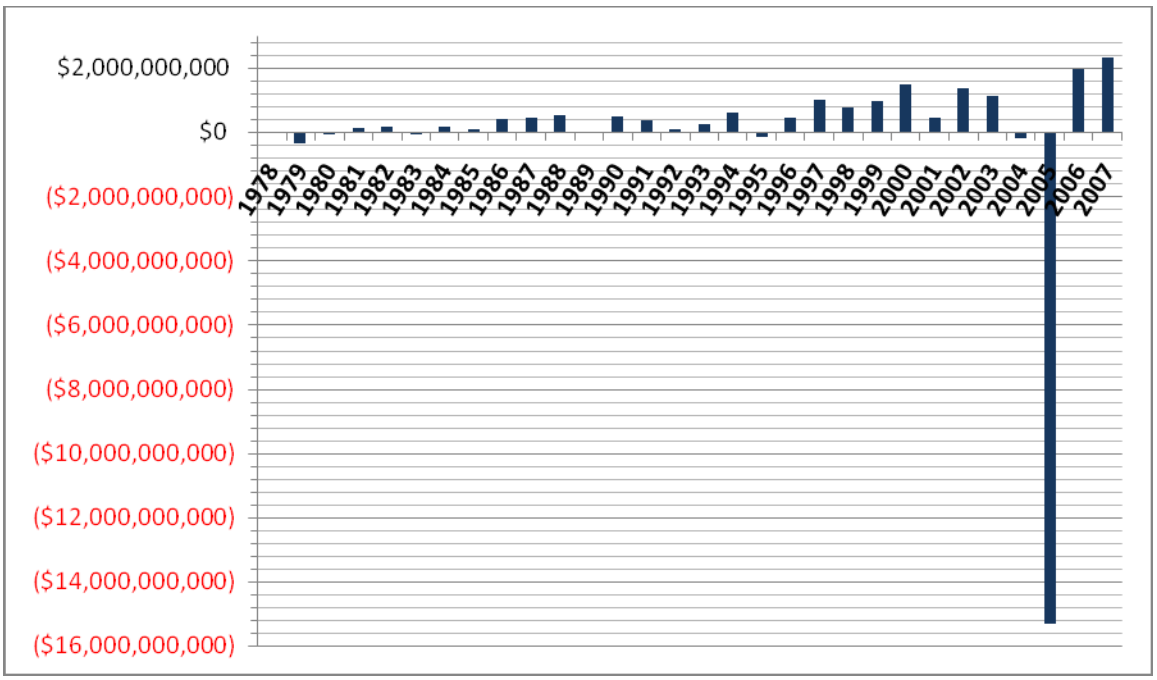
Homeowners often favor suppression and compression of rates, particularly when they do not understand the nature of the risk they face. It is difficult for individuals to take a longer-term view, and with fat-tailed risks, short time periods do not tell us much since losses can be highly variable from year to year. For instance, while the rate of return on net worth for homeowners insurers in the entire United States was 2.8 percent for the years 1993–2003, it was 25 percent for those in Florida. It thus appears insurers in Florida are reaping profits at the expense of homeowners. Not quite. When you add in the years 2004 and 2005—catastrophe years—things change, with the percentage for the whole United States being -0.7 percent and in Florida, -38.1 percent (Insurance Information Institute 2009). In good years, rates may appear excessive, but they are needed to cover costs in bad years. This is the difficulty with fat-tailed risks. Smoothing losses over time is much more difficult.

### THE NATIONAL FLOOD INSURANCE PROGRAM

Policymakers' preoccupation with keeping rates low is evident in the federal NFIP as well. The NFIP was created in 1968 under the belief that flood insurance was not being covered in the private sector, in part due to the catastrophic nature of flood events. The program provides flood insurance to residents in participating communities. Private companies write most policies, but the federal government bears the risk. Since 1973, coverage has been mandatory for homeowners in a 100-year floodplain with a mortgage from a federally backed or regulated lender. At the time it was passed, it was argued that implementation of the program would not be feasible without subsidies for properties in floodplains that were built before the community joined the program and had their floodplains mapped. Subsidies were thus offered to these properties, both to encourage communities to join the program and to avoid penalizing homeowners who had built in the floodplain without knowing the risk and would otherwise face high rates (Pasternick 1998). The total amount of the subsidy has decreased over time, however, as the Federal Emergency Management Agency raised rates on these properties between 1981 and 1995.

