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Toward a New Risk Architecture: The Question of Catastrophe Risk Calculus

A CAUSE FOR CONCERN

From Catastrophes to Mega-Disasters: A New Era Calls for a New Model

THE CONFERENCE ORGANIZED BY THE NEW SCHOOL ON “DISASTERS: Recipes and Remedies” in New York in fall 2007 combined the contributions of many complementary fields pertaining to catastrophe management.⁷ In this paper, I will discuss the challenge of the *calculus of risk*, but I would like to begin with a broader proposition—the need for a new risk architecture.

In many ways, the catastrophe risk management field is at a crossroads today as we are faced with disasters of a totally new nature and scale. And while a tremendous amount of research has been done to better understand disasters in past decade, there have been recent important events that have seriously challenged the established paradigm. The year 2008 is the most recent illustration of more extreme events to come.

In the new era we have entered, good risk calculus is more about finding the right balance between art and science.¹ Not very long ago, disasters were considered to be low probability events because they did not occur often. In a sense, that assumption was reassuring for the economist: the expected losses of these disasters (understood here as

the potential loss associated with a disaster multiplied by the probability of that event occurring) was often relatively low. But in the first few years of the twenty-first century, the world has faced a string of catastrophes of a totally new dimension: the September 11, 2001 terrorist attacks; a major blackout in August 2003 that deprived electricity to over 50 million North Americans in just a few seconds; and seven hurricanes that hit the United States within a 15-month period—to name a few just in the United States. And catastrophes are often even more destructive when they occur in poor or even developing countries: for instance, the Indian Ocean tsunami in December 2004, or the major earthquake in the Sichuan province in China in May 2008 that killed nearly 50,000, only a few weeks after a major cyclone killed over 100,000 in Myanmar (Burma).

In fact, there has not been a 6-month period in the past few years without a major crisis that simultaneously affected several countries or industry sectors. In the terrorist attacks of 9/11, a superpower was challenged on its own soil in an unprecedented way. After 9/11, the reality of international terrorism became clear, and national security took first priority on the US agenda. The event has had an enduring impact on the rest of the world as well. Hurricane Katrina, a violent but long-anticipated hurricane, overwhelmed a vulnerable coastline, met an unprepared government, and inflicted lasting damage on a population. A superpower failed to meet the most basic needs of its citizens in crisis (White House, 2006). In the case of the US-Canada blackout, a massive failure of the electric power-distribution system demonstrated how human error and short-term competitive pressure resulting in poor risk management can jeopardize our critical infrastructures: a 10-second event. The December 2004 tsunami was responsible for the deaths of nearly 300,000 people in just a few hours because an alert system was not in place (although in this case, the economic impact was mostly local).

While the aforementioned extreme events all seem quite different—different types of catastrophes, different countries, and different impacts on the rest of the world—they share some common features:

the speed at which they occurred and their large-scale destabilization or destruction.² We know from experience that these two characteristics deeply affect decision-making and reaction capacity. The sudden can paralyze. The large-scale disorients. In a few hours it is not clear anymore who has the power, resources, and even legitimacy to act.

Are these events somehow related in the sense that they define a new pattern? If so, is it not clear that there is a need for a new risk management architecture?

A New Risk Architecture Is Still to Be Defined

The severity of these events demonstrates that the world is changing, and that we have entered a new era (Lagadec and Michel-Kerjan, 2005; Lagadec, 2007). On many critical points relating to extreme event preparedness, the conventional thinking is wrong. Conventional thinking holds that risks are mainly local and routine; that it is possible to list all unforeseen events that could take place, determine their probability based on past experience, measure the costs and benefits of specific risk protection measures, and implement these measures for each risk. Many organizations and governments are making decisions using risk and crisis management tools based on these outdated assumptions. As a result, these organizations do not have the agility needed to move quickly to respond to unplanned events and global risks that have occurred at an increasing rate in the recent past. Their failure to adequately prepare impacts not only them, but also a number of other interconnected organizations.

This state of affairs is no longer sustainable. It is clear that the hallmarks of this new era include more and more unthinkable events, previously unseen contexts, and pressure for private companies and government authorities to react extremely quickly, even when they cannot predict the impact their actions will have. Bottom line: if a company, a city, or a country still applies the old paradigm to this new era, it is allocating its resources in the wrong direction. I would like to offer a view of six defining features of this new risk architecture.

Growing interdependencies—globalization: As a result of a growing globalization, social and economic activities are more dependent on each other. While this is not totally new, we have reached a degree of interdependence that no other society has experienced before us: what happens on one continent today can affect those on another continent tomorrow. In other words, we see the emergence of “*security externalities*” (Auerwald, Brancomb, Laporte, and Michel-Kerjan, 2006; see also Kunreuther and Heal, 2003 on “interdependent security”). Conventional thinking holds that individual countries and individual organizations have the capacity and expertise to manage catastrophic risks. In an increasingly globally interdependent world, this is not true.

Change in scale—from local to global risks: Hyperconcentration of value at risk will lead to more devastating consequences when catastrophe strikes. Dealing with large-scale disasters is much more challenging than dealing with a series of local small accidents. Many do not appreciate the radical difference. Resources and collaborative effort needed simultaneously are not simply cumulative, but exponential. Furthermore, global response and global reaction capacity are needed. Multinational coordination becomes critical.

Extreme costs, extreme benefits—a new loss dimension: The new risk architecture is also characterized by a much greater variance in possible losses and gains. With increasing urbanization and concentration of social and economic activities in high risks areas (over 50 percent of the United States population is now living in coastal areas), costs of catastrophes are increasing because of the concentration of assets and first- and second-order ripple effects.

The recent events in the United States have translated into unprecedented economic consequences. Hurricane Katrina killed 1,300 people and forced 1.5 million people to evacuate the affected area—a historic record for the nation. Economic damages are estimated in the range of \$150 to \$200 billion, a third of which was covered by either private insurance (wind damage; about \$45 billion) or public insurance (flood damage; \$20 billion by the Federal National Flood Insurance

Table 1. The 20 Most Costly Insured Catastrophes in the World, 1970-2007³

	Event	Victims (Dead or Missing)	Year	Area of Primary Damage
\$46.3*	Hurricane Katrina	1,836	2005	USA, Gulf of Mexico, et al.
35.5	9/11 Attacks	3,025	2001	USA
23.7	Hurricane Andrew	43	1992	USA, Bahamas
19.6	Northridge Earthquake	61	1994	USA
14.1	Hurricane Ivan	124	2004	USA, Caribbean, et al.
13.3	Hurricane Wilma	35	2005	USA, Gulf of Mexico, et al.
10.7	Hurricane Rita	34	2005	USA, Gulf of Mexico, et al.
8.8	Hurricane Charley	24	2004	USA, Caribbean, et al.
8.6	Typhoon Mireille	51	1991	Japan
7.6	Hurricane Hugo	71	1989	Puerto Rico, USA, et al.
7.4	Winterstorm Daria	95	1990	France, UK, et al.
7.2	Winterstorm Lothar	110	1999	France, Switzerland, et al.
6.1	Winterstorm Kyrill	54	2007	Germany, UK, NL, France
5.7	Storms and floods	22	1987	France, UK, et al.
5.6	Hurricane Frances	38	2004	USA, Bahamas
5.0	Winterstorm Vivian	64	1990	Western/Central Europe
5.0	Typhoon Bart	26	1999	Japan
4.5	Hurricane Georges	600	1998	USA, Caribbean
4.2	Tropical Storm Alison	41	2001	USA
4.2	Hurricane Jeanne	3,034	2004	USA, Caribbean, et al.

