CLIMATE CHANGE, INSURABILITY OF LARGE-SCALE DISASTERS, AND THE EMERGING LIABILITY CHALLENGE

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This Article focuses on the interaction between uncertainty and insurability in the context of some of the risks associated with climate change. It discusses the evolution of insured losses due to weather-related disasters over the past decade and the key drivers of the sharp increases in both economic and insured catastrophe losses over the past twenty years. In particular, the authors examine the impact of development in hazard-prone areas and of global warming on the potential for catastrophic losses in the future. In this context, the authors discuss the implications for insurance risk capital and the capacity of the insurance industry to handle large-scale events. A key question that needs to be addressed is which factors determine the insurability of a risk and the extent of coverage offered by the private sector to provide protection against extreme events when there is significant uncertainty surrounding the probability and consequences of a catastrophic loss. The authors further discuss the concepts of insurability by focusing on coverage for natural hazards, such as earthquakes, hurricanes, and floods. The Article also focuses on the liability issues associated with global climate change and possible implications for insurers, including issuers of Directors' and Officers' policies, given the difficulty in identifying potential defendants, tracing harm to their actions, and apportioning damages among them. The Article concludes by suggesting ways that insurers can help mitigate future damages from global climate change by providing premium reductions and rate credits to companies investing in risk-reducing measures.

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INTRODUCTION

The World Economic Forum recently stated that climate change is one of the most important global risks that key decision makers will face in the years to come.[1] In the same vein, a report commissioned by the Chancellor of the Exchequer in the United Kingdom echoes this perspective and notes that "climate change presents very serious global risks, and it demands an urgent global response."[2] The *Stern Review* notes that global climate change "presents a unique challenge for economics" due to the long time horizons involved, the uncertainty associated with the risk, and the unprecedented scale on which one needs to envision such a problem.[3] These points reinforce the common sentiment that we need to address the role of different industrial sectors in reducing the impacts of global warming.

This Article focuses on the role that the insurance sector can play in this regard and the challenges insurers and reinsurers face in dealing with the impact of climate change on their risk management strategies. Indeed, the direct and indirect impact of firms' activities to limit future emissions of greenhouse gases (GHGs) and to adapt in other ways to climate change is likely to have major implications on the insurance sector. In a recent interview, John Coomber, former CEO of the Swiss Reinsurance Co. (Swiss Re), a world reinsurance leader, stated that climate change "is the number one risk in the world ahead of terrorism, demographic change and other global risk scenarios . . . ."[4] In May 2006, American International Group (AIG), the largest insurer in the United States, issued a statement that "[c]limate change is increasingly recognized as an ongoing, significant global environmental problem with potential risks to the global economy and ecology, and to human health and wellbeing."[5]

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[1] WORLD ECONOMIC FORUM, GLOBAL RISKS 2007, at 4 (2007), *available at* http://www.weforum.org/pdf/CSI/Global_Risks_2007.pdf.

[2] NICHOLAS STERN, STERN REVIEW: THE ECONOMICS OF CLIMATE CHANGE i (2007). A prepublication version of the *Stern Review* is available at http://www.hm-treasury.gov.uk/indepenent_reviews/stern_review_economics_climate_change/stern_review_report.cfm.

[3] *Id.*

[4] Climate Group Interview with John Coomber, former CEO of Swiss Reinsurance Co., *available at* http://www.swissre.com/internet/pwswpspr.nsf/fmBookMarkFrameSet?ReadForm&BM=../vwAllbyIDKeyLu/rscd-6necs4?OpenDocument (last visited May 1, 2007).

[5] AM. INT'L GROUP, AIG'S POLICY AND PROGRAMS ON ENVIRONMENT AND CLIMATE CHANGE 1 (2006), *available at* http://media.corporate-ir.net/media_files/irol/76/76115/aig_climate_change_updated.pdf; *see also AIG Adopts Policy on Climate Change,*

Extreme-weather-related events (such as hurricanes, floods, and ice storms) will impact the premiums and available coverage for property damage and business interruption losses. They may affect health and life insurance as well. Because insurance policies are usually renewed annually, insurers are faced with the problem of how to set premiums and what coverage to offer in the coming year. This can be a difficult challenge, given the inability to distinguish between random weather patterns and systematic changes in climate in the short run.

Insurers have also begun paying attention to the liability issues associated with climate change because shareholders could accuse some companies of failing to prepare for climate-related financial exposures. To the extent that shareholders take such cases to court, insurers have to defend those firms who have purchased Directors' and Officers' (D&O) liability coverage from them.

The Article is organized as follows. Part I discusses the evolution of catastrophic losses over the past twenty years. In particular, we examine the impact of climate change, coupled with the development of hazard-prone areas, on the potential for large losses to insurers in the near future. In this context we discuss the capacity of the insurance industry to handle large-scale disasters without assistance from the public sector. Part II addresses the issue of attribution by examining the main drivers of this new dimension of catastrophic losses. While climate change may impact the intensity and frequency of future hurricanes, the growing concentration of population and industry in high-risk areas is largely responsible for the billions of dollars in losses that will result from such events.

Part III discusses the concept of insurability by focusing on coverage for natural hazards—such as earthquakes, hurricanes, and floods—and showing how these extreme events impact whether these hazards are insurable by the private sector alone (and, if so, under what market conditions). The seven major hurricanes that devastated Florida in 2004 and the Gulf Coast in 2005 served as a wake-up call not only to insurers and reinsurers, but to other stakeholders as well. Among these stakeholders are modeling firms that have developed and revised catastrophe models for quantifying insurers' and reinsurers' exposure, rating agencies that have modified their rating methodologies and imposed more stringent conditions of catastrophe exposure management by insurers and reinsurers, and investors who

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INS. J., May 17, 2006, *available at* http://www.insurancejournal.com/news/international/2006/05/17/68491.htm.

now require a higher return on equity to reflect the higher volatility of insurers' portfolios, due to the new scale of extreme events. Part IV then demonstrates how these stakeholders are modifying the frontier of the insurability of catastrophic risks.

Part V focuses on another challenge that will face the insurance sector in the coming years: the liability issues associated with global climate change given the difficulty in identifying potential defendants, tracing harm caused by their actions, and apportioning damages between them. We also suggest ways that insurers can help mitigate future damages from global climate change by providing premium reductions and rate credits to companies that have taken actions that produce short-run tangible benefits and have a long-run positive impact on global climate change. Part VI provides a brief summary of our findings and issues a call for a more systematic collection of data to allow well-informed strategies and policies.

I. CHANGES IN EXTREME-WEATHER-RELATED EVENTS

Catastrophes have had a more devastating impact on insurers over the past fifteen years than in their entire history. Between 1970 and the mid-1980s, annual insured losses from natural disasters (including forest fires) were in the $3 to $4 billion range. The insured losses from Hurricane Hugo, which made landfall in Charleston, South Carolina on September 22, 1989, exceeded $4 billion (in 1989 values). It was the first natural disaster in the United States to inflict more than $1 billion of insured losses. In the 1990s, the scale of insured losses from major natural disasters changed radically: it grew to $17 billion in 1991, greater than $30 billion in 1992 (with $20 billion from Hurricane Andrew alone), more than $20 billion in 1994 (with $18 billion from the Northridge earthquake alone), and $25 billion in 1999 (mainly due to major storms and floods in Europe).

Damages reached a new record in 2004 with total financial losses of $123 billion from natural disasters throughout the world. Insurance covered $49 billion of these losses.[6] This upward trend is continuing. In 2005, insured losses from Hurricane Katrina alone are estimated at

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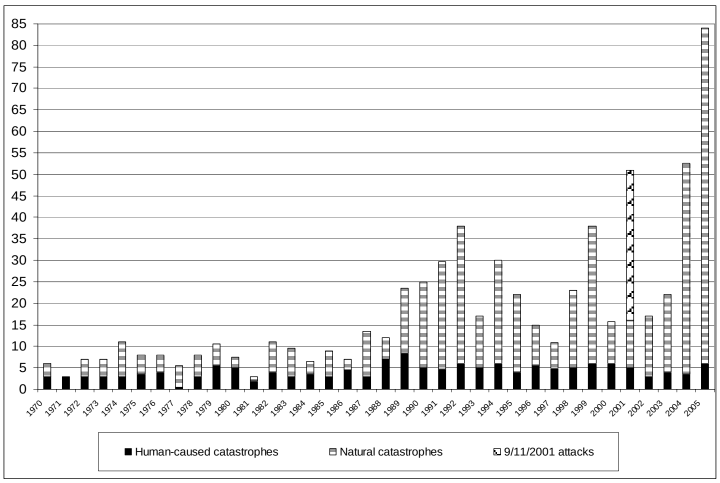
[6] SWISS REINSURANCE CO., SIGMA, NO. 1, NATURAL CATASTROPHES AND MAN-MADE DISASTERS IN 2004, at 3 (2005), *available at* http://www.swissre.com/Internet/pwsfilpr.nsf/vwFilebyIDKEYLu/MPDL-6A2D64/$FILE/sigma1_2005_e.pdf.

[7] SWISS REINSURANCE CO., SIGMA, NO. 2, NATURAL CATASTROPHES AND MAN-MADE DISASTERS 2005 (2006), at 3, *available at* http://www.swissre.com/Internet/pwsfilpr.nsf/vwFilebyIDKEYLu/EWAL-6MBJQ2/$FILE/Sigma2_2006_e.pdf.

$45 billion.[7] Worldwide major catastrophes in 2005 inflicted $230 billion in economic damage, $83 billion of which was covered by insurance.[8] Figure 1 depicts the upward trend in worldwide insured losses from catastrophes between 1970 and 2005 in 2005-indexed prices.[9]

Figure 1: Worldwide Evolution of Catastrophe Insured Losses, 1970-2005[10]



[8] *Id.*

[9] There is a growing literature studying the evolution of insured losses due to major catastrophes in the world. Total figures differ from one source to another, mainly due to divergent definitions of a "catastrophe," yet all reach the same conclusion. For example, natural disasters inflicting insured losses above $38.7 million or total losses above $77.5 million are considered a major catastrophe by Swiss Re (we use this threshold in Figure 1). *Id.* at 38. Munich Re uses a higher threshold. As a result, most figures used in the literature regarding the evolution of catastrophe losses underestimate the real effect on insurers. In the United States, for example, Property Claim Services (PCS) defines a "catastrophe" as an event that inflicts insured losses above $25 million; smaller events (even those that are repeated) are not included in the PCS catastrophe database. *See* ISO Props., Inc., PCS Catastrophe Serial Numbers, http://www.iso.com/products/2800/prod2802.html (last visited May 1, 2007) ("PCS now defines catastrophes as events that cause $25 million or more in direct insured losses to property and that affect a significant number of policyholders and insurers."). Nonetheless, all studies of which we are aware conclude that insured catastrophe losses have rapidly increased in recent years.

[10] This figure is indexed to 2005 dollars. September 11, 2001 insured losses include property and business interruption. *See* Erwann O. Michel-Kerjan & Howard C. Kunreuther, Improving Homeland Security in the Wake of Large-Scale Disasters: Would Risk-Based All-Hazard Disaster Insurance Help in the Post-Katrina World?, at slide 7 (Aug. 18-19, 2006), *available at* http://www.usc.edu/dept/create/assets/003/51953.pdf. These data are from the Wharton Risk Center, Swiss Re, and the Insurance Information Institute.

Table 1 shows the twenty most costly catastrophes for the insurance sector over the past thirty-five years in 2005 dollars. With the exception of the terrorist attacks of September 11, 2001, all of the most costly events were natural disasters.[11] Among these natural disasters, more than 80% were weather-related events: hurricanes and typhoons, storms, and floods constituted nearly three-quarters of the claims emanating from the United States. The era we have now entered is best illustrated by data showing that of the twenty most costly events over this thirty-five-year period, ten occurred during the past five years.

The insured losses from Hurricane Andrew in 1992 and the Northridge earthquake in 1994 led insurers and reinsurers to pay much more attention to the catastrophic potential of natural disasters. These two events, considered the first two "super-catastrophes" (insurance losses above $10 billion), caused insurers to reflect on what constitutes an insurable risk. To assist them in making this determination, many firms began utilizing catastrophe models to estimate the likelihood and consequences of specific disasters in hazard-prone areas to their insured portfolios.[12]

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[11] The two most costly industrial catastrophes in regards to insurance claims over this thirty-five-year period are the explosion of the offshore oil platform Piper Alfa in the United Kingdom in July 1988, which cost about $3.2 billion to insurers, and the explosion of a petrochemical plant in the United States in October 1989, which inflicted insured damage of $2 billion (in 2004 dollars). SWISS REINSURANCE CO. 2004, *supra* note 6, at 34 tbl.9.