The goal of the NFIP regarding its pricing is not fiscal solvency, but collection of enough premiums to cover the operating expenses and losses associated with the "historic average loss year" (Hayes and Spafford 2008). With fat-tailed risks, however, a short period of historical data can dramatically underestimate potential losses. The NFIP was thus unprepared for the 2005 hurricane season (see Figure 7). Hurricane claims forced the program to borrow around $17 billion from the U.S. Treasury. In computing the historic average loss year for pricing post-Katrina, the NFIP decided to weight the damages from 2005 at 1 percent, "in an attempt to reflect the events of 2005 without allowing them to overwhelm the pre-Katrina experience" (Hayes and Spafford 2008, page 6). The NFIP is itself overwhelmed with Katrina's claims and on its own admission is unlikely to be able to cover the interest on its debt to the treasury. The Obama administration has asked Congress to simply forgive the debt.[8] Fat-tailed losses create catastrophe years, and we, as a society, need to decide if this risk should be borne by those who choose to live in floodplains (with sufficient aid to low-income residents) or by all taxpayers, as the Obama request suggests.

**Figure 7: NFIP Premiums Minus Claims**

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[8] A letter from U.S. Homeland Security Secretary Janet Napolitano to Representative Barney Frank articulates the Obama administration's position on this point. One of many articles on the letter can be found at http://www.insurancejournal.com/news/national/2009/05/13/100471.htm (accessed May 25, 2010).

### THE CASE OF FLORIDA

Failure to price for catastrophes is not just an NFIP issue. Florida provides another example. Many states have set up state insurance programs to offer coverage to those unable to find or afford them in the voluntary market. In response to political pressure, state legislators allowed the Florida state insurer, Citizens Property Insurance Corporation, to directly compete with private insurers beginning in early 2007 and froze rate increases until 2009. Citizens thus had lower prices than those offered by many private companies. Adding to its advantage, Citizens does not have to maintain surplus, rates do not reflect private reinsurance costs or a profit margin, rates are not subject to all the taxes of a private company, and rates can be lower due to the ability of Citizens to make ex-post assessments (Karlinsky and Fidei 2008). As a result, Citizens became the largest insurer in the state. Through these policies, Citizens' exposure is currently around $450 billion, but it only has $3 billion in surplus (Lehmann 2009). The Florida Hurricane Catastrophe Fund, the state reinsurer, is also in trouble with a shortfall of $13.5 billion (Lehmann 2009). Should the next big hurricane hit, these programs would be bankrupt. The state has taken the positive step of starting to raise Citizens rates to make them closer to risk based.

### EQUITY ISSUES

If catastrophe insurance did incorporate extra charges to cover the fat-tailed nature of the risk, however, premiums in certain disaster-prone areas would be much higher than they are currently. On the one hand, it is difficult to argue why people locating in safer areas should subsidize the location costs of those in high-risk areas. As other writers have observed, it seems to be good policy to put the cost of catastrophes on those who "create the exposure by their decisions and who benefit from the related rewards" (Davidson 1998). If those making location and mitigation decisions must bear all the benefits and costs of their decisions, more efficient choices will be made.

On the other hand, if premiums did reflect the fat-tailed nature of the risk, some homeowners in hazardous areas would be unable to pay. Kunreuther (2008) has suggested that providing insurance vouchers to homeowners might better protect them without erasing the risk signal from high rates. Any such policy should be based on income levels. In some places, like much of the Florida coast, taxpayers are subsidizing the very affluent who can afford homes, or even vacation homes, on the coast. Citizens sells 2 percent of its policies to homeowners with homes worth more than $1 million, but they account for 10 percent of losses (Litan 2006). These homeowners can afford to pay for the risks they are taking upon themselves.

In addition, economic activity in certain hazardous areas of the country—for example, oil rigs in the Gulf of Mexico—may provide net benefits to all citizens and we may wish to distribute the risk of locating business in these areas among all citizens. This could again be achieved through a voucher system or government provision of commercial insurance policies that are subsidized for very specific locations or industries.

### LOWERING COSTS

Options also exist to lower the cost to insurance companies of having capital available to cover fat-tailed losses. This would bring down rates for everyone. One such option allows for tax-deferred catastrophe reserves (Harrington and Niehaus 2001; Milidonis and Grace 2007). Insurers could choose to allocate catastrophe (cat) funds to a trust or separate account where they could accumulate tax-free and only be withdrawn for payment of claims following pre-defined triggers (Davidson 1998). The trigger could be based on specific events or firm-specific catastrophic loss levels. Such a reserve could have firm-specific caps based on tail value-at-risk measures or some other tool. A provision could allow for use of the funds for other purposes conditional on paying the appropriate taxes. Legislation enabling this type of fund could increase the catastrophe reserves firms have available and has merit for increasing the available reserves for fat-tailed lines.

Insurance-linked securities could also be used to help insurance companies increase the amount of capital they have access to for covering tail risks. Cat bonds provide one example. Cat bonds are issued by (re)insurance companies that set up a separate legal structure called a special purpose vehicle to issue the bond and invest the proceeds in low-risk securities. Investors in the bond receive the interest on the investment as well as some fraction of premiums paid by the (re)insurer. If the natural disaster for which the bond is designed does not occur, investors get their principal back at the end of the time period of the bond. If the event occurs—the trigger—the investors lose their money as it is given to the (re)insurer to cover claims.