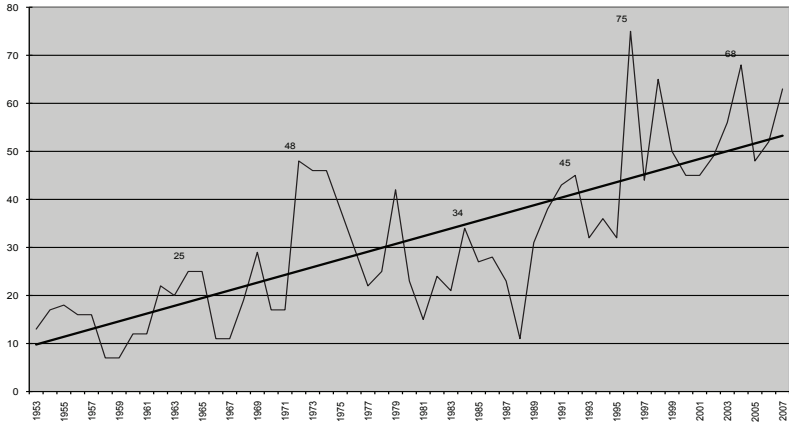
*In billions of US dollars. (indexed to 2007.)

Sources: Data from Swiss Re and Insurance Information Institute

Program—another historic record). Federal relief to the victims and for local reconstruction is estimated to be over \$125 billion—yet another historic record.

On the financial side, the figures are telling: twenty of the most costly catastrophes to the insurance industry in the world over the past 38 years (1970-2007) occurred after 1987 (in 2007 prices corrected for inflation). Furthermore, of these 20 catastrophes, half of them (10) occurred since 2001 (see table 1), 9 of them in the United States.

Figure 1. Disaster Presidential Declarations Per Year (Peak-Values Correspond to Some Presidential Election Years)



Sources: Author’s calculation with data from the U.S. Department of Homeland Security

Hurricanes Ike, which hit the United States in September 2008, will undoubtedly be in this top 20 ranking.

On a positive side, this wider variance in the level of risk also creates new business opportunities. For instance, catastrophe bonds (cat bonds), which are financial instruments transferring catastrophe exposure to investors on the financial markets, have quickly developed in the aftermath of the 2005 hurricane season in the United States (Lewis, 2007). In 2006, 20 cat bonds were issued (\$4.7 billion issued and \$8.7 billion capital outstanding), compared with 11 in 2005 (\$2.1 billion issued and \$2.9 outstanding), the previous record. In 2007, the total value of cat bonds issued for natural disasters alone was \$7.1 billion; 27 transactions were completed, a new record compared with the 10 transactions closed in 2005 (Michel-Kerjan and Morlaye, 2008).

Another measure of the recent change in disaster occurrence in the United States is the increase of the number of US presidential disaster declarations over the past 53 years, which shows clearly an upward trend (as depicted in figure 1). Overall, the number of presidential disas-

ter declarations has dramatically increased over the past 50 years: there had been 162 over the period 1955-1965, 282 over 1966-1975, 319 over the period 1986-1995, and 545 for 1996-2005 (Michel-Kerjan, 2008). On average, the average annual number of declarations has increased by 10 every decade since the 1950s.

Under the current US system of disaster assistance, the governor of the state(s) can request that the president declare a “major disaster” and offer special assistance if the damage is severe enough. Although the president does not determine the amount of aid (the House and Senate do), he or she is responsible for a crucial step in the process. This obviously raises the questions of what are the key drivers of such a decision, whether some states are more likely to benefit from such situation than others, and if so, when does this occur.

As figure 1 also shows, many (although not all) of the peak years correspond to presidential election years. This is consistent with recent research that has shown that election years are a very active time for disaster assistance (all other things being equal). Four salient examples are the Alaska earthquake in 1964 (a presidential election year), Tropical Storm Agnes in June 1972, Hurricane Andrew in September 1992 and the four hurricanes in 2004. More recently, it has also been shown that a battleground state with 20 electoral votes has received more than twice as many presidential disaster declarations as a state with only three electoral votes (Reeves, 2004, 2005). In that sense, it is almost impossible to dissociate the economics of catastrophe management from politics (Gross, 2008). Research also shows that a driving force with respect to the actual provision of government relief is the occurrence of disasters where the losses are large (Moss, 2002). All things being equal, a victim of natural disasters might get access to more disaster relief if the disaster affects a large number of people.

In the case of Hurricane Katrina, Governor Kathleen Blanco declared a state of emergency on August 26, 2005 and requested disaster relief funds from the federal government on August 28. President George W. Bush declared a state of emergency on August 28, an action that frees federal government funds and puts emergency response activ-

ities, debris removal, and individual assistance and housing programs under federal control (Congressional Research Service, 2005). Under an emergency declaration, federal funds are capped at \$5 million. On August 29 in response to Governor Blanco's request, the president declared a "major disaster," allotting more federal funds to aid in rescue and recovery. By September 8, Congress had approved \$52 billion in aid to victims of Hurricane Katrina. As of October 2007, the total federal relief allocated by Congress for the reconstruction of the areas devastated by the 2005 hurricane season was nearly \$125 billion.

Confusing distribution of the role and responsibilities—preparedness: If one asks people on the street, "Who do you think is in charge of preparing the country against future crises?" the most cited response will certainly be state and federal governments (whether as regulators or first responders). However, although government entities certainly play a crucial role, a large portion of critical services that allow our countries to operate is owned or operated by the private sector (85 percent in the United States, for example). We must look at how private actions affect public vulnerability so that we are better prepared.

Celerity—toward a just-in-time society: The development of rapid transportation and cheap communication has created a "just-in-time" society. People and products are moving faster and faster from one part of the globe to the other. While this provides a wide range of positive return, there is also a flip side: risks are more likely to spread across very rapidly. Thanks to jet travel, for instance, viruses now fly business class, too, so a pandemic starting in Asia today might very well spread extremely rapidly.

Uncertainty, if not ignorance: We were trained to solve problems with clear questions and clear scientific knowledge. Knowing the risk profile, we made investment decisions. Unfortunately, historical data does not shape the future anymore, given how rapidly the world is changing.

While this is a simplified framework, these six complementary features fit a large number of recent crises we all have witnessed in different parts of the world and across industries. The rest of the paper

focuses on the last element of this framework—the challenge of quantifying risks under uncertainty, if not ignorance. We will use large-scale natural disasters and terrorism threats as two illustrative cases. Calculating risks associated with natural hazards has typically been easier than calculating risks associated with terrorism. In their similarities and differences, these two risks highlight the fact that, in a quickly evolving environment, the calculus of risk might become as much a matter of art as science.