[12] CATASTROPHE MODELING: A NEW APPROACH TO MANAGING RISK 25 (Patricia Grossi & Howard Kunreuther eds., 2005).

Table 1: The Twenty Most Costly Insured Catastrophes in the World, 1970-2005[13]

Rank	*U.S. $ Bil. (indexed to 2005)*	*Event*	*Victims (Dead or Missing)*	*Year*	*Area of Primary Damage*
1	45*	Hurricane Katrina	1326	2005	United States, Gulf of Mexico, etc.
2	35	9/11 Attacks	3025	2001	United States
3	22.3	Hurricane Andrew	43	1992	United States, Bahamas
4	18.5	Northridge earthquake	61	1994	United States
5	11.7	Hurricane Ivan	124	2004	United States, Carib-bean, etc.
6	10.3	Hurricane Wilma	35	2005	United States, Gulf of Mexico, etc.
7	8.3	Hurricane Charley	24	2004	United States, Carib-bean, etc.
8	8.1	Typhoon Mireille	51	1991	Japan
9	6.9	Winterstorm Daria	95	1990	France, United King-dom, etc.
10	6.8	Winterstorm Lothar	110	1999	France, Switzerland, etc.
11	6.6	Hurricane Hugo	71	1989	Puerto Rico, United States, etc.
12	5.2	Hurricane Frances	38	2004	United States, Bahamas
13	5.2	Storms and floods	22	1987	France, United King-dom, etc.
14	5.0*	Hurricane Rita	34	2005	United States, Gulf of Mexico, etc.
15	4.8	Winterstorm Vivian	64	1990	Western & Central Europe
16	4.7	Typhoon Bart	26	1999	Japan
17	4.2	Hurricane Georges	600	1998	United States, Carib-bean
18	4.1	Hurricane Jeanne	3034	2004	United States, Carib-bean, etc.
19	3.7	Typhoon Songda	45	2004	Japan, South Korea
20	3.5	Tropical Storm Allison	41	2001	United States

[13] Disasters that occurred between 2001 and 2005 are shaded in gray. *See* WHARTON RISK CENTER, MANAGING LARGE-SCALE RISKS IN A NEW ERA OF CATASTROPHES: REPORT ON PHASE I OF THE STUDY 5 tbl.1.1 (2007), *available at* http://opim.wharton.upenn.edu/risk/library/Report_on_Phase_I.pdf. Data are from the Wharton Risk Center, Swiss Re, and the Insurance Information Institute. Asterisks indicate that the figure excludes $2 to $3 billion in offshore energy losses.

A. *Insured Versus Economic Impact*

Insurance does not decrease the global losses from an untoward event, but rather spreads its financial impact by enabling those at risk to pay a relatively small premium so that they can be protected against a large loss that has a small chance of occurring. Hence, insured losses reflect only a part of the total economic damage inflicted by a disaster. By definition, the ratio of economic losses to insured losses (L/I) will be very high when there is a limited insurance market, as is often the case in developing countries. For example, in 1996, major floods in China inflicted about $24 billion in economic loss, less than $500 million of which was covered by insurance, leading to an L/I ratio of approximately fifty. Two years later, in 1998, other floods in China cost about $30 billion in direct economic loss, but only $1 billion was covered by insurance, leading to an L/I ratio of thirty. High L/I ratios have also been observed in industrialized countries in which there are no minimum insurance requirements. For example, the large-scale earthquake that devastated Kobe, Japan in 1995 cost $110 billion (L), only $3 billion of which was covered by insurance (I).

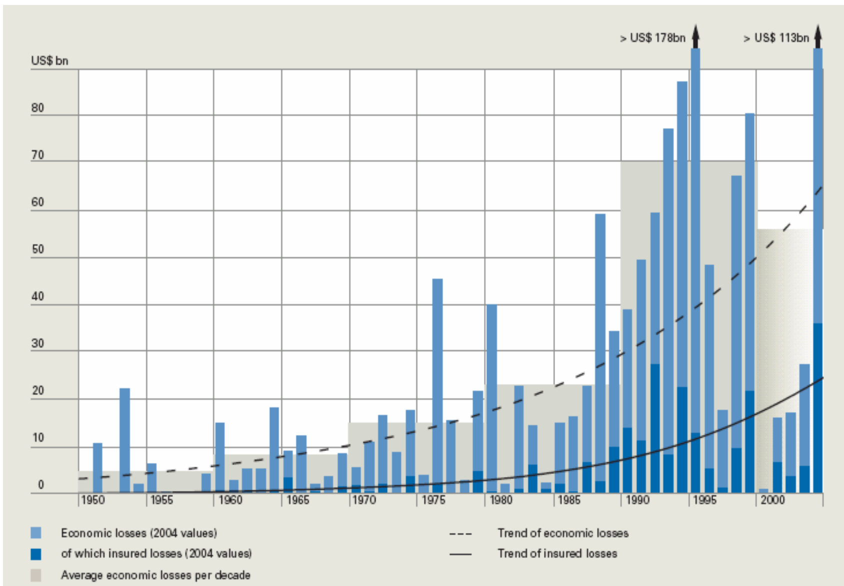
Traditionally, there has been a much lower L/I ratio in the U.S. market, ranging from two to four, principally because banks and financial institutions often make insurance a condition for a mortgage and because of the use of effective mitigation measures for reducing losses from natural disasters. In the cases of Hurricane Andrew and the Northridge earthquake, the L/I ratio was about 1.5 (26/17) and 2.8 (44/15.5), respectively, with both L and I specified in billions of dollars. For Hurricane Katrina, the ratio is estimated to be in the three-to-four range [(150-170)/45].[14]

Figure 2 compares economic loss and insured losses for "great natural disasters" from 1960-2004. Economic losses follow the same increasing trend described earlier for insured losses. The light gray multiyear rectangles in the graph represent the average annual economic loss by decade (in 2004 values). A comparison of these economic losses over time reveals a huge increase: $44.9 billion (1950-1959); $80.5 billion (1960-1969); $147.6 billion (1970-1980); $228 billion (1980-1989); and $703.6 billion (1990-1999). While the economic losses during the first four years of the twenty-first century (2000-2003) were less severe than losses in previous years, disasters in 2004 inflicted about $113 billion in economic loss, making it the sec-

[14] Total economic losses due to Hurricane Katrina are still not definitive.

ond most devastating year of this forty-four-year period.[15] And disasters in 2005 alone inflicted twice as much economic loss as in 2004.

Figure 2: Evolution of "Great Natural Catastrophes" from 1960-2004: Economic Versus Insured Impact[16]



B. *Economic Versus Human Impacts*

Fatalities often do not factor into insurance loss rankings. The correlation between insured losses and fatalities is even less clear than the relationship between insured and economic losses, as a large

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[15] MUNICH RE GROUP, TOPICS GEO 2004 14-15 (2005), *available at* http://www.munichre.com/publications/302-04321_en.pdf?rdm?457.

[16] Dataset obtained from Munich Re. As discussed in note 9 *supra*, figures differ from one source to another. Munich Re and Swiss Re, the two leading reinsurers in the world, do not use the same definition of catastrophe. Typically, Munich Re's estimates are lower than Swiss Re's, the former selecting only very large natural catastrophes, whereas the latter is less restrictive in its definition. These differences can be very important. For example, when Munich Re estimated insured loss at about $35 billion in 2004, Swiss Re's estimate was $49 billion. More generally, the Swiss Re and Munich Re data underestimate the actual total cost of natural disasters. However, they also constitute the most extensive (both in time and in scale) approximation of that sort.

number of natural disasters occur in the developing world or in poor areas of developed countries where there is limited insurance in place. For example, the tsunami that devastated South Asia in December 2004 cost the insurance industry about $5 billion, primarily from losses to tourism activities, but the disaster killed over 280,000 people and constitutes the second most deadly natural disaster event over the past 100 years (a 1972 storm and flood killed almost 300,000 people in Bangladesh). More generally, the most deadly natural disasters, from the point of view of lives lost, occur in developing countries. Between 1970 and 2004, twenty catastrophes each killed over 10,000 people, with all but one (the Izmit earthquake in Turkey in 1999) occurring in non-OECD[17] countries.[18]

II. THE QUESTION OF ATTRIBUTION: A FOCUS ON WEATHER-RELATED EVENTS

In the preceding section, we discussed natural disasters without differentiating between weather-related events (e.g., storms, floods, droughts, heat waves, cold, and frost) and non-weather-related events (e.g., earthquakes). With respect to the relationship between climate change and insurance, it is important to focus on weather-related events.[19]

Between 1970 and 2004, storms and floods were responsible for over 90% of the total economic costs of extreme weather-related events. Storms (hurricanes in the U.S. region, typhoons in the Japan region, and windstorms in Europe) account for 75% of insured losses. Floods represent about 10%. According to a recent study by the Association of British Insurers (ABI), in every year since 1990 there have been at least twenty weather-related events that were severe enough to be classified by leading reinsurers as significant catastrophes. In con-

[17] OECD, which stands for Organisation for Economic Co-operation and Development, is an international organization in which the thirty members, democratic countries in the world with the highest income, brainstorm ways to address the issues surrounding globalization. Organisation for Economic Co-operation and Development, http://www.oecd.org (last visited May 1, 2007).

[18] SWISS REINSURANCE CO. 2004, *supra* note 6, at 35.

[19] Earthquakes are a major source of catastrophes as well. While not related to climate change, they can also seriously affect insurance capacity. A major earthquake in California today would be economically devastating and have a large impact on how the insurance industry could handle future catastrophes, including weather-related ones. A major earthquake in Tokyo could inflict economic losses at the trillion dollar level, with a critical impact on financial markets worldwide, and even lead to a recession.

trast, between 1970 and 1990, only three years experienced more than twenty such significant catastrophes. In constant prices, adjusted to 2004 dollars, insured losses due to weather-related events averaged $3 billion annually between 1970 and 1990 and then increased significantly to $16 billion annually between 1990 and 2004.[20] In 2005, 99.7% of all catastrophe losses worldwide were due to weather-related events.[21]

This raises several questions: What are the key drivers of the increase in these losses? More specifically, what role did socioeconomic factors play in affecting this trend? How is a change in climate likely to affect the number and severity of catastrophes in the future?

A. *The Impact of Socioeconomic Factors on Increased Losses*

At least two principal socioeconomic factors directly influence the level of economic losses due to weather-related events: degree of urbanization and value at risk.

In 1950, approximately 30% of the world's total population, then 2.5 billion people, lived in cities. In 2000, about 50% of the world's population, then 6 billion, resided in urban areas. Projections by the United Nations show that by 2025, that figure will have increased to 60% of the projected 8.3 billion people in the world. A direct consequence of this movement is the increasing number of so-called megacities with a population greater than 10 million. In 1950, New York City was the only mega-city. In 1990, there were twelve such cities. By 2015, there are expected to be twenty-six such cities, several of which are located in areas highly prone to natural hazards. Tokyo[22] is projected to lead the way, with an estimated 29 million inhabitants, followed by many others, including Shanghai (estimated at 18 million), New York (estimated at 17.6 million), and Los Angeles (estimated at 14.2 million).

In hazard-prone areas, this urbanization and increase of population translate into increased concentration of exposure. The devel-

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[20] ASS'N OF BRITISH INSURERS, FINANCIAL RISKS OF CLIMATE CHANGE 16 (2005), *available at* http://www.abi.org.uk/Display/File/Child/506/Financial_Risks_of_Climate_Change.pdf.

[21] EVAN MILLS & EUGENE LECOMTE, FROM RISK TO OPPORTUNITY: HOW INSURERS CAN PROACTIVELY AND PROFITABLY MANAGE CLIMATE CHANGE 1 (2006), *available at* http://www.ceres.org/pub/docs/Ceres_Insurance_Climate_Report_082206.pdf.

[22] Although not weather-related, the experience of the Kobe earthquake in 1995 highlights the potential for real cataclysms in the Tokyo region. An even bigger earthquake in Greater Tokyo could inflict economic losses in the range of $1 to $3 trillion.

opment of Florida is an example. The population of Florida 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 population in 2010, translating to an increase of nearly 700% since 1950.[23]

The increase in the value exposed to natural hazards amplifies the potential for severe economic and insured losses. If Hurricane Andrew had occurred in 2002 rather than 1992, it would have inflicted twice the economic losses, principally due to increasing coastal development and rising asset values in Miami-Dade County and the adjoining coastal areas affected by the storm.[24]

Florida also has a very high density of insurance coverage, with almost all houses insured against hurricanes by private insurers and about one-third of residences insured against floods under the U.S. National Flood Insurance Program (NFIP),[25] according to a study undertaken several years ago by Munich Re.[26] The modeling firm AIR Worldwide estimates that nearly 80% of insured assets in Florida today are located near the coasts, the high risk area in the state. In real terms this represents a huge amount of exposure: $1.9 trillion of commercial and residential property located in coastal areas.[27] Insurance density is thus another critical socioeconomic factor to consider when evaluating the evolution of insured losses due to weather-related catastrophes.