If buyers are present, cat bonds could be used to cover the higher end of the distribution of fat-tailed risks, but there are reasons to be skeptical about demand. The possibility of total loss means cat bonds are usually given a non-investment-grade rating. The modeling used for the pricing is difficult for lay people to follow, which might discourage some investors. It had been argued cat bonds would be attractive to investors since they were likely uncorrelated with the market. This cannot be assumed to be true; a cat bond failed to meet an interest payment when Lehman Brothers failed (Hartwig 2009). It likely appears that cat bonds and the stock market generally may be tail dependent (Cooke and Kousky 2010).

## Tail Thinning

A more robust option for addressing fat-tailed risks is to actively lower risk levels. A wide range of mitigating activities can reduce the damages from natural disasters and effectively thin the tails of loss distributions. Homes can be built to withstand hurricane-strength winds, rising waters, and earthquakes. A study of earthquake and hurricane risks found that property-level mitigation reduced the worst-case loss an insurer faced and thus allowed it to write more policies in catastrophe-prone areas for a given solvency constraint (Kleindorfer and Kunreuther 1999). Community-level policies can also reduce losses; for instance, initial evidence shows that communities that adopt flood-reduction measures have lower flood claims (Michel-Kerjan and Kousky 2010).

Even when cost-effective mitigation measures are available, however, homeowners may fail to adopt them because they underestimate or dismiss the probability of a disaster, are myopic, do not see or understand the mitigation in place when purchasing a home, do not have the necessary up-front costs, do not consider the benefits to their neighbors, and/or are not particularly concerned about disaster losses due to federal aid (Kunreuther 2006; Lewis and Murdock 1999). For instance, a 2003 survey of Florida homeowners found that 62 percent had no window coverage;[9] of these, 57 percent said they did not need them and almost 20 percent said they could not afford them (Peacock 2003). Insurance companies can help overcome these problems by educating residents about effective mitigation and offering premium discounts to homeowners who adopt mitigation measures shown to reduce losses.

Mitigation can provide public as well as private benefits. When one member of the community fortifies a home or business against a disaster, that action helps lower overall costs to the community by reducing lost economic activity. It will also lower the amount needed in ex-post relief. Certain hurricane mitigation measures, such as latching down one's roof, also provide a public benefits, in that the roof does not fly off in the next storm and crash into a neighbor's property. Homeowners will not factor in these benefits to others and thus will mitigate too little. To internalize these external benefits, the federal government or states could offer tax credits to homeowners who fortify their homes, a proposal that was introduced in Congress this year. Alternatively, homes that fail to comply with building codes or mitigation standards could be taxed and the funds used to offer grants for mitigation.

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[9] Shutters on windows and coverings for all openings in the home can prevent the roof from failing.

Policies to promote mitigation are being tested around the country at a more local level. In South Carolina, homeowners get tax reductions and insurance discounts for adopting mitigation measures. In Florida, homes are rated based on their ability to withstand hurricane winds; those with high ratings can get insurance discounts. In Alabama and Mississippi, state insurance programs offer discounts to policyholders with fortified homes. In Berkeley, California, home buyers can receive a reduction on their transfer tax for undertaking seismic upgrades. One promising approach to encouraging mitigation is a strong building code coupled with the creation of state funds. The funds could be used to subsidize retrofits to existing homes to bring them up to the building-code standard and could be matched by the federal government.

Thinning tails can also be accomplished by reducing our exposure—that is, curbing development in the highest-risk areas. Under some estimates, catastrophe losses are predicted to double roughly every decade from increased density and more expensive capital in risky location (Insurance Information Institute, 2009). To help reduce building in hazardous areas and put more costs of their decisions on homeowners, one idea is to implement a transfer tax that increases for purchases in high-risk areas. This extra money could go into a mitigation fund.

## Conclusion: Looking Forward

We have seen that for many natural disasters, damages—a product of the hazard and our building decisions—are fat tailed. There is concern that these tails will fatten even more with changes in extreme events from climate change. This suggests that improved management of catastrophic risks should be a part of adaptation planning at the federal, state, and local level. As discussed here, many actions can be incorporated into adaptation plans to reduce losses and improve the ability to insure these risks.

Current programs and regulations place much of the risk of fat tails from natural disasters onto the public. Several congressional proposals have sought to have the federal government assume even more of this catastrophe risk by adding wind coverage to the NFIP, offering reinsurance to state catastrophe insurance programs, or guaranteeing state bonds used to cover catastrophe losses. While the federal government can smooth losses over time and a federal program could potentially pool independent risks from around the country, these programs run the risk of introducing moral hazard and should be undertaken with caution. Offering explicit or implicit subsidies (through loan guarantees, for example) to states, companies, or individuals could discourage proper risk management. Any federal intervention should also stress mitigation as a priority.

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