THE CALCULUS OF RISK I: THE CASE OF NATURAL DISASTERS

Our discussion in the previous section raises the question as to what the future will look like. Using the United States as an example, we would like to focus on three drivers of the radical evolution of the cost due to natural disasters. These three drivers—*increasing urbanization in hazard-prone areas, increasing value at risk, and global warming*—are likely to continue to influence the social and economic cost of future disasters.

Increasing Development and Value at Risk in Hazard-Prone Areas

In 1950, about 30 percent of the world's population—then 2.5 billion people—lived in urban areas. By 2000, the number of people living in urban areas had increased to 50 percent, and the United Nations estimates that this will increase to 60 percent of the world population, projected to be 8.3 billion by 2025. A direct consequence of this trend is the increasing number of so-called megacities, with populations above 10 million located in hazard-prone areas. In 1950, New York City was the only such a megacity. By 2015, there are estimated to be 26, including New York (17.6 million) and Los Angeles (14.2 million). This urbanization and increase in population translates into an increased concentration of exposure to natural disasters.

The development of Florida for tourism and retirement is an illustrative example. The population of the state has increased significantly over the past 50 years: 2.8 million inhabitants in 1950, 6.8 million in 1970, 13 million in 1990, and a projected 19.3 million residents in 2010

Table 2. Top 20 Hurricane Scenarios (1900–2005) Ranked Using 2005 Inflation, Population, and Wealth Normalization

Rank	Hurricane	Year	Category	Cost range (\$ billion) in 2005
1	Miami (SE FL/MS/AL)	1926	4	140-157
2	Katrina (LA/MS)	2005	3	81
3	North Texas (Galveston)	1900	4	72-78
4	North Texas (Galveston)	1915	4	57-62
5	Andrew (SE FL and LA)	1992	5-3	54-60
6	New England (CT/MA/NY/RI)	1938	3	37-39
7	SW Florida	1944	3	35-39
8	Lake Okeechobee (SE FL)	1928	4	32-34
9	Donna (FL-NC, NY)	1960	4-3	29-32
10	Camille (MS/SE LA/VA)	1969	5	21-24
11	Betsy (SE FL and LA)	1965	3	21-23
12	Wilma	2005	3	21
13	Agnes (FL/CT/NY)	1972	1	17-18
14	Diane (NC)	1955	1	17
15	4 (SE FL/LA/AL/MS)	1947	4-3	15-17
16	Hazel (SC/NC)	1954	4	16-23
17	Charley (SW FL)	2004	4	16
18	Carol (CT/NY/RI)	1954	3	15-16
19	Hugo (SC)	1989	4	15-16
20	Ivan (NW FL/AL)	2004	3	15

Source: Data from Pielke et al. (2008)

(a nearly 600 percent increase since 1950). With more individuals living in these areas, coupled with an increase in property values of their homes, there is a much higher probability of large-scale losses from hurricanes and flooding than 15 years ago. If Hurricane Andrew had occurred in 2007 rather than 1992, it would have inflicted more than double the economic losses than at the time of the disaster. In the same vein, the large 1926 Miami hurricane that hit the state when Florida was far less populated would inflict more than \$140 billion of direct economic damage if it were to happen again today (Pielke et al., 2008).

These figures do not come as a surprise if one looks at the concentration of assets in Florida. Today, nearly 80 percent of insured assets in Florida are located near the coast, the area most subject to hurricane damage. As of December 2007, this represented over \$2.3 trillion of insured exposure (\$1.4 trillion for commercial exposure and \$900 billion of residential exposure), according to the modeling firm AIR Worldwide.

Likewise, New York has over \$2 trillion of insured value located directly on the coast (which is about 60 percent of the total insured value in the state). The coastal insured value for the top 10 states (ranked in terms of insured value on their coast) combined accounts for more than \$8.3 trillion. Such huge concentrations of insured value in highly exposed areas almost guarantees that any major storm that hits these regions will inflict billions if not hundreds of billions of dollars in economic losses unless the residential construction and infrastructures are properly protected by effective risk reduction measures.⁴

To better understand our new vulnerability, table 2 shows the cost of major hurricanes that occurred in the United States in the past century, adjusted for inflation, population, and wealth normalization (that is, an estimate of what each of these hurricanes would have cost had they hit in 2005 in total direct cost).⁵ This exercise has been done in several studies, the most recent of which, by Pielke et al. (2008), normalizes mainland US hurricane damage from 1900–2005 to 2005. Table 2 provides estimates for the top 20 most costly hurricanes, assuming they had occurred in 2005. The authors propose two ways to normalize these losses, each of which gives a cost estimate. The table provides the range of costs between these two estimates, along with the year when the hurricane originally occurred, as well as the hurricane category on the Saffir-Simpson scale.

Risk Calculus: Application to Hurricane Risks in Florida⁶

As part of a multiyear research effort currently undertaken by the Wharton Risk Center in conjunction with Georgia State University and

Table 3. Exceedance Probability of Insured Residential Losses in Florida (in billions of dollars)

\$1	\$2	\$5	\$10	\$15	\$20	\$25	\$30	\$40
42.5%	35.9%	24.5%	15.0%	10.1%	6.9%	5.0%	3.9%	2.5%
\$50	\$60	\$75	\$100	\$125	\$150	\$200	\$250	\$350
1.7%	1.3%	0.81%	0.41%	0.22%	0.11%	0.028%	0.005%	0.00012%

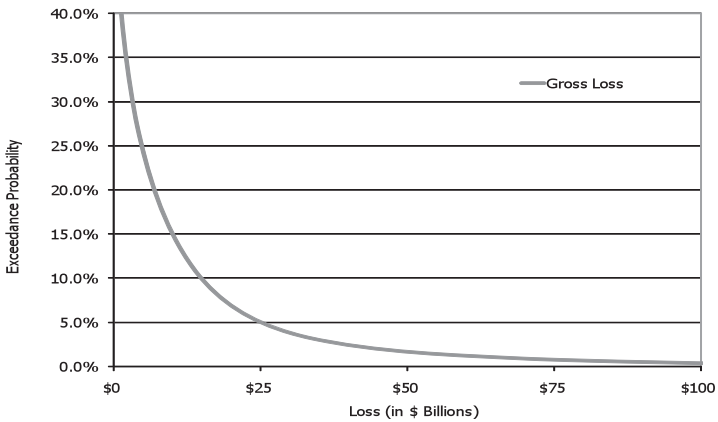
Sources: Wharton Risk Center - FHCF Data 2005; simulation by RMS.

the Insurance Information Institute, we have worked with one of the leading catastrophe modeling firms, Risk Management Solutions (RMS), to help us better quantify the risk of hurricane in several states. RMS has provided us with an analysis of the data from the Florida Hurricane Catastrophe Fund (FHCF) book of business as of 2005. Because the FHCF is a mandatory state reinsurance program, it has every residential insurance policy written in the state by private insurers and the state-run insurer, called Citizens. Data collected for this simulation include all lines of coverage of the FHCF. Total insured value (TIV) by the fund at the end of 2005 was estimated to be \$1.7 trillion for the entire state of Florida. We focus on wind coverage only.⁷

Table 3 provides estimates of the annual probability that insured wind losses from hurricanes will equal or exceed different magnitudes for 18 thresholds ranging from \$1 billion to \$350 billion. For example, there is a 42.5 percent chance that there will be at least \$1 billion of insured residential losses in Florida next year. The probability that hurricanes will inflict at least \$10 billion of insured residential losses in Florida next year is 15 percent, and there is a 1.7 percent chance that insured losses will be at least \$50 billion.