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[23] U.S. BUREAU OF THE CENSUS, RESIDENT POPULATION AND APPORTIONMENT OF THE U.S. HOUSE OF REPRESENTATIVES: FLORIDA 1 (2000), *available at* www.census.gov/dmd/www/resapport/states/florida.pdf; OFFICE OF ECON. & DEMOGRAPHIC RESEARCH, THE FLA. LEGISLATURE, FLORIDA DEMOGRAPHIC SUMMARY, *available at* http://edr.state.fl.us/population/popsummary.pdf.

[24] Andrew Dlugolecki, *Thoughts About the Impact of Climate Change on Insurance Claims*, *in* WORKSHOP ON CLIMATE CHANGE AND DISASTER LOSSES: UNDERSTANDING AND ATTRIBUTING TRENDS AND PROJECTIONS 54, 66 (Peter Höppe & Roger Pielke, Jr. eds., 2006), *available at* http://sciencepolicy.colorado.edu/sparc/research/projects/extreme_events/munich_workshop/full_workshop_report.pdf.

[25] The NFIP is a public insurance program created in 1968, in which insurers play the role of intermediaries between the policyholders and the federal government. Following Hurricane Katrina, the program had to borrow $20 billion from the federal government in 2006 to meet its claims. Congress is considering substantially modifying the program.

[26] MUNICH RE GROUP, TOPICS 2000: NATURAL CATASTROPHES—THE CURRENT POSITION 91 (1999).

[27] Robert P. Hartwig, Ins. Info. Inst., Hurricane Season of 2005: Impacts on U.S. P/C Insurance Markets in 2006 & Beyond, at slide 53 (Mar. 2006) *available at* http://server.iii.org/yy_obj_data/binary/744082_1_0/katrina.ppt.

Another example in the United States relates to industrial development in the Gulf of Mexico. The first offshore oil platform was built for water depths more than 100 meters in the 1960s. Today, there are numerous such platforms in the Gulf of Mexico and North Sea, two regions highly exposed to major storms. Indeed, 75% of the 4000 platforms administered by the Minerals Management Service were in the path of Hurricanes Katrina and Rita, which destroyed a large number of them. Hurricane Katrina shut down an estimated 95% of crude production and 88% of natural gas output in the Gulf of Mexico, thus inflicting major losses covered by business interruption insurance. According to the U.S. Department of Energy, two months after Katrina made landfall as a Category 3 hurricane on August 29, 2005, the shortfall of oil production was still one million barrels per day.[28] This example suggests that the economic cost and, correspondingly, the size of insurance-claim payments related to business interruption from future storms could be quite high.[29]

These factors will continue to have a major impact on the level of insured losses from natural catastrophes. Consequently, there is a need for a more granular approach to increase understanding of trends in specific areas and the opportunities to reduce losses through mitigation measures tailored to these properties. However, quantifying each of these factors—increased urbanization, inflation, increased value at risk, as well as higher density of insurance coverage—at a local level remains a challenge.

B. *Likelihood Versus Intensity*

We now turn to the second question: how is a change in climate likely to affect the number and severity of weather-related catastrophes? One of the expected effects of global warming is an increase in hurricane intensity. Higher ocean temperatures lead to an exponentially higher evaporation rate in the atmosphere, which increases the intensity of cyclones and precipitation. MIT's Kerry Emanuel recently proposed indexing potential hurricane destructiveness to the total

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[28] Erwann Michel-Kerjan, *Energy Infrastructure: Coping with Disasters*, WHARTON RISK MGMT. REV., Fall 2005, at 7, *available at* http://opim.wharton.upenn.edu/risk/review/Fall2005.pdf.

[29] It is fair to say that the impact on the energy infrastructure would have been even more devastating had a major hurricane hit a city like Houston, Texas. Such a scenario would result in large-scale property and business interruption losses for oil and chemical industry firms and their insurers.

dissipation power over the lifetime of the storm.[30] He found a large increase in power dissipation over the past thirty years and concluded that this increase may be due to the fact that "storms have become more intense, on the average, and/or have survived at high intensity for longer periods of time."[31] His study also shows that the annual average storm peak wind speed over the North Atlantic and eastern and western North Pacific has increased by 50% over the past thirty years.[32]

Another study by a group of authors published the same year indicates that the number of Category 4 and 5 hurricanes[33] worldwide has nearly doubled over the past thirty-five years.[34] In the 1970s, an average of approximately ten Category 4 and 5 hurricanes occurred annually. Since 1990, the number of Category 4 and 5 hurricanes has averaged eighteen per year. Focusing only on the North Atlantic (including the Caribbean and the Gulf of Mexico), Category 4 and 5 hurricanes have increased from sixteen in the period of 1975-1989 to twenty-five in the period of 1990-2004 (a 56% increase). The study concludes by stating that

> global data indicate a 30-year trend toward more frequent and intense hurricanes . . . . This trend is not inconsistent with recent climate model simulations that a doubling of CO_2 may increase the frequency of the most intense cyclones, although attribution of the 30-year trends to global warming would require a longer global data record and, especially, a deeper understanding of the role of hurricanes in the general circulation of the atmosphere and ocean, even in the present climate state.[35]

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[30] Kerry Emanuel, *Increasing Destructiveness of Tropical Cyclones over the Past 30 Years*, 436 NATURE 686, 686 (2005).

[31] *Id.* at 687.

[32] *Id.*

[33] 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. *See* NATIONAL WEATHER SERVICE, NATIONAL WEATHER SERVICE MANUAL: TROPICAL CYCLONE DEFINITIONS, 3-4 (2006), *available at* http://www.weather.gov/directives/sym/pd01006004curr.pdf (describing the Saffir-Simpson Hurricane Scale).

[34] P.J. Webster et al., *Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment*, 309 SCIENCE 1844, 1846 (2005).

[35] *Id.* at 1846 (footnote omitted). This significant increase in observed tropical cyclone intensities has also been linked to warming sea surface temperatures in another recent study. *See* C.D. Hoyos et al., *Deconvolution of the Factors Contributing to the Increase in Global Hurricane Intensity*, 312 SCIENCE 94, 96 (2006) ("The implication of these results is that the strong increasing trend in [Category 4 and 5 cyclones] for the period 1970-2004 is directly linked to the trend in tropical [sea surface temperature], and that other aspects of the tropical environment, although they influence shorter-

But this is not to say that there is a consensus by scientists on this issue.[36] In an article published in 2006 in *Science* magazine, Landsea and his coauthors further point out that subjective measurements and variable procedures make existing tropical cyclone databases insufficiently reliable to detect trends in the frequency of extreme cyclones. They note that "modeling and theoretical studies suggest only small anthropogenic changes to tropical cyclone intensity several decades into the future" (an increase on the order of 5% near the end of the 21st century).[37]

This conclusion is reinforced in a recent summary of articles on global climate change by Patrick Michaels, past president of the American Association of State Climatologists. He 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 mid-twentieth century.[38] Studies using data from 1970 onward begin at a cool point in the hemisphere's temperature history and hence may draw erroneous conclusions regarding global climate change and hurricane activity.[39]

The current debate in the scientific community regarding changes in the frequency and intensity of hurricanes and their relationship to global climate change is likely to be with us for a long time. The results to date do, of course, raise issues for the insurance industry to

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term variations in hurricane intensity, do not contribute significantly to the global trend of increasing hurricane intensity.").

[36] Indeed, a spirited debate persists on this issue. *Compare* Christopher W. Landsea, *Hurricanes and Global Warming*, 438 NATURE E11, E11-E12 (2005) (questioning the data used in Emanuel, *supra* note 30, by suggesting that earlier estimates of hurricane wind speed may have underestimated the true figures), *with* Roger Pielke, Jr. et al., *Are There Trends in Hurricane Destruction?*, 438 NATURE E11 (2005) (criticizing the index proposed in Emanuel, *supra* note 30, as a "misleading" indication of destructiveness), *and* Johnny C.L. Chan, *Comment on "Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment"*, 311 SCIENCE 1713b (2006) (questioning the conclusion of Webster, *supra* note 34, instead suggesting that factors such as wind shear are responsible for the observed increase in cyclone activity, and determining that "it is difficult to conclude that more intense typhoons are likely to occur in a warmer world"), *and with* P.J. Webster et al., *Response to Comment on "Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment"*, 311 SCIENCE 1713c (2006) (contending that the factors identified by Chan, *supra*, such as wind shear and moist static energy, are not correlated with hurricane intensity in a statistically significant manner).

[37] Christopher W. Landsea et al., *Can We Detect Trends in Extreme Tropical Cyclones?*, 313 SCIENCE 452, 452 (2006) (footnotes omitted).

[38] Patrick J. Michaels, *Is the Sky* Really *Falling? A Review of Recent Global Warming Scare Stories*, 576 POLICY ANALYSIS 1, 17 (2006).

[39] *Id.* at 18-19.

the extent that an increase in the number of major hurricanes over a shorter period of time is likely to translate into a higher number hitting the coasts.[40] As discussed above, hurricanes are more likely to damage a much larger number of residences and commercial buildings today than if a similar storm had occurred in the 1940s. This raises the question of whether major hurricanes in particular are insurable, and also whether large-scale disasters in general are insurable, a question to which we now turn.

III. DEALING WITH UNCERTAIN CATASTROPHIC LOSS: THE INSURABILITY CHALLENGE

Hurricane Andrew in 1992 and the Northridge earthquake in 1994 forced the insurance industry to reconsider its approach to dealing with catastrophes.[41] The dramatic increase in economic and insured losses due to weather-related events in the ensuing ten years, culminating with the seven major hurricanes that hit the United States in 2004 and 2005 and inflicted over $90 billion in insured losses, intensified this trend. Today, insurers and reinsurers are reexamining their ability to provide protection against wind damage from hurricanes and are asking whether these events are insurable and, if so, at what price.

To understand the concept of insurability, consider a standard insurance policy whereby premiums are paid at the start of a given time period to cover losses during this interval (usually a year). Two conditions must be met before insurance providers are willing to offer coverage against an uncertain event. The first is that the provider must be able to identify, quantify, and estimate the chances of the event occurring and the extent of losses likely to be incurred. The second condition is that the insurer must be able to set premiums for each potential customer or class of customers.

If both conditions are satisfied, a risk is considered to be insurable. However, it still may not be profitable. In other words, it may be impossible to specify a rate for which there is sufficient demand and incoming revenue to cover the development, marketing, operating, and claims-processing costs of the insurer and still yield a net positive profit over a prespecified time horizon. In such cases, the insurer will opt not to offer coverage against this risk.

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[40] For more discussion on this issue, see generally Dlugolecki, *supra* note 24, and Evan Mills, *Insurance in a Climate of Change*, 309 SCIENCE 1040 (2005).

[41] *See supra* note 12 and accompanying text.

The above two conditions are relevant to the climate change debate. To be clear, insurance does not cover climate change, but does cover a series of prespecified perils and causes, some of which could occur as a result of climate change or be affected by it.

A. *Determining Premiums and Coverage: Basic Concepts*

The insurance business, like any other business, has its own vocabulary. A *policyholder* is a person who has purchased insurance. A *premium* is the amount that a policyholder pays in return for the promise of a payment from the insurer should she suffer a loss covered by her policy. A *claim* means that the policyholder is seeking to recover financial payments from the insurer for damage covered by the policy. A claim will not result in a payment by the insurer if the amount of the insured's financial loss is below the stated *deductible* (i.e., the amount or proportion of an insured loss that the policyholder agrees to pay before any recovery from the insurer) or if the loss is subject to policy exclusions (e.g., war or insurrection). However, insurers will still incur expenses in investigating the claim.