As we can see from this table, the probability decreases significantly as the threshold level of losses increases. For very high levels of insured losses (\$100 billion and greater), the exceedance probability is less than 0.5 percent. This translates into a hurricane that occurs less than once every 200 years. Of course, such an unlikely catastrophic event could occur during the next hurricane season. By undertaking this analysis for all possible levels of insured hurricane losses, one can

Figure 2. Loss Exceedance Probability Curve for FHCF Portfolio



Source : 2005 Florida Hurricane Catastrophe Fund Portfolio and RMS.

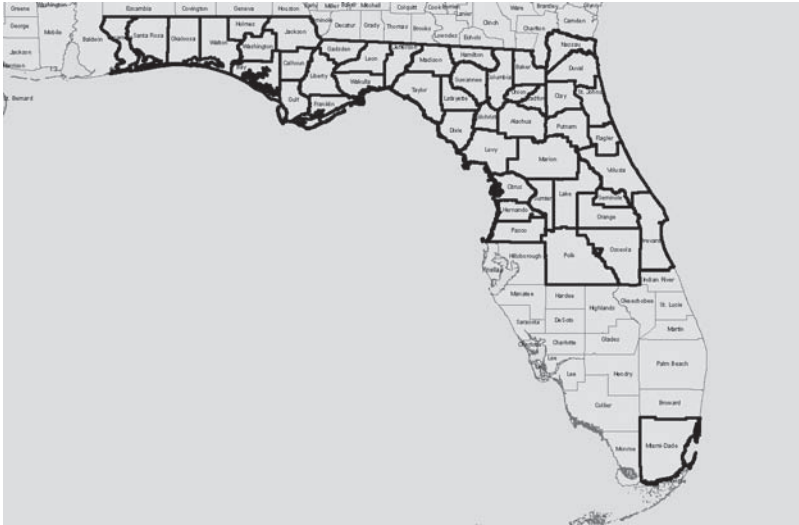
generate the entire exceedance probability curve for the FHCF.⁸ Figure 2 provides this curve for losses up to \$100 billion.

To measure the uncertainty surrounding these estimates, one needs to utilize data on the average annual expected losses and the standard deviation for each postal zone in the state. For all Florida postal zones combined, the average annual expected loss for Florida residential insurance is \$5.4 billion and the standard deviation is \$13.9 billion (a 2.55 coefficient of variation).

Even if the average expected loss is identical in two regions, their standard deviations can differ significantly. To illustrate this point, we compared the insured losses from hurricanes in the postal zones within Miami-Dade County with 46 counties in the northern part of Florida, depicted in figure 3.

The 46 counties taken together had the same expected annual insured losses as Miami-Dade County. Figure 4 depicts the two EP curves for these two regions. Although the EP curves between the two regions look similar, their standard deviations are quite different. For both Miami-Dade County and the 46 northern counties in Florida, the average annual expected loss is approximately \$900 million. The standard deviation of losses for Miami-Dade is \$4.2 billion (a coefficient of

Figure 3. 46 Counties Whose Combined Annual Expected Loss Equals Miami-Dade's Alone



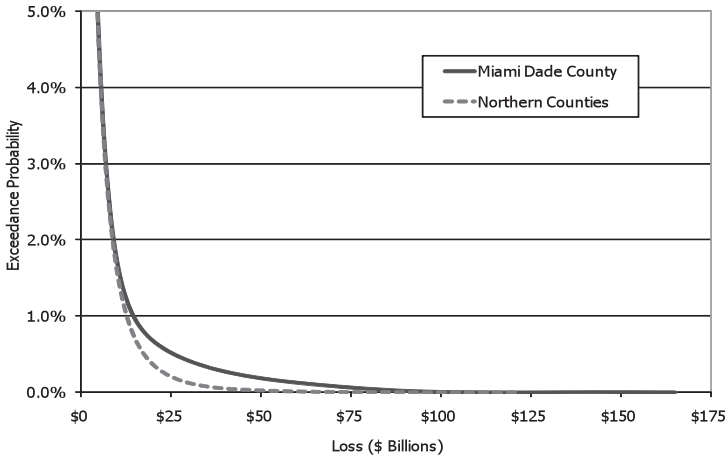
variation of nearly 5) and for the 46 northern counties it is \$2.8 billion (a coefficient of variation of nearly 3).⁹ This uncertainty in losses poses serious problems for preparedness and resource allocation.

Possible Impact of Climate Change on Risk Estimate: Likelihood versus Intensity¹⁰

There have been numerous discussions and scientific debates as to whether the series of major hurricanes that occurred in 2004 and 2005 might be partially attributable to the impact of a change in climate.¹¹ Without passing judgment on these issues, we summarize below the key questions and the scientific evidence presented to address them.

Is a change in climate likely to affect the number and severity of weather-related catastrophes? One of the expected effects of global warming will be an increase in hurricane intensity. This has been predicted by theory and modeling and substantiated by empirical data on climate change. Higher ocean temperatures lead to an exponentially higher evaporation rate in the atmosphere which increases the intensity of cyclones and precipitation.

Figure 4: Loss Exceedance Probability Curve comparing Miami-Dade County to 46 counties in Northern Florida

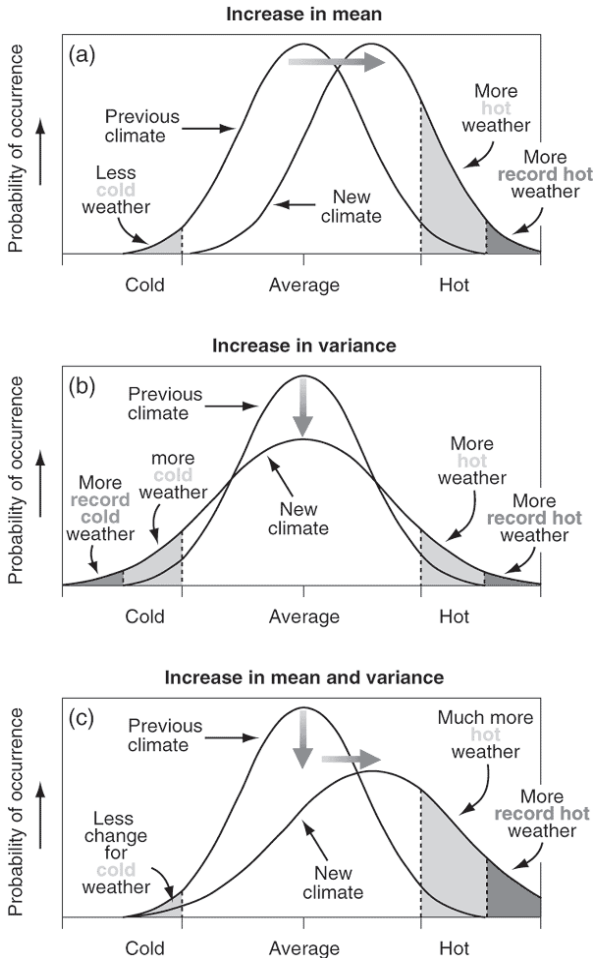


Source: 2005 Florida Hurricane Catastrophe Fund Portfolio and RMS.

Emanuel (2005) introduces an index of potential destructiveness of hurricanes based on the total dissipation power over the lifetime of the storm. He shows a large increase in power dissipation over the past 30 years and concludes that this increase may be due to the fact that storms have become more intense, on the average, and/or have survived longer at high intensity. His study also shows that the annual average storm peak wind speed over the North Atlantic and eastern and western North Pacific have increased by 50 percent over the past 30 years.

A paper by Webster et al. (2005), published a few weeks later, indicates that the number of Category 4 and 5 hurricanes worldwide has nearly doubled over the past 35 years.¹² In the 1970s, there was an average of about ten Category 4 and 5 hurricanes per year globally. Since 1990, the number of Category 4 and 5 hurricanes has averaged 18 per year. Focusing only on the North Atlantic (Atlantic/Caribbean/Gulf of Mexico), Category 4 and 5 hurricanes have increased from 16 in the period of 1975-1989 to 25 in the period of 1990-2004 (a 56 percent increase).

Figure 5. Global Warming and Its Impact on Variability in the Extremes



Note: The graph shows the effect on extreme temperatures when (a) the mean temperature increases; (b) the variance increases; and (c) when both the mean and variance increase for a normal distribution of temperature.

Source: Intergovernmental Panel on Climate Change.

The Webster et al. (2005) study concludes that “global data indicate a 30-year trend toward more frequent and intense hurricanes.” This significant increase in observed tropical cyclone intensities, linked to warming sea surface temperatures that may be associated with global

warming, has been shown in another study (Hoyos et al., 2006). One consequence of global warming is that we are likely to see more variability in the extremes, as depicted in figure 5.

But this is not to say that there is consensus by scientists on the relationship between hurricane activity and global warming.¹⁴ In a perspective article published in *Science*, Landsea et al. (2006) point out that subjective measurements and variable procedures make existing tropical cyclone databases insufficiently reliable to detect trends in the frequency of extreme cyclones. This conclusion is reinforced in a summary of articles on global climate change by Patrick Michaels, past president of the American Association of State Climatologists, who notes that all studies of hurricane activity that claim a link between human causation and the recent spate of hurricanes must also account for the equally active period around the middle of the twentieth century. Studies using data from 1970 forward begin at a cool point in the hemisphere's temperature history, and hence may draw erroneous conclusions regarding global climate change and hurricane activity (Michaels, 2006).

In 2007, a reanalysis of global tropical cyclone data since 1980 that addressed inaccuracies related to the interpretation of satellite recordings was published (Kossin et al., 2007). The reanalyzed data shows a lack of global trend in the number and percentage of Category 4 and 5 hurricanes and power dissipation index (PDI) globally, thus contradicting the results of Webster et al. (2005). An increase in PDI and in number and proportion of Category 4 and 5 hurricanes was still found for the Atlantic. While this supports the results of Emanuel (2005) for the Atlantic, the lack of a global increase in tropical cyclones activity, despite the increase in tropical sea-surface temperatures in all basins, "poses a challenge to hypotheses that directly relate globally increasing tropical sea surface temperature to increase in long-term mean global hurricane intensity" (Kossin et al., 2007). The Atlantic also appears to be characterized by large natural variability on the multidecadal scale with a shift to a more active phase around 1995 (World Meteorological Organization, 2006; Goldenberg et al., 2001).

The current debate in the scientific community regarding changes in the frequency and intensity of hurricanes and their relationship to global climate change is expected to be with us for a long time to come. The results to date do raise issues for the insurance industry to the extent that an increase in the number of major hurricanes over a shorter period of time may translate into a greater number hitting the coasts, likely causing damage to many more residences and commercial buildings today than they would have in the 1940s.

Another important aspect of the emerging consensus that anthropogenic climate change is occurring is that other stakeholders will likely become much more vocal than they have been up to now. Indeed, discussions and proposals to address potential consequences of global warming have not only emerged in more countries, they have also emerged in sectors that had not traditionally paid a lot of attention to it. For instance, while the debate on climate change had mainly been driven by NGOs, government and international bodies, and research institutions, now the private sector in general, and the financial institutions in particular, are increasingly involved and are sometimes the true drivers.

For instance, in April 2004, a group of 13 public pension funds managing over \$800 billion in assets wrote a letter to US Securities and Exchange Commission (SEC) Chairman William Donaldson asking him to clarify that climate change is indeed a material risk requiring disclosure on SEC filings and to strengthen current disclosure requirements, for example, by providing interpretive guidance on the materiality of climate change risks. More recently, in June 2006, this now-enlarged group of investors—50 members of the Investor Network on Climate Risk (INCR), representing nearly \$3 trillion in assets—reiterated this demand to the new SEC chairman (Ceres, 2006). The way these new stakeholders in the climate change field perceive the risk of future disasters and how they prepare—or expect companies they invest in to prepare—is likely to have important consequences.

THE CALCULUS OF RISK II: THE CASE OF TERRORISM THREAT

We now turn to another source of extreme events, the threat of terrorism. The discussion will focus on the main features of terrorism that makes this risk more difficult, if not impossible, to quantify, examine how terrorism risk financial coverage has been priced before and after the September 11, 2001 terrorist attacks, and try to infer some proxies for an implicit probability of attack.

Calculating Risk of Extreme Events: Why Is Terrorism Different?

The nature of international terrorism has changed drastically in the past two decades. Twenty years ago, terrorism consisted primarily of local political activities. But recent years have seen the emergence of a new kind of threat: extremist, religious-based terrorism (Hoffman, 2006; Enders and Sandler, 2006). Most of these terrorist groups, including Al Qaeda, have demonstrated a willingness to inflict mass casualties and to view civilians as a legitimate target. That change has led to fewer but larger attacks with a considerably larger number of casualties. The world's 15 worst terrorist attacks, as indicated by the number of casualties and fatalities, have all occurred since 1982, with two-thirds of them occurring between 1993 and 2006. In that sense, here we have also entered an era of potential catastrophes of a totally new scale. Moreover, there have been many near misses in the last few years. Among the most recent attempts were the attempted bombings of commuter trains in Germany on July 31, 2006 and the thwarting of a plot to bomb as many as 10 passenger planes bound for the United States from the UK in August 2006. Large terrorist attacks have the potential to destabilize entire nations, with numerous ripple effects and long-term impacts. While mega-terrorism risk shares several of the features of other extreme events, it also presents a set of distinctive characteristics:

- ▶ There are many plausible scenarios of attacks that would lead to

overwhelming losses; the possible methods of a mega-terrorist attack are limited only by terrorist ingenuity. Consider the following illustration: the direct property losses, business interruption costs, and workers' compensation payments resulting from a five-ton truck bomb in one of the tallest high-rises in a major US city could go as high as \$15 billion for a single building, depending on the location and the timing of the attack. Simultaneous attacks could inflict losses in the \$100 billion range.¹⁶ The use of weapons of mass destruction (WMD) is even more threatening. A 10-kiloton nuclear bomb planted in a shipping container that explodes in the port of Long Beach, California could have an even more devastating impact, with total *direct* costs estimated to exceed \$1 trillion (not to mention ripple effects on trade and global supply chains; the ports of Los Angeles and Long Beach handle 30 percent of US shipping imports by value and are the largest ports of entry in the US) (Meade and Molander, 2006).