Insurer *capital* represents the net worth of the company (assets minus liabilities). Capital enables the insurer to pay any losses above those that were expected. It serves as a safety net to support the risk that an insurer takes on by writing insurance and helps to ensure that the insurer will be able to honor its contracts. As such, it supports the personal safety nets of homeowners, business owners, workers, dependents of heads of households, and others who rely on insurance to provide financial compensation to rebuild their lives and businesses after covered losses occur. Insurer capital is traditionally referred to as *policyholders' surplus*: it is an essential component supporting the insurance promise. The cost of that capital is an insurer expense that must be considered in pricing insurance—along with expected losses, sales, and administrative expenses for policies written.[42]

The capital needed by an insurer varies directly as a function of the risk that the insurer assumes. If an insurer wishes to take on more

[42] Consider, for example, insurance for property damage caused by hurricanes. An insurer's expected losses are relatively low, because in a typical year, the policyholder will not suffer a hurricane loss. However, it is possible that losses will be quite high—far in excess of those expected at the time policies are priced. In the event of a serious hurricane, a substantial portion of the loss must be paid from insurer capital. For other extreme events, such as terrorism, maximum losses are extremely high relative to expected losses, so the capital issue is critical.

risk, it must have capital to support the additional coverage it offers against that risk. *Insurance regulators* and *rating agencies* devote significant efforts toward evaluating the adequacy of the insurer capital relative to the amount and types of risk they are taking on (a) to assure policyholders that they will be able to recoup their claims following a large-scale disaster and (b) to assure investors in insurance companies that the latter have achieved a certain level of financial strength. Adequate capitalization is thus critical to the continued viability of an insurer.

Insurance markets function best when the losses associated with a particular risk are independent of each other and the insurer has accurate information on the likelihood of the relevant events occurring and the resulting damage. By selling a large number of policies for a given risk, the insurer is likely to have an accurate estimate of the claim payments it expects to make during a given period of time. To illustrate this point with a simple example, consider an insurer who provides fire insurance to a set of identical homes each valued at $100,000. Using historical data, the insurer estimates that there is a 0.1% chance that each home will be destroyed by fire next year. In this case, the expected annual loss for each home from fire would be $100 (i.e., 1/1000 × $100,000).

If the insurer issued only a single policy to cover the full loss from a fire, then there would be a variance of approximately $100 associated with its expected annual loss.[43] As the number of policies issued (n) increases, the variance of the expected annual loss, or the mean loss per policy, decreases in proportion to n. Thus, if $n = 10$, the variance of the mean loss will be approximately $10. When $n = 100$, the variance decreases to $1, and when $n = 1000$, the variance is $0.10. It is thus not necessary to issue a very large number of policies to reduce significantly the variability of expected annual losses per policy if the risks are independent. This insurance model works well for risks such as fire, automobile, and loss of life because they satisfy the assumptions of independence and the ability to estimate probabilities and losses. Risks associated with climate change do not satisfy the above conditions, however, so they are more problematic to insure.

[43] The variance for a single loss L with probability p is $Lp(1\text{-}p)$. If L = $100,000 and $p = 1/1000$, then $Lp(1\text{-}p)$ = $100,000(1/1000)(999/1000) or $99.90.

B. *Risk, Ambiguity, Uncertainty, and Ignorance*

An important element when it comes to climate change and insurance is the distinction between "risk" and "uncertainty." An event is considered to be *risky* when the probabilities that certain states will occur in the future are precisely known, such as in a fair roulette game. In contrast, a risk is *uncertain* when the probabilities are not precisely known. Examples of uncertainty are the likelihood of a terrorist attack in New York City or the chance of a Category 5 hurricane hitting the coast of Florida in the next twelve months.

The term *uncertainty* is often used interchangeably with the term *ambiguity*, which implies that there are vague beliefs about the likelihood of events occurring. If people are not able to form any beliefs about probabilities, this special case is termed *complete ignorance*.[44] Similar distinctions can be made relative to the outcome. Based on current knowledge, the likelihood and consequences of weather-related events associated with climate change are characterized by high levels of uncertainty.

C. *Modeling Catastrophe*

Before insurance providers are willing to offer coverage against an uncertain event, they must be able to identify and quantify, or at least partially estimate, the chances of the event occurring and the extent of losses likely to be incurred. Such estimates can be based on past data (for example, loss history of the insurer's portfolio of policyholders or loss history in a specific region) coupled with data on what experts know about a particular risk through the use of catastrophe models.

The four basic components of a catastrophe model, as depicted in Figure 3, are hazard, inventory, vulnerability, and loss and are herein illustrated for a natural hazard such as a hurricane. First, the model determines the risk of the *hazard* phenomenon, which in the case of a hurricane is characterized by its projected path and wind speed. Next, the model characterizes the *inventory* (or portfolio) of properties at risk as accurately as possible. This is done by first assigning geographic coordinates to a property and then determining how many structures in the insurer's portfolio are at risk from hurricanes of dif-

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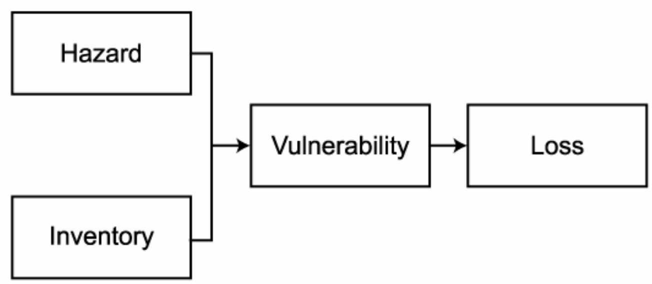
[44] *See* Colin Camerer & Martin Weber, *Recent Developments in Modeling Preferences: Uncertainty and Ambiguity*, 5 J. RISK & UNCERTAINTY 325, 325-26 (1992) (discussing situations in which individuals are unable to characterize ambiguous risks).

ferent wind speeds and projected paths. After identifying each property's spatial location, other factors are considered, including its construction type, the number of stories in the structure, and its age.

Figure 3: Structure of Catastrophe Models



The hazard and inventory modules enable one to calculate the *vulnerability*, or susceptibility, to damage of the structures at risk. In essence, this step in the catastrophe model quantifies the physical impact of the natural hazard phenomenon on the property at risk. How this vulnerability is quantified differs from model to model. Once it is calculated, the *loss* to the property inventory is evaluated. In a catastrophe model, loss is characterized as direct or indirect in nature. Direct losses include the cost to repair or replace a structure, which must anticipate future increases in cost of material and workforce due to the demand surge in the aftermath of a major disaster. Indirect losses include business interruption and the expense of relocating residents who are forced to evacuate their homes.

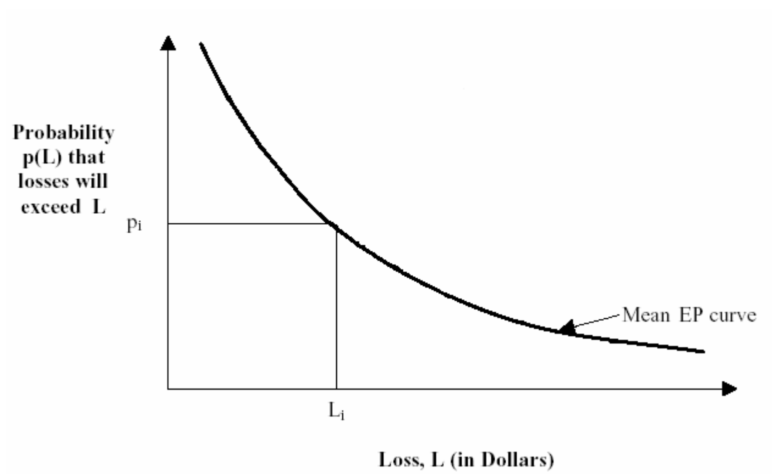
D. *Exceedance Probability Curves*

Based on the outputs of a catastrophe model, the insurer can construct an exceedance probability (EP) curve that specifies the probability that a certain level of losses will be exceeded in a specific location (or in its entire portfolio) over a specific period of time (for example, one year, ten years, etc.). These losses can be measured in dollars of damage, fatalities, illness, or some other unit of analysis.

Suppose one were interested in constructing an EP curve for an insurer with a given portfolio of insurance policies covering hurricane wind damage in a southeastern United States coastal community. One would combine the set of events that could produce a given dollar loss and then determine the resulting probabilities of exceeding losses of different dollar magnitudes. Based on these estimates, one can construct a mean EP curve, such as the one depicted in Figure 4. The *x*-axis measures the loss to the insurer in dollars and the *y*-axis depicts the probability that losses will exceed a particular level. Suppose the insurer focuses on a specific loss, L_i. One can see from Figure 4 that the likelihood that insured losses exceed L_i is given by p_i.

An insurer utilizes its EP curve to determine how many structures it will want to include in its portfolio. More specifically, if the insurer wanted to reduce the probability that a loss from hurricanes exceeding L_i will occur below p_i, it will have to select one of several options. It could reduce the number of policies in force for these hazards, increase the premium it charges, or decide not to offer this type of coverage at all.

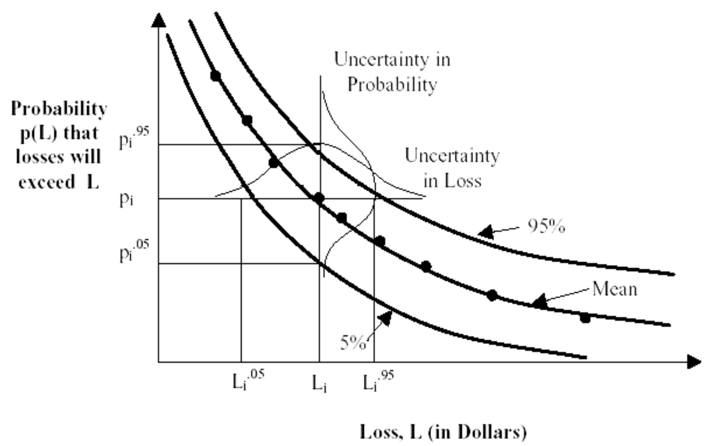
Figure 4: Sample Mean Exceedance Probability Curve



Government agencies may want to use EP curves to estimate the likelihood that losses to specific communities or regions from natural disasters will exceed certain levels. This, in turn, will help determine the likelihood that the government will need to provide disaster assistance to these stricken areas. At the start of the hurricane season in 2004, Florida could have used an EP curve to estimate the likelihood of insured damage exceeding $23 billion. This probability would have been extremely low, but we now know that a confluence of major events (Hurricanes Charley, Frances, Ivan, and Jeanne) produced aggregate losses that exceeded this dollar value. This raises the question of how confident we are in the construction of a specific EP curve.

The uncertainty surrounding an EP curve is reflected in the 5% and 95% confidence interval curves shown in Figure 5. The curve depicting the uncertainty in loss shows a range of values, $L_i^{.05}$ and $L_i^{.95}$ that losses can take for a given mean value, L_i, so that there is a 95% chance that the loss will be exceeded with probability p_i. In a similar vein, one can determine the range of probabilities $p_i^{.05}$ and $p_i^{.95}$ so that there is 95% certainty that losses will exceed L_i. For low probability, high consequence risks, the spread between the 5% and 95% confidence intervals depicted in Figure 5 can be significant.

Figure 5: Confidence Intervals for a Mean Exceedance Probability (EP) Curve



The EP curve serves as an important tool for evaluating risk management strategies. It puts pressure on experts to make explicit the assumptions on which they base their estimates of the likelihood of certain events occurring and the resulting consequences. The more specific the EP curve, the higher the uncertainty associated with the estimates is likely to be. Thus, the EP curve for a particular insurer's exposure to hurricane claims in Miami will be much more uncertain than the EP curve for the hurricane exposure of the entire industry in the southeastern United States.

E. *Application to Florida: Focus on Hurricane Risks*[45]

Risk Management Solutions (RMS) has provided us with an analysis of the data from the Florida Hurricane Catastrophe Fund (FHCF) book of business as of 2005. Since the FHCF is a state-mandated reinsurance program, it has every residential insurance policy written in the state. 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.[46]

Table 2 provides estimates of the annual probability that insured wind losses from hurricanes will equal or exceed different magnitudes for eighteen thresholds ranging from $1 billion to $350 billion. More specifically, there is a 42.5% 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% and there is a 1.7% chance that insured losses will be at least $50 billion.

Table 2: Exceedance Probability of Insured Residential Losses in Florida (in billions of dollars)[47]

$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%

As one 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

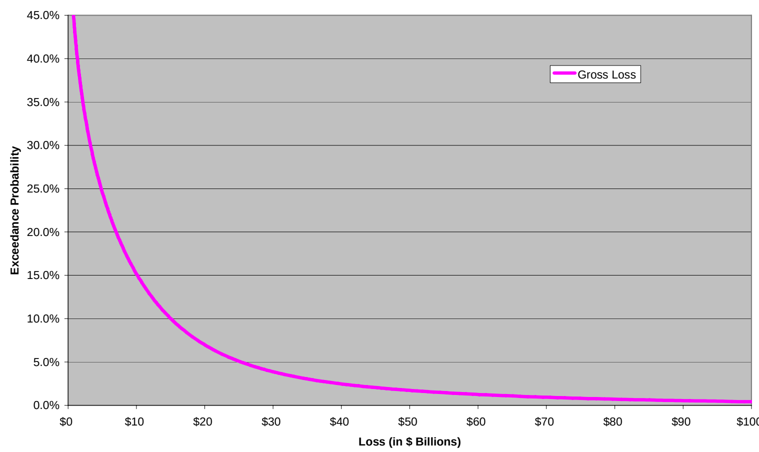
[45] We would like to thank Jack Nicholson of the Florida Hurricane Catastrophe Fund (FHCF) for providing us with the FHCF database and Patricia Grossi and Robert Muir-Wood of Risk Management Solutions (RMS) for their analyses of the FHCF data. They provided us with the relevant EP curves and tables presented in this section.