- ▶ The origin of the attack and its effects do not require proximity; for example, the destruction of the World Trade Center's towers in New York City could be attributed in part to the failure of security at Logan Airport in Boston, which shows that one company's operation can be disrupted by the failure of others to take sufficient protection measures (Kunreuther and Michel-Kerjan, 2005).
- ▶ Although terrorism risk models have been developed in the past two years, they are primarily designed to specify insurer's *potential exposure* to losses from a wide range of scenarios characterizing the attack (Kunreuther, Michel-Kerjan, and Porter, 2005). The models are not well suited to estimating the likelihood of any of these scenarios *occurring*. In contrast to natural disasters, for which large historical databases and scientific studies are publicly available, data on current terrorism threats are either not available at all or partly concealed by federal agencies for national security reasons.
- ▶ In addition to the lack of historical data relevant to the nature of today's threats, estimating the likelihood of a terrorist attack

means aiming at a moving target, resulting in *dynamic uncertainty*, which is a key feature of terrorism risk. The risk of future terrorist attacks depends on the terrorists' will to attack and their chosen modes, as well as on the protective measures undertaken by those at risk and on actions taken by the government to enhance general security and commercial entities to protect their employees and assets. This point was underscored by the 9/11 National Commission (2004) report on terrorist attacks. Thus, terrorism risk depends on actions by both the private and public sectors and is continuously evolving, which makes the risk of future terrorist events extremely difficult to estimate.

- ▶ There is uncertainty about the *timing of an attack*. From the eight years that separated the first World Trade Center bombing in 1993 and the 2001 attacks, one could infer that terrorist groups program their attacks far in advance and strike when the public's attention and concern about terrorism have receded.
- ▶ When it comes to sharing the watch and responsibilities, a government's actions here and abroad directly affect the level of risk imposed on businesses and citizens (security measures, intelligence, foreign policy). Moreover, foreign policy decisions made by a government can affect the desire of terrorist groups to attack a certain country or its interests abroad (Lapan and Sandler, 1988; Lee, 1988; Pillar, 2001).

As a result, one faces a serious problem in quantifying terrorism risk and evaluating the best strategy to protect citizens and physical assets. It is worth noting here that due to the difficulty in estimating the likelihood of a terrorist attack, insurance companies that cover commercial firms against the risk of terrorism use scenarios to determine their maximum exposure to a range of possible attacks that vary by location and mode of attack.¹⁷ However, few insurers consider the likelihood of these scenarios occurring in determining their exposure;¹⁸ most use the "what if" approach.

Table 4. Natural Hazards Versus Terrorism Risks

	Natural Hazards Potential catastrophic losses	Terrorism Risks Potential catastrophic losses
Historical Data	Some historical data	Very limited historical data 9/11 event was the first mega-terrorist attack.
Risk of Occurrence	Risk reasonably well specified	Considerable ambiguity of risk Terrorists can intentionally adapt their strategy depending on their information on vulnerabilities.
Geographic Risk	Specific areas at risk	All areas at risk Some cities may be considered riskier than others, but terrorists may attack anywhere, at any time.
Information	Information sharing New scientific knowledge on natural hazards can be shared with all stakeholders.	Asymmetry of information Governments keep secret new information on terrorism for obvious national security reasons.
Event Type: Interdependent Security	Natural event To date, no one can influence the occurrence of an extreme natural event (e.g., earthquake).	Resulting event Governments can influence terrorism (e.g., foreign policy; international cooperation; national security measures).

Table 4 summarizes some of the differences between natural hazards and terrorism threat that affect the quantification of these two categories of risks.

Inferring Implicit Probability of Terrorist Attacks from Terrorism Insurance Prices

Before September 2001—and despite terrorist attacks that occurred in the 1990s in several European countries, including Spain, France, and the UK, and the first attack on the World Trade Center in New York City in 1993—terrorism risk was, in practice, covered as an unnamed peril by standard risk commercial policies in the United States. Hence, on the morning of 9/11, many companies that suffered

Table 5. Change in Implicit Probability of Terrorist Attack: Illustration with Chicago's O'Hare Airport

Before 9/11 (in \$ million)			After 9/11 (in \$ million)			Change
Limit	Premium	Implicit probability	Limit	Premium	Implicit probability	
\$750	\$0.175	1 in 4300	\$150	\$6.9	1 in 22	200-fold

the attacks may have been surprised to discover that they were actually covered against such events. And many insurers and their reinsurers were brought to the realization that they were financially responsible for the insured portion of the losses: \$35 billion, one-third of which was for business interruption. At that time, this was the most costly catastrophe ever in the history of insurance (now the second, after Hurricane Katrina).

As a response to 9/11, public-private partnerships were established in several developed countries (for example, the United States, Germany, France) in order to provide commercial enterprises with financial coverage. More than six years have passed since this tragedy, and terrorism insurance markets that developed after 2001 have had time to mature. With regard to risk calculus, a look at the evolution of terrorism insurance prices will offer some indications of the market's (buyers and suppliers) judgment of the likelihood of future attacks.

Consider the case of the terrorism insurance policy of the Chicago's O'Hare Airport. Before 9/11, the airport was covered against the consequences of a terrorist attack up to \$750 million; it paid an annual premium of \$175,000 for this coverage. That is an implicit probability of one in 4,300 years (assuming, for sake of simplicity here, no insurance administrative cost included in the premium). After the attacks, the best deal the airport could find was at one-fifth the earlier coverage, to \$150 million for a m multiplied by nearly 40; now an implicit probability of 1 in 22. Table 5 shows the comparison between the two policies.

Was the new implicit probability for an attack against O'Hare airport right or wrong? Of course, it is hard to tell, but the airport bought that coverage.

Table 6-A. Terrorism Insurance Price Comparison between the United States And Germany (Mean, Excluding Standalone—Overall Book)

Overall Book	U.S.	Germany	Difference Germany/ U.S.
Aggregate			
Premium/Quantity of insurance purchased	0.0270% (1 in 3,700)	0.0685% (1 in 1,460)	-2.5
Small accounts	< \$200 million	< €150 million	
Premium/Quantity of insurance purchased	0.0185% (1 in 5,400)	0.0240% (1 in 4,170)	-1.3
Large accounts	> \$200 million	> €150 million	
Premium/Quantity of insurance purchased	0.0317% (1 in 3,150)	0.1299% (1 in 760)	-4.1

Note: Implicit probability in parentheses.