[46] For purposes of this Article, we use the new generation of models developed by RMS in 2006.

[47] MANAGING LARGE-SCALE RISKS, *supra* note 13, at 25 tbl.2.2.

is less than 0.5%. 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 generate the entire exceedance probability curve for the FHCF. Figure 6 provides this curve for losses up to $100 billion.

Figure 6: Exceedance Probability Curve for Florida (Entire FHCF Portfolio) for Insured Losses from Hurricanes up to $100 Billion[48]



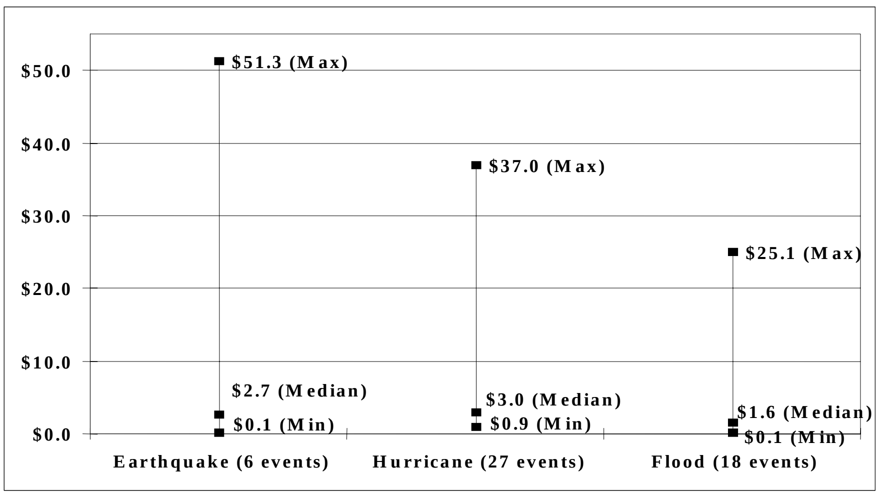
In order to measure the uncertainty surrounding these estimates, one needs to utilize data on the average annual expected losses and the standard deviation for each ZIP code in the state. For all ZIP codes combined, we found that the average annual expected loss for Florida residential insurance is $5.4 billion and the standard deviation is $13.9 billion (a 2.55 coefficient of variation).

Extreme events, such as natural disasters, are thus particularly challenging for insurers because they involve potentially high losses that are extremely uncertain. Figure 7 illustrates the total number of loss events between 1950 and 2000 in the United States for three prevalent natural hazards: earthquakes, floods, and hurricanes. Events were selected that had at least $1 billion of economic damage

[48] *Id.* at 26 fig.2.8.

and/or over fifty deaths.[49] Looking across all the disasters of a particular type (earthquake, hurricane, or flood) for this fifty-year period, the median loss is low, while the maximum loss is very high. Given this wide variation in loss distribution, it is not surprising that insurers are concerned about uncertainty when they estimate premiums, or even when they decide whether to provide any coverage in certain hazard-prone areas.

Figure 7: Historical Economic Losses in Billions of Dollars Versus Type of Significant U.S. Natural Disaster for the Fifty-Year Period from 1950 to 2000



In the case of natural disasters, the future is likely to be different from the past. As discussed earlier, among the twenty most costly insurance losses from catastrophes between 1970 and 2005, ten occurred after 2000.[50] The 2004 and 2005 seasons dramatically changed the upper limits in Figure 6. Hurricane Katrina in 2005 is said to have caused between $150 billion and $170 billion in economic losses, more than four times higher than those inflicted by the most costly

[49] Press Release, American Re Publishes Topics "Annual Review of North American Natural Catastrophes 2001" (May 8, 2002), *available at* http://www.munichreamerica.com/content/press/topics_05-8-02.htm.

[50] *See supra* notes 6-9 and accompanying text.

hurricane between 1950 and 2000. In 2006, not a single major hurricane hit the United States.

F. *Determining Whether To Provide Coverage*

Based on its knowledge of likelihood and outcome, an insurer still has to make a decision as to whether to cover the risk (unless it is required to do so by law). In his study on insurers' decision rules regarding when they would market coverage for a specific risk, Stone[51] develops a model whereby firms maximize expected profits subject to satisfying a constraint related to the survival of the firm.[52] An insurer satisfies its survival constraint by choosing a portfolio of risks with an overall expected probability of total claims payments greater than some predetermined amount, L^*, that is less than some threshold probability, p_1. This threshold probability reflects the tradeoff between the expected benefits of insuring another risk and the costs to the firm of a catastrophic loss that reduces the insurer's surplus by L^* or more. This threshold probability does not necessarily correspond to what would be efficient for society. The value of L^* is determined by an insurer's concern with insolvency and/or a sufficiently large loss in surplus, which may lead a rating agency to downgrade its credit rating.

A simple example illustrates how an insurer would utilize its survival constraint to determine whether a particular portfolio of risks is insurable with respect to hurricanes. Assume that all homes in a hurricane-prone area are identical and equally resistant to damage such that the insurance premium, z, is the same for each structure. Further, assume that an insurer has A dollars in current surplus and that it wants to determine the number of policies it can write and still satisfy its survival constraint. Then, the maximum number of policies, n, satisfying the survival constraint is given by:

$$\textit{Probability}\ [\textit{Claims Payments}\ (L^*) > (n \times z + A)] < p_1.$$

[51] *See* James M. Stone, *A Theory of Capacity and the Insurance of Catastrophe Risks*, pts. 1&2, 40 J. RISK & INS. 231, 339 (1973).

[52] Stone also introduces a constraint regarding the stability of the insurer's operation. *See* Stone (pt. 1), *supra* note 51, at 232 (recognizing the stability constraint and suggesting it results from investors' and managers' preferences for "some regularity"). However, insurers have traditionally not focused on this constraint in the context of catastrophic risks.

The insurer will use the survival constraint to determine the maximum number of policies it is willing to offer, possibly with an adjustment in the amount of coverage and premiums and/or a transfer of some of the risk to others in the private sector, such as reinsurers or capital markets. It may also rely on governmental programs to cover its catastrophic losses.

Following the series of natural disasters that occurred at the end of the 1980s and in the 1990s, insurers focused on the survival constraint to determine the amount of catastrophe coverage they were willing to provide because they wanted to ensure that their aggregate exposure to a particular risk did not exceed a certain level. This was driven, at least in part, by rating agencies such as A.M. Best, which considered insurers' exposure to catastrophic losses as a relevant element in determining credit ratings.

At that time, the insurance industry was unaware of the potentially large losses they could suffer from natural disasters. More specifically, some insurers were surprised at the magnitude of their losses from Hurricane Andrew in 1992 and the Northridge earthquake in 1994. In fact, following Hurricane Andrew, many insurers only marketed coverage against wind damage in Florida because they were required to do so and state insurance pools were formed to limit their risk.[53] In California, insurers refused to renew homeowners' earthquake policies after the 1994 Northridge earthquake, and in their place the California Earthquake Authority was formed by the state in 1996 with funds from insurers and reinsurers.[54]

G. *Setting Premiums*

If the insurer decides to offer coverage, it needs to determine a premium rate that yields a profit and satisfies the survival constraint given by the above equation. State regulations often limit insurers in their rate-setting process. Competition may also limit what premium can be charged in a given marketplace. Even in the absence of these influences, an insurer must consider problems associated with the *am-*

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[53] *See* MARTIN F. GRACE ET AL., CATASTROPHE INSURANCE: CONSUMER DEMAND, MARKETS AND REGULATION 62-64 (2003) (noting that Florida imposed a moratorium on policy terminations after Hurricane Andrew and discussing the pools set up by the state to insure those unable to obtain coverage in the voluntary market).

[54] Richard J. Roth, Jr., *Earthquake Insurance Protection in California*, *in* PAYING THE PRICE: THE STATUS AND ROLE OF INSURANCE AGAINST NATURAL DISASTERS IN THE UNITED STATES 67, 69-78 (Howard Kunreuther & Richard J. Roth, Sr. eds., 1998).

biguity of the risk, the asymmetry of information (*adverse selection* and *moral hazard*), and the degree of *correlation* of the risk in determining what premium to charge. We will examine each of these factors in turn.

1. Impact of the Ambiguity of the Risk

The infrequency of major catastrophes in a single location implies that the loss distribution is not well specified. The ambiguities associated with the probability of an extreme event and with the outcomes of such an event raise a number of challenges for insurers when they price their policies. As shown by a series of empirical studies, actuaries and underwriters are averse to ambiguity and want to charge much higher premiums when the likelihood and/or consequences of a risk are highly uncertain than when these components of risk are well specified.

Kunreuther and his co-authors conducted a survey of 896 underwriters in 190 randomly chosen insurance companies to determine what premiums would be required to insure a factory against property damage from a severe earthquake.[55] The survey examined changes in pricing strategy as a function of the degree of uncertainty in either the probability and/or the loss. A probability was considered to be well specified when there was enough historical information on an event that all experts agreed that the probability of a loss was p. When there was wide disagreement about the estimate of p among the experts, they referred to this ambiguous probability as Ap. L represents a known loss reflecting a general consensus as to what insurers' claims would likely be in the event of a disaster. When the experts' estimates range between L_{min} and L_{max}, this uncertain loss is denoted as UL. Combining the degree of probability and loss uncertainty leads to the four cases shown in the columns of Table 3.

To see how underwriters reacted to different situations, four scenarios were constructed, as shown by the rows in Table 3. The probability of the earthquake, where the risk is well specified, is either 0.01 or 0.005; the loss, should the event occur, is either $1 million or $10 million. The premium set by the underwriter is standardized at one for the nonambiguous case. One can then examine how ambiguity affects pricing decisions.

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[55] Howard Kunreuther et al., *Ambiguity and Underwriter Decision Processes*, 26 J. ECON. BEHAV. & ORG. 337, 342-44 (1995).

Table 3 shows the ratio of the other three cases relative to the nonambiguous case (*p,L*) for the four different scenarios, which were distributed randomly to underwriters in primary insurance companies. For the highly ambiguous case (*Ap,UL*), the premiums were significantly higher than if underwriters priced a nonambiguous risk. The ratios for the other two cases were always above 1, but less than the *Ap,UL* case. Since measuring the impact of global warming on the likelihood and consequences of weather-related catastrophes is even more ambiguous than measuring the earthquake risk, one would expect the ratio of *Ap,UL* relative to *p,L* to be higher if underwriters were asked the same questions for setting the corresponding premiums for these disasters.

Table 3: Ratios of Underwriters' Premiums for Ambiguous or Uncertain Earthquake Risks Relative to Well-Specified Risks[56]

Scenario	Cases				
	1	2	3	4	
	p,L	*Ap,L*	*P,UL*	*Ap,UL*	N**
p = .005 *L* = $1 million	1	1.28	1.19	1.77	17
p = .005 *L* = $10 million	1	1.31	1.29	1.59	8
p = .01 *L* = $1 million	1	1.19	1.21	1.50	23
p = .01 *L* = $10 million	1	1.38	1.15	1.43	6

The nature of the ambiguity is also important. Recent research shows, for instance, that insurers are sensitive to sources of ambiguity. Cabantous provides the results of an insurers' survey in France. The seventy-eight actuaries surveyed typically charged a much higher premium when ambiguity came from conflict and disagreement regarding the probability of a loss than when the ambiguity came from imprecision (i.e., an imprecise forecast).[57]

[56] Howard Kunreuther, *Insurability Conditions and the Supply of Coverage*, *in* PAYING THE PRICE, *supra* note 54, at 17, 34 tbl.2-1. Ratios are based on mean premiums across number of respondents for each scenario. N = number of respondents.

[57] Laure Cabantous, *Ambiguity Aversion in the Field of Insurance: Insurers' Attitude to Imprecise and Conflicting Probability Estimates*, 62 THEORY & DECISION 219, 235 (2007).

There also are other insurability issues that result from the asymmetry of information that exists between the insurers and the insured.