Table 6-B. Terrorism Insurance Price Comparison between the United States And Germany (Mean, Excluding Standalone—Financial Institutions Only)

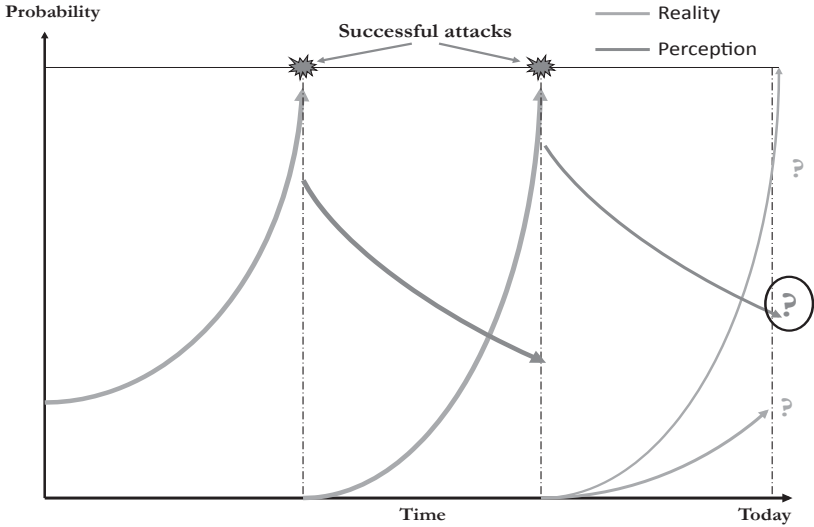
Financial Institutions	U.S.	Germany	Difference Germany/ U.S.
Aggregate			
Premium/Quantity of insurance purchased	0.0697% (1 in 1,430)	0.0688% (1 in 1,450)	-1.0
Small accounts	< \$200 million	< €150 million	
Premium/Quantity of insurance purchased	0.0782% (1 in 1,280)	0.0259% (1 in 3,860)	-0.3
Large accounts	> \$200 million	> €150 million	
Premium/Quantity of insurance purchased	0.0796% (1 in 1,250)	0.1400% (1 in 715)	-1.8

In order to provide more substantial evidence on terrorism insurance pricing (in effect, a proxy for implicit likelihood of an attack), it is possible to undertake a series of analyses of insurance pricing in the United States and several European countries (France, Germany, and the UK) over the past five years.

Below, we provide a snapshot of a much broader analysis of US and German terrorism insurance markets by focusing on the following two sets of data: 1) a sample of 1,623 large firms in the US market (insured value higher than \$200 million); and 2) the 1,153 large firms in Germany. For each of these companies, we collected data on premiums paid for terrorism insurance along with quantity of insurance purchased by the company. Using the means of these distributions, it is possible to run the data for all companies (as summarized in table 6-a), which provides a macro-perspective on implicit probability for different sizes of company at an aggregate country level. One can also focus on a specific industry sector to compare similar companies (table 6-b for instance provides the results for financial institutions). The last column on the right reports the multiple of German prices in relation to those in the United States. Figures in parentheses provide a proxy for the implicit probability of loss given these prices (in the case where the price would perfectly represent the expected loss and would not include any other elements such that administrative cost or the cost of capital—a simplifying assumption)

As shown in these summary tables, five years after 9/11 a huge disparity exists in the price of coverage in the United States and Germany. After taking into account differences in the size of the firms, the price of comparable coverage in Germany appears to be at least 30 percent—and, by some estimates, as much as four times—higher than in the United States. On the other hand, if we confine our analysis to financial institutions only and consider the aggregate samples, the price of coverage appears roughly equivalent. For smaller firms, the price is as much as two or three times lower in Germany than it is in the United States, but 50 percent to 80 percent higher for large accounts (depending on what measure of price one selects). This result can be explained

Figure 6. Difference between Terrorism Risk and Risk Perception Over Time



in part by the fact that, in the case of small accounts, Extremus does not charge different premiums to different industry sectors, while premiums in the United States are highest for financial institutions.

This analysis illustrates how the price for terrorism coverage varies from one country to another. While one might expect that terrorism is a greater threat to the United States than it is to Germany, on average, the perceived likelihood—as translated into the price of financial coverage against that risk—goes in the opposite direction. There may be other reasons for this price difference that are independent of the perception of the risk (federal reinsurance provided for free to US insurers, adverse selection in the German market, difference in the nature of coverage, etc.).²⁰

The main takeaway here is that it is hard to quantify with certainty the probability of future terrorist attacks. Today, the market perception of the probability of an attack against financial institutions (most of them located in large cities, often considered a prime target) is nearly 1 in 1,400. That seems to be a very low probability if one considers that terrorism is one of the top issues on the US political agenda today.

Seven years without any (publicized) terrorist attacks on US soil might have lowered the perception of that risk considerably. An attack on US soil next month will certainly lead to a major increase in prices, reflecting a reevaluation of the risk, despite the fact that the risk itself has not necessarily changed (some might actually argue that the risk of a new attack the year after one has taken place is low because of increased attention and reinforced level of security established as a reaction to the first attack) (see figure 6 for an illustration).

ART OR SCIENCE? HOW RISK ESTIMATES CHANGE AFTER DISASTERS

I would like to conclude on a last note: the uncertainty related to the estimate of future disaster is even more challenging because it is dynamic. Indeed, as illustrated by large-scale natural disasters and continuously evolving terrorism threat, a series of major disasters tomorrow is likely to influence many stakeholders to change their view about future events. The series of seven hurricanes that made US land-fall in 2004 and 2005 offers a perfect illustration of that dynamic aspect of risk estimate. Let's focus here two important groups of stakeholders in that regard: rating agencies and modeling firms.

Rating agencies provide independent evaluations of economic strength of commercial enterprises, including the financial stability of insurers/reinsurers and their ability to meet their obligations to policyholders in the case of a disaster. During the past few years, rating agencies have paid increasing attention to the impact that catastrophic risks will have on their assessment of the financial stability of insurers and reinsurers. The rating given to a company will affect its ability to attract business, and hence its pricing and coverage decisions. For example, the rating agency A. M. Best undertakes a quantitative analysis of an insurer's balance sheet strength, operating performance, and business profile. Evaluation of catastrophe exposure plays a significant role in determining ratings since these are events that could threaten the solvency of a company. Projected losses from disasters occurring at specified return periods (a 100-year windstorm/hurricane or a 250-year

earthquake) and the associated reinsurance programs to cover them are two important components of the rating questionnaires that insurers are required to complete.

A. M. Best's approach has been an important step forward in the incorporation of catastrophic risk into an insurer's capital adequacy requirements. Until recently, the rating agency has been including probable maximum loss (PML) for only *one* of these severe events (100-year windstorm/250-year earthquake, depending on the nature of the risk the insurer was mainly exposed to) in its calculation of a company's risk-adjusted capitalization. In 2006, as a result of the 2004 and 2005 hurricane seasons, A. M. Best introduced a second event as an additional stress test. If the main exposure facing the insurer is an earthquake, the second event is increased from a 1-in-250-year event to a 1-in-100-year event (A. M. Best, 2006). These new requirements have increased the amount of risk capital that insurers have been forced to allocate to underwrite this risk and have made them more reluctant to provide this coverage unless they are able to raise premiums sufficiently to reflect these additional costs.

The changes in risk estimates and the new requirements by rating agencies have significantly affected the way insurers are managing their exposure. Indeed, the exact same portfolio of risks that an insurer was covering in July 2004 was much more "risky" in July 2006, due to the changes in the way these ratings have been redefined.

Modeling firms. As illustrated by the analysis of hurricane risk in Florida presented earlier in this paper, many organizations in the public and private sectors have turned to firms that specialize in the business of modeling catastrophe risks to assist them in determining catastrophe risk exposure.²¹ Over the past 10 years, these companies have become important players in the field of catastrophe insurance and reinsurance. These firms were subject to some criticism for failing to increase their risk assessment in advance of the 2004-2005 storm seasons. It should be noted that catastrophe modeling and risk assessment face a number of informational challenges, as well as market and regulatory acceptance. For instance, the Florida Commission on Hurricane Loss

Projection Methodology refused to certify Risk Management Solution's medium-term view of hurricane activity filed in 2006 that reflected the recent increase in hurricane frequency and intensity being experienced in the Atlantic basin. RMS had to modify its model so its estimates of hurricane activity rates for the next five years are now based on a straight historical average of the number of hurricanes recorded since 1900 (RMS, 2007).

Ultimately, it may have been necessary for the United States to experience the recent increase in the occurrence of natural disasters in order for modeling firms to adjust their models. Due to parameter uncertainty, it is never possible to know whether a given model has accurately estimated the true underlying risk of loss and associated probability distributions. Indeed, it is a challenge to estimate the risk of catastrophes in an inconstant and rapidly evolving environment.

While the old risk management paradigm focused mainly on expected loss as the key measure to consider in making decisions, recent catastrophes make it clear that the uncertainty associated with this estimate has become an element of considerable importance. A high variance means that some periods will be very quiet while others will be particularly devastating. A good preparedness plan is one that takes a long view on these issues. In this regard, one needs to be mindful that it might be extremely difficult to maintain the long view if our country has *not* experienced any major disasters during several years. There is a tendency for all of us, whether in the role of homeowner, decision maker in a private or public sector organization, or as a political representative at the state, local, or federal level, to pay attention only to short-run crises. In the new era of global risks and interdependencies we have entered, how people make long-term decision under uncertainty will be an important element to consider in developing the new risk architecture.

NOTES

- * I would like to thank Howard Kunreuther for ongoing interaction on these issues over the years, as well as Elliot Aronson, Lee Clarke,

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1. The word “architecture” is chosen here on purpose. The word comes from the Greek “*architekton*,” which can be broken in two. The beginning of the word, “arch,” is the part that means “the first,” the responsibility that comes with priority. The second part of the word “tekton” is closely related to “tekniki,” the word that the Greeks used for a technique. But this word, in turn, is very close to “techni,” the word Greeks also used for “art.”
2. The two crises that are unfolding as this paper is written, the subprime crisis and the food price crisis, certainly share these attributes as well.
3. This table excludes payments for flood by the National Flood Insurance Program in the US—for example, \$17.3 billion in 2005 as a result of Hurricanes Katrina and Rita.
4. In Kunreuther and Michel-Kerjan (forthcoming), we show that proper mitigation measures in place can reduce the level of loss associated with a 100-year-return period hurricane in Florida by nearly 50 percent.
5. These estimates might vary, depending on underlying assumptions over such a long period of time, such as inflation, population growth, and wealth normalization in the studied area; moreover, mitigation and building codes will have an important impact on total losses.
6. I thank Jack Nicholson of the Florida Hurricane Catastrophe Fund (FHCF) for providing us with the FHCF data base and Patricia Grossi and Robert Muir-Wood of Risk Management Solutions (RMS) for their analyses of the FHCF data. They provided us with the relevant exceedance probability curves and tables presented in this section.
7. I use here the new generation of models developed by RMS in 2006; see my discussion about the changes that occurred in cat risk modeling as a result of the 2004/2005 hurricane seasons earlier in this paper.

8. An exceedance probability (EP) curve specifies the probabilities that a certain level of losses will be exceeded in a specific location (or its entire portfolio) over a specific period of time (e.g., one year, five years, etc.). These losses can be measured in terms of dollars of damage, fatalities, illness or some other unit of analysis.
9. The coefficient of variation is the ratio of the standard deviation of a given variable to its mean.
10. This subsection is based on Kunreuther and Michel-Kerjan (2007).
11. For more details on the scientific evidence regarding climate change and its impact see the Stern Report (2006).
12. Category 4 hurricanes have sustained winds from 131 to 155 miles per hour; Category 5 systems, such as Hurricane Katrina at its peak over the Gulf of Mexico, have sustained winds of 156 mph or more.
13. See Weitzman (2007, 2008) for an insightful discussion about the importance of considering the possibility of truly catastrophe output related to climate change. The author argues that the Stern Report underestimates this risk of catastrophe change in climate.
14. See for instance the exchange between Pielke, Landsea, and Emanuel (2005) and Chan (2006).
15. For more discussion on this issue see Mills (2005).
16. See chapter 6 in Wharton Risk Center (2005).
17. When asked the question “Does your company consider scenarios in its catastrophe/exposure management process?” 92 percent of the insurers who responded to a 2005 Wharton questionnaire answered “Yes.” One company responded to the above question by noting: “Our company uses deterministic terrorist attack scenarios, and the associated Probable Maximum Loss (PML) estimates of these scenarios, to establish and manage exposure concentrations within major metropolitan areas and/or surrounding landmark properties.” See Wharton Risk Center (2005).
18. As illustrated by the following responses to the question: “Do you take estimates of the likelihood of the various known scenarios into account when making underwriting decisions?”

“Not really. There is little historical data to predict future events.”

“Likelihood is very unpredictable for terrorist acts.”

“Our company does not believe that estimates of the frequency of terrorist attacks are credible at a country, regional or specific property level.”

See Wharton Risk Center (2005)

19. These two datasets were provided by Marsh, a leading insurance broker, for the US market and by Extremus, the German insurance company established in 2002 to cover against terrorism for the German market. I am grateful to Marsh’s John Rand and Jill Dalton and Extremus’s Bruno Gas for providing special runs of their datasets. The complete set of results, which constitutes the first international comparison of terrorism insurance prices, was published in Michel-Kerjan and Pedell (2006).
20. For a discussion of these other elements, see Michel-Kerjan and Pedell (2006).
21. For a comprehensive presentation of the evolution of catastrophe modeling, see Grossi and Kunreuther (eds.) (2005).

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