2. Adverse Selection

Suppose that the insurer cannot differentiate the risks facing two groups of potential insurance buyers and that each buyer knows her own risk. In this case, the insurer is likely to suffer losses if it sets the same premium for both groups by using the entire population as a basis for this estimate. Then only the highest-risk group is likely to purchase coverage for that hazard and the premium is below the insured's expected loss, meaning that the insurer will have a portfolio of "bad" risks. This situation, referred to as *adverse selection*, can be rectified if the insurer charges a high enough premium to cover the losses from the bad risks. In so doing, the good risks might purchase only partial protection or no insurance at all because they consider the price of coverage to be too expensive relative to their risk.[58]

The problem of adverse selection only emerges in unregulated markets if those considering the purchase of insurance have more accurate information on the probability of a loss than the firms selling coverage. If the policyholders and insurers both cannot distinguish their risks, then coverage will be offered at a single premium based on the average risk and both good and bad risks will want to purchase policies.

In the context of climate change, adverse selection is not likely to be a problem, as there is no evidence that those at risk have an informational advantage over the insurer. In fact, the opposite might be true: if insurance companies spend significant resources estimating the risk, they might gain an informational advantage over their policyholders who cannot afford that costly risk assessment or do not want to do so. Over the past five or six years, there has been a growing literature studying the impact of insurers being *more* knowledgeable about the risks than the insureds themselves. Research in this field reveals that insurers might want to exploit this "reverse information asymmetry," which results in low risks being optimally covered while high risks are not.[59]

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[58] For a survey of adverse selection issues, see Georges Dionne et al., *Adverse Selection in Insurance Markets*, *in* HANDBOOK OF INSURANCE 185 (Georges Dionne ed., 2000).

[59] *See* Dominique Henriet & Erwann O. Michel-Kerjan, Optimal Risk-Sharing Under Dual Asymmetry of Both Information and Market Power: A Unifying Approach 20 (June 7, 2006) (unpublished working paper, *available at* http://

3. Moral Hazard

The concept of "moral hazard" refers to an increase in the expected loss (probability or amount of loss conditional on an event occurring) caused by insurance-induced changes in the behavior of the policyholder. An example of moral hazard is more careless behavior on the part of the insured vis-à-vis natural hazards or other types of risk as a result of purchasing coverage. Providing insurance protection may lead the policyholder to change behavior in ways that increase the expected loss from what it would have been without coverage. If the insurer cannot predict this behavior and relies on past loss data from uninsured individuals to estimate rates, the resulting premium is likely to be insufficient to cover losses.

Even after the insurer is aware that people with insurance have higher losses, its inability to observe loss-enhancing behavior may create problems of moral hazard. The introduction of specific deductibles, coinsurance, or upper limits on coverage can be useful tools for reducing moral hazard by encouraging insureds to engage in less risky behavior, as they know they will have to incur part of the losses from an adverse event. It is unclear whether moral hazard plays a role in the context of global climate change.

4. Correlated Risks

For extreme events, the potential for high correlation between the risks impacts the tail of the distribution. In other words, at a predefined probability p_i, the region below the EP curve is likely to expand for higher correlated risks covered by insurers. This requires additional capital for the insurer to protect itself against large losses. Even risks that are assumed to be independent, such as fire, can be highly correlated. For example, the Oakland conflagration of October 20, 1991 damaged or destroyed 3000 structures for a total insured loss of $1.7 billion. More recently, the fires in Southern California between October 23 and November 6, 2003, destroyed over 750,000 acres of land and approximately 4000 residential properties.[60]

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opim.wharton.upenn.edu/risk/library/06-10.pdf) ("[W]hen the insurer is better informed than the insured about risk, then whatever his position (principal or agent), that is whatever his bargaining power, low risk is better insured than high risk.").

[60] Pat West, *Lessons Learned from Southern California's Firestorms Released*, FIRE CHIEF, Jan. 23, 2004, *available at* http://firechief.com/news/firefighting_lessons_learned_southern.

Hurricanes Katrina and Rita, which devastated the U.S. Gulf Coast in August and September of 2005, dramatically impacted several lines of insurance, including life, property damage, and business interruption. Edward Liddy, Chairman of Allstate, which provided insurance coverage to 350,000 homeowners in Louisiana, Mississippi, and Alabama, declared:

> Extensive flooding, particularly in New Orleans, has complicated disaster planning . . . . [y]et the high water has essentially halted efforts to assess the damage . . . .
>
> . . . .
>
> . . . We now have 1,100 adjusters on the ground . . . . We have another 500 who are ready to go as soon as we can get into some of those most-devastated areas. . . .
>
> . . . .
>
> . . . It will be many weeks, probably months, before there are anything approaching reliable estimates.[61]

IV. OTHER STAKEHOLDERS AFFECTING INSURERS' DECISIONS

Our analysis of insurability would not be complete without considering the environment in which insurers have to make decisions. There are several other important players whose actions affect insurers' decisions on whether to provide coverage against certain risks and, if so, how much to offer and what price to charge. We discuss the roles of five key parties: reinsurers, insurance commissioners, rating agencies, modeling firms, and investors.

A. *Reinsurers*

How much coverage an insurer can provide in a certain area depends also on what portion of its exposure it can transfer to reinsurers. Reinsurers provide protection to private insurers in much the same way that insurers provide coverage to their policyholders. They charge a premium to indemnify an insurance company against a layer of catastrophic losses that the insurer would otherwise be responsible for covering. Reinsurers are also concerned with their concentration

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[61] Theo Francis, *CEO Says Allstate Adjusts Storm Plan*, WALL ST. J., Sept. 6, 2005, at C1.

of risk and thus restrict their exposure in catastrophe-prone areas to keep the probability of a severe loss at an acceptable level. Large reinsurers who operate worldwide can diversify their risk geographically and per line of coverage much more easily than most insurers can.

Reinsurers typically play a key role in sharing a significant portion of the insured losses with the insurers. For example, reinsurers paid about 50% of the insured losses due to Hurricane Katrina. As a result of the 2004 and 2005 hurricane seasons, the price of catastrophe reinsurance in the United States increased significantly and there is considerable uncertainty concerning the availability of coverage and the resulting prices in the coming year. It should not come as a surprise that the two largest reinsurers in the world, Swiss Re and Munich Re, have been active in climate change research for some time now.

B. *Capital Markets*

Capital markets emerged in the 1990s as a complement to reinsurance for covering large losses from natural disasters through new financial instruments. Examples of these instruments include industry loss warranties, catastrophe bonds, and, more recently, sidecar reinsurers.

The shortage of reinsurance following Hurricane Andrew in 1992 and the Northridge earthquake in 1994 led to higher reinsurance prices and made it appealing for insurers to offer catastrophe bonds with high enough interest rates to attract capital from investors. In addition, the prospect of an investment that is uncorrelated with the stock market or with general economic conditions is attractive to capital market investors. Finally, catastrophe models have emerged as a tool for more rigorously estimating loss probabilities, so disaster risk can be more accurately quantified—and priced—than in the past.

Since Hurricane Katrina, there has been a significant increase in the number and volume of catastrophe bond issuances and the creation of sidecars, but the total volume of financial protection remains somewhat limited relative to what is currently provided by traditional reinsurance. Hence, there is a need to assess the constraints on the availability and volume of securities that diversify catastrophe risk and how the use of these vehicles could be expanded to augment reinsurance capacity.

The 2005 hurricane season led insurers and reinsurers to use alternative risk transfer instruments with unprecedented frequency. For instance, the market for catastrophe bonds recorded a total issuance of over $2.1 billion in 2005, a 75% increase over the $1.14 billion issuance in 2003 (the previous record holder). For the first five months in 2006, the total issuance was close to the total capital issued for the entire year of 2005.[62]

C. *State Insurance Commissioners*

In the United States, insurance is regulated at the state level, with the principal authority residing with insurance commissioners. Domestic reinsurers are subject to solvency regulation but not to rate or policy form regulation. Solvency regulation addresses the question of whether the insurer or reinsurer is sufficiently capitalized to fulfill its obligations if a significant event occurs and inflicts major losses on its policyholders. Insurance commissioners regard solvency as a concern even if it means requiring higher premiums. On the other hand, they want insurance to be sold at affordable prices. In balancing the solvency and consumer protection goals, insurance regulators are concerned that rates are adequate, not excessive, and not unfairly discriminatory. These terms are somewhat imprecise, so regulators have some latitude in controlling insurer behavior.

In March 2006, the National Association of Insurance Commissioners (NAIC) established a task force to study how climate change may affect the availability and affordability of insurance for consumers and the financial health of insurance companies. The task force, led by Tim Wagner, Director of the Nebraska Department of Insurance, and Mike Kreidler, Insurance Commissioner for the State of Washington, will also consider actions that would enable state regulators and insurers to work together to mitigate risks associated with climate change.[63]

D. *Modeling Firms*

As discussed above, many insurance and reinsurance companies have turned to firms specializing in the business of modeling catastrophe risks to assist them in determining how much coverage to offer and what premiums to charge for losses from natural disasters. Over the past ten years, these companies have become important players in

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[62] MANAGING LARGE-SCALE RISKS, *supra* note 13, at 105.

[63] *See Regulators Establish Task Force on Climate Change*, INS. J., Mar. 14, 2006, *available at* http://www.insurancejournal.com/news/national/2006/03/14/66451/htm?print=1 (reporting the establishment of the task force and its objectives).

the field of catastrophe insurance and reinsurance. As a result of the 2005 hurricane season, Risk Management Solutions, one of the leading catastrophe modeling firms, announced in March 2006 that changes of hurricane landfall frequencies in its new model will increase its estimates of average annual insurance losses by 40% across the Gulf Coast, Florida, and the Southeast. The new model also increased RMS's annual insurance loss predictions by 25% to 30% in the mid-Atlantic and Northeast coastal regions from its former predictions.[64]

This revised view of hurricane risk is driven by an increase of more than 30% in the modeled frequency of major hurricanes (Category 3-5) in the Atlantic basin that is expected to persist for at least the next five years. How the insurance market and regulators will react to this new dimension is still an open issue and will certainly depend on estimates by the other two leading modeling firms, AIR Worldwide and EQECAT, both of whom have adjusted their estimates upward by a much smaller percentage than has RMS. However, both of these firms offer a near-term model reflecting higher rates due to current warming of sea surface temperatures, which they expect to cause an increase in hurricane activity.[65]

E. *Rating Agencies*

Rating agencies, such as A.M. Best, Standard & Poor's, Moody's, and Fitch, provide independent evaluations of insurers' and reinsurers' financial stability and their ability to meet their obligations to policyholders. The rating assigned to an insurer or reinsurer has significant consequences with respect to the premiums it can set and its ability to raise capital. For example, many large publicly traded companies require their insurers to have a rating above a certain minimum level. Similarly, insurers are less willing to cede their risks to a poorly rated reinsurer. A low rating has an impact on the premium an insurer or reinsurer can charge or the amount of coverage it is able to sell. It is also likely to have a negative effect on the share price of publicly traded firms.

To illustrate how ratings are determined, consider A.M. Best. It undertakes a quantitative analysis of an insurer's balance sheet

[64] Press Release, Risk Mgmt. Solutions, New RMS View of U.S. Hurricane Activity Rates Increases Losses by 40% in Fla. and Gulf Coast (Mar. 23, 2006), *available at* http://www.rms.com/NewsPress/PR_2006_0323_HUActivityRates.asp.

[65] *See supra* Part II.

strength, operating performance, and business profile. Evaluating catastrophe exposure plays a significant role in the determination of ratings, as catastrophes are events that could threaten the solvency of a company. Projected losses from disasters occurring at specified return periods (e.g., 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.

For several years now, A.M. Best has been requesting such information on natural disasters. Its approach has been an important step toward incorporating catastrophe 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 (for example, a 100-year windstorm or 250-year earthquake, depending on the nature of the primary risk to which the insurer was exposed) in its calculation of a company's risk-adjusted capitalization. In 2006, A.M. Best introduced a second event as an additional stress test. The PML used for the second event is the same as for the first event in the case of a severe hurricane (which is considered to be an independent, 1-in-100-year event). If the main exposure facing the insurer is an earthquake, however, the second event is reduced from a 1-in-250-year event to a 1-in-100-year event (as the occurrence of one earthquake reduces the probability that another severe earthquake will occur in the short term).[66]

F. *Investors*

The large increase in insured losses in the last ten years, the changes in the catastrophic risk models in 2006, and the requirement by rating agencies to include a second stress test have important consequences for determining the insurability of hurricanes and other natural disasters. Moreover, recent catastrophes have revealed a much higher degree of volatility for any given portfolio than was observed in the past. This will also have an impact on the cost of capital to insurers and reinsurers. With higher volatility, investors will demand a higher return on equity. This requires insurers to restrict their coverage, charge higher premiums, and improve their exposure management. Parallel to this, if the price of insurance or reinsurance

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[66] A.M. BEST, METHODOLOGY: CATASTROPHE ANALYSIS IN A.M. BEST RATINGS 2-3 (2006), *available at* http://www.ambest.com/ratings/methodology/catastrophe.pdf.

is high, opportunities for investors to launch new companies will increase, as they did after the 2005 hurricane season.

V. ANOTHER UNCERTAINTY FACING INSURERS: LIABILITY FROM CLIMATE CHANGE

We now turn to the following related issue facing insurers: their potential liability for losses claimed to have been due to climate change induced by their policyholders (i.e., firms). For example, the issue could arise from legal actions against executives for failing to report to their shareholders some of the climate-related risks faced by the company. We first address the liability question by examining the role that tort law plays in holding individuals accountable for damage and discuss the current debate regarding its applicability to climate change. We then examine the role of Directors' and Officers' liability insurance (D&O) in the context of climate change risks. The section concludes with a brief discussion of how companies can be encouraged by insurance to mitigate future damage from climate change.

The first carbon dioxide lawsuit in the United States was filed in July 2004. Eight states and New York City sued five large electricity utilities comprising the country's biggest emitters of carbon dioxide and operating 174 power plants in twenty states. Although the case was dismissed,[67] the use of liability as a wedge for climate policy action may play a greater role in coming years. If this case had not been dismissed, the insurers of the five utilities could have been financially responsible for the damage settlement and the court costs.

One of the open issues is whether tort law is appropriate for holding firms financially accountable for specific losses suffered by others because their actions were partially responsible for global warming. As Michael Faure and David Grimeaud note, the first goal of tort law is to minimize the sum of accident costs and the costs of accident avoidance—in other words, to minimize the total cost of accidents.[68]

Steven Shavell[69] has laid out a simple analytic model for determining the level of care, x, that should be taken by a potential victim, A, and the level of care, y, that should be taken by a potential injurer, B, to minimize total expected cost $[C(x,y)]$ where:

[67] Some states may, however, appeal this judgment.

[68] Michael Faure & David Grimeaud, *Principles of Liability: A Theoretical Framework*, *in* DETERRENCE, INSURABILITY, AND COMPENSATION IN ENVIRONMENTAL LIABILITY 19-20 (Michael Faure ed., 2003).

[69] STEVEN SHAVELL, ECONOMIC ANALYSIS OF ACCIDENT LAW 32-46 (1987).

$$C(x,y) = p(x,y)\ L + A(x) + B(y)$$

$p(x,y)$ = probability of an accident

L = the magnitude of the resulting loss.

This model is appropriate for cases where both $p(x,y)$ and L are well defined. However, it is difficult to characterize these parameters with respect to global climate change based on our current state of scientific knowledge.

Despite this element of uncertainty, litigation has emerged regarding global warming, with respect to carbon dioxide lawsuit emissions, as noted above. In another recent case, *Massachusetts v. EPA*,[70] twelve states and several cities and organizations (plaintiffs) challenged the denial of a petition asking the Environmental Protection Agency (EPA) to regulate carbon dioxide and other GHG emissions from new motor vehicles. Indeed, the EPA administrator determined in 2003 that the Agency lacked authority under the Clean Air Act to regulate carbon dioxide. But section 202(a)(1) of the Clean Air Act[71] actually requires the EPA Administrator to set emission standards for "any air pollutant" from motor vehicles or motor vehicle engines that "in his judgment cause[s], or contribute[s] to, air pollution which may reasonably be anticipated to endanger public health or welfare."[72] Originally, there was controversy among the three circuit court judges. Judge Randolph ruled for the EPA, given uncertainty with respect to the relationship between motor vehicle emissions, GHGs, and climate change.[73] Judge Tatel, on the other hand, found that the plaintiffs had standing because a rise in sea level would hurt Massachusetts, and that sea level rises were caused by human emissions.[74] The third judge, Judge Sentell, felt that causation was uncertain but he could not review the EPA's position without first giving Massachusetts standing.[75]

This case was argued in front of the U.S. Supreme Court on November 29, 2006 and decided on April 2, 2007. The Court decided in

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[70] 127 S. Ct. 1438 (2007).

[71] 42 U.S.C. § 7521(a)(1) (2000).

[72] *Id.*

[73] *Massachusetts v. EPA*, 415 F.3d 50, 58 (D.C. Cir. 2005), *rev'd*, 127 S. Ct. 1438 (2007).

[74] *See id.* at 64-74 (contending that Massachusetts has standing, the EPA has the authority to regulate GHG emissions, and that the EPA's decision not to do so failed to meet the "arbitrary and capricious" standard).

[75] *Id.* at 60. For an additional analysis of *Massachusetts v. EPA*, see Daniel A. Farber, *Uncertainty as a Basis for Standing*, 33 HOFSTRA L. REV. 1123, 1128 (2005).

favor of the plaintiffs. More specifically, the Court ruled that the Clean Air Act does give the EPA the authority to regulate emissions of GHGs, and hence found the EPA rationale for not taking this action inadequate.

In a similar vein, inhabitants of Pacific Island nations claim that rising sea levels due to climate change have submerged their homes. They have announced intentions to commence litigation against major sources of carbon dioxide emissions under the Alien Tort Claims Act,[76] through which noncitizens can bring suits in federal court for violating international law. The nations' claim is that they will incur costs for relocating their populations or otherwise adapting to higher sea levels.[77] Such litigation would face "enormous hurdles" given the difficulty in establishing specific causal links between activity of a corporation and harm.[78] Moreover, "an *individual* greenhouse gas-producer's liability for global climate change is generally nonquantifiable and may be largely dependent on external factors outside the producer's control."[79]

A. *Compensation Based on Proportional Liability*

Climate change is subject to fluctuations in frequency and severity so that it is "difficult to differentiate a particular pattern change in temperature or sea level caused by anthropogenic climate change from one caused by natural variability."[80] Nonetheless, even if it is impossible to attribute a specific event to climate change, one may still be able to compensate individuals because global warming increased the likelihood that an event would occur.

Oxford University's Myles Allen has taken this tack in dealing with the causality issue as it relates to climate change. He considers the case of flooding in southern England in January 2003. There, disaster victims claimed that the flooding was attributable to past GHG emissions. Allen cites the Third Assessment Report of the Intergovernmental Panel on Climate Change as concluding that "most of the ob-

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[76] 28 U.S.C. § 1350 (2000).

[77] *See* J. Kevin Healy & Jeffrey M. Tapick, *Climate Change: It's Not Just a Policy Issue for Corporate Counsel—It's a Legal Problem*, 29 COLUM. J. ENVTL. L. 89, 101-02 (2004).

[78] *See Id.* at 102.

[79] Elizabeth E. Hancock, Note, *Red Dawn, Blue Thunder, Purple Rain: Corporate Risk of Liability for Global Climate Change and the SEC Disclosure Dilemma*, 17 GEO. INT'L ENVTL. L. REV. 233, 244 (2005).

[80] David A. Grossman, *Warming Up to a Not-So-Radical Idea: Tort-Based Climate Change Litigation*, 28 COLUM. J. ENVTL. L. 1, 24 (2003).

served warming over the past 50 years is likely [meaning, specifically, a better than two-in-three chance] to have been due to the increase in GHG concentrations."[81] Allen proposes payments based on a form of proportional liability where the emitter is responsible for the increased risk of flooding caused by the GHGs it produced.[82]

It is interesting to note that this approach has features similar to the assigned shares model developed twenty years ago by Stephen Lagakos and Frederick Mosteller for providing compensation to cancer victims where the cause of the disease was difficult to determine.[83] In their model, two subgroups of individuals are compared: one exposed to a specific dose of radiation and another that was not. It is then possible to compute the ratio of the number of excess cancer cases in the exposed subgroup over the number of cancer cases in the nonexposed subgroup. This fraction is designated as the assigned share and represents the probability that the cancer was caused by the radiation dose. For instance, if there is a 20% chance that a randomly selected individual from the exposed group will have had his cancer caused by his previous radiation exposure, then the firm that exposed the individual to this radiation dose would pay 20% of the amount of compensation normally given to such a person who contracts cancer.

With respect to global climate change, suppose that scientists believe that global warming due to GHG emissions has increased the frequency of hurricanes in a region by 40%. If the property damage from a hurricane in Florida was $1 billion, according to this proportional probabilistic liability approach, those whose actions have produced GHG emissions would be responsible for paying their share of 40% of the losses.

While this approach has theoretical merit, it faces practical difficulties on several grounds. First, it will be difficult to achieve any definitive agreement by scientists on the extent to which global warming has increased the likelihood that natural disasters will occur. Quantifying the link between carbon dioxide emissions and an increase in

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[81] Myles Allen, *Liability for Climate Change: Will It Ever Be Possible To Sue Anyone for Damaging the Climate?*, 421 NATURE 891, 891 (2003).

[82] *See id.* at 891-92 (describing "apportion[ing] liability according to the change in risk" as the "equitable solution" to compensating victims of climate change); *see also* Myles R. Allen & Richard Lord, *The Blame Game: Who Will Pay for the Damaging Consequences of Climate Change?*, 432 NATURE 551, 552 (2004) (observing that English law permits increased risks to serve as a basis for compensation).

[83] Stephen W. Lagakos & Frederick Mosteller, *Assigned Shares in Compensation for Radiation-Related Cancers*, 6 RISK ANALYSIS 345, 346-47 (1986).

sea surface temperature is not easy. Furthermore, as discussed earlier, there is a growing debate about the link between sea surface temperature and the increased frequency and/or severity of hurricanes.[84] Second, it will be extremely difficult to determine who is responsible for increasing GHGs unless one has some yardstick for measuring the amount in the atmosphere.

On the other hand, polluters bear some responsibility for their impact on climate change. Based on the current state of knowledge, the use of economic tools such as tradable emissions permits would certainly help in quantifying how many GHGs are emitted by each emitter. But here again, as emissions are typically global, another challenge would be to assure that all emitters are paying for their portion of the 40% of the loss.

In the end, we might also see some judges ruling that if a specific industry, such as the electricity sector, is responsible for a large majority of the emissions in a country and is financially strong, it should be held responsible for the consequences of global warming and pay for it. How much responsibility, again, remains an open question.[85]

Perhaps of even greater importance in encouraging firms to take steps to reduce the risks of climate change is the threat of global warming class action suits. This might be sufficient to encourage large emitters to restrict their future pollution to avoid being sued and for insurers to deny coverage to these firms unless they undertook such measures.

There are precedents in other areas that may provide some guidance as to what may happen in the future. As Joni Hersch and Kip Viscusi note in this Symposium:

> While environmental litigation of this type is unprecedented, the cigarette cases were novel as well. The cigarette litigation did not establish legal precedents because the cases were settled without any court verdicts, but the threat of the suits was sufficiently real that it led to damages payments of close to $250 billion.[86]

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[84] *See supra* notes 35-39 and accompanying text.

[85] There might be positive externalities associated with global climate change as well. For example, it has been shown that, under certain assumptions, climate change on U.S. agricultural land will increase annual profits by $1.3 billion (in 2002 dollars), or 4%. *See* Olivier Deschenes & Michael Greenstone, *The Economic Impacts of Climate Change: Evidence from Agricultural Output and Random Fluctuations in Weather*, 97 AM. ECON. REV. 354, 354 (2007).

[86] Joni Hersch & W. Kip Viscusi, *Allocating Responsibility for the Failure of Global Warming Policies*, 155 U. PA. L. REV. 1657, 1657 (2007).

B. *Impact of Climate Change on Directors' and Officers' Coverage*

We now turn to another liability challenge that insurers will face in the coming years—possible legal actions against executives of companies for failing to disclose to their shareholders some of the climate-related risks faced by the company. If such firms have D&O coverage, these individuals may be covered by this insurance should they be sued for wrongful acts committed in their role as company officers. Directors and officers must act with due diligence in carrying out their responsibilities and can be held personally liable if their actions result in a loss to the corporation or its shareholders.[87] Anyone with an interest in a corporation, whether a shareholder or a stakeholder alike, can file a claim if they feel wronged by corporate actions. These claims can be costly, even if they are not considered valid, because the large expenses associated with any court case are normally covered by the insurer.

The impact of court cases on an insurer providing D&O coverage to a firm can be better appreciated with respect to the financial reporting requirements imposed on publicly traded corporations under federal law in the United States. The sufficiency of such a firm's financial disclosure can be questioned by its shareholders through a class action lawsuit. In addition to the corporation itself, the defendants in these cases are likely to include the board of directors and other members of the senior management. Should this happen, these directors and officers would quite understandably turn to the firm for indemnification. Corporations are permitted to indemnify officers and directors for virtually any act undertaken in good faith or with the belief that it was in the best interest of the corporation. To manage this financial exposure, and also reassure their board, companies often purchase D&O coverage.[88]

Moreover, shareholders in a number of firms heavily involved with fossil fuels, as well as other firms that might be held responsible for contributing to global warming through their carbon dioxide emissions, are pressuring companies to disclose how global warming could impact their businesses. As the debate on climate change intensifies, there is a risk that the directors and officers of these firms will

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[87] *See, e.g.*, Smith v. Van Gorkom, 488 A.2d 858 (Del. 1985) (holding directors personally liable for breaching their duty of care in their approval of a merger without adequately informing themselves of the terms of the merger).

[88] The two largest insurance companies in the American D&O market are Chubb and AIG.

be sued for failing to exercise their fiduciary duty in the event that they do not take action to prepare for contingencies which may result from climate change.

In April 2004, a group of thirteen public pension funds managing over $800 billion in assets wrote a letter to then-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.[89] More recently, in June 2006, this now enlarged group of investors—fifty members of the Investor Network on Climate Risk (INCR), representing nearly $3 trillion in assets—reiterated this demand to the new SEC Chairman. As of today, the SEC has not finalized rules regarding disclosure of climate-change-related risks.

In May 2005, a group of fourteen leading investors and other organizations worldwide launched a new effort to improve corporate disclosure of the risks and opportunities posed by global climate change—the Climate Risk Disclosure Initiative. In October 2006, it released the *Global Framework for Climate Risk Disclosure* to provide specific guidance to companies regarding the information they provide to investors on the financial risks posed by climate change.[90]

In this context, it might be increasingly difficult for any publicly traded company not to consider seriously how climate change will affect its operations and financial results, and to report these as a part of environment liabilities in its annual SEC filings.

A recent review of climate change reporting in the SEC filings of automobile, manufacturing, integrated oil and gas, insurance, petrochemicals, and utilities companies indicates that over the past five years, climate reporting has steadily increased in quality and has also doubled in number. According to the report, all twenty-six electric utilities reported on climate risk, whereas five years ago, only half of the electric utilities disclosed climate risks to shareholders.[91] How-

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[89] Letter from the Investor Network on Climate Risk to Christopher Cox, Chairman, SEC (June 14, 2006), *available at* http://www.ceres.org/pub/docs/Ceres_INCR_SEC_letter_061406.pdf.

[90] CERES, GLOBAL FRAMEWORK FOR CLIMATE RISK DISCLOSURE (2006), *available at* http://www.ceres.org/pub/docs/Framework.pdf.

[91] MICHELLE CHAN-FISHEL, FIFTH SURVEY OF CLIMATE CHANGE DISCLOSURE IN SEC FILINGS OF AUTOMOBILE, INSURANCE, OIL & GAS, PETROCHEMICAL, AND UTILITIES COMPANIES 23 (2006), *available at* http://www.foe.org/camps/intl/SECFinalReportandAppendices.pdf.

ever, only six of the twenty-three automobile companies and only four of the largest twenty-seven property-casualty insurers in the United States surveyed for climate disclosure in 2005 had reported any climate change risk in their annual filings.[92]

In light of their cautious effort to exclude most liability exposure associated with pollution since 1985, one can anticipate that insurance companies providing D&O policies would resist covering "claims in which an insured failed to adequately disclose environmental liability on financial statements"[93] or has not maintained appropriate control of how the company has managed its environmental risks, including those related to climate change.

For example, Swiss Re, a large player in D&O reinsurance, is treating climate change seriously in its dealings with corporations. According to Ivo Menzinger, Head of Sustainability and Emerging Risk Management at Swiss Re:

> If the risk to be insured in our Directors and Officers insurance business for Large Corporate Risks has a potential carbon exposure, then we investigate how the company manages this aspect of its business operations. This is primarily done through analyzing returns made to the annual Carbon Disclosure Project survey of large corporates. However, if there is insufficient information from this source we would request details from the company concerned directly. This, together with other underwriting relevant information, flows into the decision about what coverage to offer and the pricing of the product. This process has been in place since 2003.[94]

A recent report by the insurance broker Marsh also confirms that insurers are becoming more concerned about their clients' potential exposure to liability risk associated with climate change. Among questions that insurers would typically ask their clients with respect to assessing climate change and D&O risk are: (1) "Does [your] company allocate responsibility for the management of climate-related risks? If so, how does it do so?"; (2) "Is there a committee of independent board members addressing the issues?"; (3) "What progress, if any, has a company made in quantifying, disclosing, and/or reporting its emissions profile?"; and (4) "How well has a company planned for future

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[92] *Id.* at 10-13.

[93] Kenneth E. Anderson & Donna Ferrara, *Disclosing Environmental Liabilities: Director, Officer, and Insurance Issues*, 16 ENVTL. CLAIMS J. 3, 11 (2004).

[94] E-mails from Swiss Re (Nov. 23 & 24, 2006) (on file with authors).

regulatory scenarios?"[95] Corporate directors have the duty to provide "good and prudent management" to the corporations they serve, and liability could thus arise from inaction of a corporate board where prudence dictates that action be taken.[96]

C. *Mitigation of Future Damage from Climate Change*

What can companies do to manage their climate change risks today? As one commentator notes:

> In contrast to claims seeking recovery for future damages, sea-level rise plaintiffs appear to have much stronger claims based on the *present* costs of *preventing* future harms. The general tort rule is that plaintiffs who are harmed by defendants are entitled to recover their reasonable expenditures needed to abate, mitigate, or prevent future recurrences of those harms. . . . [c]ourts have held that plaintiffs can recover from defendants their reasonable expenditures for erecting walls to keep water off their property.[97]

Insurance can and does play a key role in encouraging mitigation actions that reduce the impact of future climate change. For example, Fireman's Fund Insurance Company is providing 5% rate credits to building owners who utilize solar panels, green roofs, and recycled water supply systems "[b]ecause green buildings are proven to be less prone to water damage, electrical fires, or full loss due to fire . . . ."[98] Traveler's Auto Insurance also offers a "10% discount on auto insurance to drivers of hybrid-electric vehicles."[99] American International Group (AIG) is also actively seeking to incorporate environmental and climate change considerations across its businesses, focusing on the development of products and services to help AIG and its clients respond to the worldwide drive to cut GHG emissions.[100]

Mills and Lecomte point out that the U.S. Department of Energy catalogued "nearly 80 technologies and practices . . . that can lower greenhouse gas emissions while reducing the direct risk of property damage from mechanical equipment breakdown, professional liability, builders' risk, business interruption, and occupational health and

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[95] Marsh Inc., *Climate Change: Business Risks and Solutions*, RISK ALERT 23 (2006), *available at* http://solutions.marsh.com/climates/.

[96] Healy & Tapick, *supra* note 77, at 102-03.

[97] Grossman, *supra* note 80, at 17-18 (citations omitted).

[98] ALLIANZ GROUP & WORLD WILDLIFE FUND, CLIMATE CHANGE AND INSURANCE: AN AGENDA FOR ACTION IN THE UNITED STATES 33 (2006).

[99] *Id.*

[100] *Id.* at 33.

safety."[101] For example, energy-efficient lighting fixtures often give off less heat, thus reducing fire hazards.[102] Facility-integrated solar power systems can also help a firm avoid business interruptions following outages on its electricity grid.[103] Energy-efficient windows can likewise reduce energy losses by half or more and are more resistant to breakage by windstorms.[104]

An example of a green building actually reducing losses is the "Harmony Resort on the island of St. John, which weathered Hurricanes Marilyn, Bertha, Georges, and Lenny with no loss of (solar) power or (solar) hot water, while operations on other facilities on the islands were disrupted for weeks or months."[105]

VI. SUMMARY AND CONCLUSIONS

Despite the overwhelming scientific evidence that global warming is real, there is still considerable uncertainty as to its impact on weather-related disasters such as hurricanes, storms, and floods. A look at the data on past losses from large-scale natural disasters indicates that many of the most costly events in history have occurred in recent years. There are several causes of this increased damage, most notably the large-scale development in coastal areas of the United States. There has also been a lively debate by scientists as to whether warming sea surface temperatures are a cause of the increased intensity and frequency of hurricanes. Today, some insurers feel that the risks from hurricanes and other weather-related events in certain areas are uninsurable by the private sector alone due to the large catastrophic losses of recent years and the impact of global warming on weather patterns.

Extreme events pose challenges for insurers because there is considerable ambiguity associated with the probability of such an event occurring, and because insurers' losses are often highly correlated with such events. Catastrophe models and exceedance probability (EP) curves are useful decision aids for determining risk exposure and whether extreme events, such as natural disasters, are insurable risks. Given the limited historical data on these low-probability events, it is necessary to supplement this information with scientific models. One

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[101] MILLS & LECOMTE, *supra* note 21, at 17 (citation omitted).
[102] *Id.*
[103] *Id.*
[104] *Id.*
[105] *Id.* at 20.

also needs to recognize that even after utilizing the outputs from catastrophic models, there is considerable uncertainty in estimates of the likelihood and consequences of specific events.

Based on a thorough study of the insurance claims from the 2004 and 2005 hurricanes that hit Florida and other Gulf Coast states, modeling firms have revised the underlying assumptions used to estimate the economic damage and insured losses from future catastrophes. With these new models, the same insurance portfolio today would be considered much more risky than it was a year ago. Rating agencies have also modified their rating methodologies in recent years by incorporating catastrophe exposures of insurers as an integral part of the analysis. In addition, investors are now requiring a higher return on equity from insurers and reinsurers because of the perceived increased volatility of their portfolios. These other stakeholders have forced insurers to focus attention on their underwriting decisions in risky areas and improve their exposure management strategy. This is the new catastrophe risk management.

In addition, there is a growing concern that lawsuits may be filed against firms for not taking appropriate action to reduce their GHG emissions or other pollutants that could cause global warming. We expect that insurers will be more concerned with providing D&O liability coverage to firms that they believe are not behaving responsibly in this area. On a more positive note, some insurers are encouraging firms, through premium discount offers, to take positive measures to reduce climate change that also have short-term benefits, including damage mitigation against disaster.

A better understanding and quantification of the different factors causing the increase over the last few years in economic losses due to major catastrophes will be critical to defining better strategies for private companies and implementing more effective public policies to deal with future disasters, such as land use regulation, mitigation standards, and well-enforced building codes. To help in that process, the insurance industry, partnering with government and international organizations (e.g., the OECD, United Nations, World Meteorological Organization, World Health Organization, and World Bank) might develop standardized data collection processes at a more granular level than what is currently done.[106] These datasets should be made available to the public as well as to the research community.

[106] For a discussion on the data quality challenge, see, for example, Eberhard Faust, Peter Höppe, Angelika Wirtz & Silvio Schmidt, *Trends in Natural Catastrophes*—

Today, data collection methods differ from one country to another, and the quality of this information is heterogeneous. At least two standardized international databases should be developed: historical loss data for all type and size of disasters,[107] and data on insurance market penetration (who is and is not covered). These databases are likely to suggest ways that insurance coupled with other policy tools can reduce the risks associated with climate change, while providing the financial resources to aid the recovery process when the next large-scale disaster occurs.

If insurers and reinsurers conclude that some climate-related risks have a high enough potential for causing catastrophic losses in specific areas, they will not want to continue offering coverage unless they are required by law to do so. This raises the following policy questions that go beyond the scope of this Article: Should insurance be required in certain highly hazard-prone areas? If so, will the private sector be able to provide this coverage alone or will some type of public-private partnership be necessary? Should land use regulation restrict new construction in highly hazard-prone areas? Can building codes be better designed and enforced? Do certain regulations negatively impact the operation of private insurance and reinsurance markets? There is also the equity issue: how should we deal with individuals who have been living in high-hazard areas for some time but cannot afford to pay for higher insurance premiums that reflect the new risk assessment?

These and other questions are currently being addressed in detail in a complementary study undertaken by the Wharton Risk Center in conjunction with Georgia State University and the Insurance Information Institute, and in partnership with over fifteen large insurers, reinsurers, their trade associations, financial institutions, and other stakeholders from the private and public sectors interested in these critical issues.

Potential Role of Climate Change, *in* WORKSHOP ON CLIMATE CHANGE AND DISASTER LOSSES: UNDERSTANDING AND ATTRIBUTING TRENDS AND PROJECTIONS, *supra* note 24, at 89, 89.

[107] Swiss Re, Munich Re, and Leuven University have developed time series on some disaster data, but they differ in their scope and are usually not public information. *Workshop Summary Report*, *in* WORKSHOP ON CLIMATE CHANGE AND DISASTER LOSSES: UNDERSTANDING AND ATTRIBUTING TRENDS AND PROJECTIONS, *supra* note 24, at 4, 5.