

The Development of New Catastrophe Risk Markets

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Abstract

The large-scale disasters that have occurred since 2001 suggest that we have entered a new era of catastrophes. We are more vulnerable to extreme events as a result of the increasing concentration of population and activities in exposed areas of the country. The question is not whether large-scale catastrophe will occur, but when and how frequently they will strike. One key question is, Who will pay for the economic losses future disasters will inflict? This paper discusses how new catastrophe risk markets can be developed to provide the necessary financial coverage to make our country more resilient. We look specifically at insurance-linked financial instruments to complement traditional insurance and re-insurance. We also propose the development of long-term insurance and long-term loans to overcome behavioral biases such as myopia and misperception of risks. The paper concludes by proposing risk management strategies that apply to other extreme events such as the financial crisis of 2008–2009.

1. A CAUSE FOR CONCERN

Over the past few decades, natural disasters have caused significant fatalities, injuries, and property damage. Table 1 illustrates the new era of costly catastrophes we have entered: Of the 25 most costly insured catastrophes in the world between 1970 and 2008, all of

Table 1 The 25 most costly insured catastrophes in the world 1970–2008 (2008 prices)^a

\$ billion	Event	Victims (dead or missing)	Year	Area of primary damage
48.1	Hurricane Katrina	1836	2005	USA, Gulf of Mexico
36.8	9/11 attacks	3025	2001	USA
24.6	Hurricane Andrew	43	1992	USA, Bahamas
20.3	Northridge Earthquake	61	1994	USA
16.0	Hurricane Ike	348	2008	USA, Caribbean
14.6	Hurricane Ivan	124	2004	USA, Caribbean
13.8	Hurricane Wilma	35	2005	USA, Gulf of Mexico
11.1	Hurricane Rita	34	2005	USA, Gulf of Mexico
9.1	Hurricane Charley	24	2004	USA, Caribbean
8.9	Typhoon Mireille	51	1991	Japan
7.9	Hurricane Hugo	71	1989	Puerto Rico, USA
7.7	Winterstorm Daria	95	1990	France, UK
7.5	Winterstorm Lothar	110	1999	France, Switzerland
6.3	Winterstorm Kyrill	54	2007	Germany, UK, Netherlands, France
5.9	Storms and Floods	22	1987	France, UK
5.8	Hurricane Frances	38	2004	USA, Bahamas
5.2	Winterstorm Vivian	64	1990	Western/Central Europe
5.2	Typhoon Bart	26	1999	Japan
5.0	Hurricane Gustav	153	2008	USA, Caribbean
4.7	Hurricane Georges	600	1998	USA, Caribbean
4.4	Tropical Storm Alison	41	2001	USA
4.4	Hurricane Jeanne	3034	2004	USA, Caribbean
4.0	Typhoon Songda	45	2004	Japan, South Korea
3.7	Storms	45	2003	USA
3.6	Hurricane Floyd	70	1999	USA, Bahamas, Colombia

^aPayments for floods by the National Flood Insurance Program in the United States are excluded.

Abbreviations: USA, United States; UK, United Kingdom.

Sources: Wharton Risk Center with data from Swiss Re and Insurance Information Institute.

them occurred after 1987, 17 of them since 2001. Furthermore, except for the terrorist attacks on September 11, 2001, all of these events were natural disasters.

To deal with the increase in losses from these events, more attention has been devoted to ways to reduce future losses in hazard-prone areas, and there has been increased interest in the role that insurance-linked securities can play in providing financial protection against catastrophic losses with the volume of these instruments. We explore both of these developments in this article.

Section 1 details the evolution of the economic and insured losses from natural disasters over the past four decades. We then explore the key drivers of this recent change (Section 2) and discuss the challenges faced by insurers today in continuing to provide coverage against such catastrophes (Section 3). The market for catastrophe financial protection is then analyzed in Section 4. Given the behavioral biases of decision makers described in Section 5, we argue for the importance of long-term contracts as a way of providing stability and incentivizing individuals to invest in risk-reduction measures (Section 6). The article concludes by showing how the lessons from natural disasters can help us to better manage other extreme events.

Between 1970 and the mid-1980s, insured losses due to natural disasters in the world were in the range of \$3 to \$4 billion a year (unless noted, all figures presented in this section are in 2008 U.S. dollars). In fact, until Hurricane Hugo [which cost insurers more than \$4 billion in 1989 prices (or \$7.9 billion in 2008 prices)] hit the Charleston, South Carolina, area in 1989, there was not a single disaster that cost insurers more than \$1 billion. In the early 1990s, the scale of insured losses from major natural disasters changed radically, for reasons we explain in the next section. The occurrence of Hurricane Andrew in 1992 cost the insurance industry \$15.5 billion (\$24.6 billion in 2008 prices) and caused nine small insurance companies to become insolvent. Several large insurers were also severely impacted by the disaster. For example, the Florida branch of State Farm Fire and Casualty (the largest homeowner insurer in the United States) suffered a \$4 billion loss and survived only because it was rescued by its parent company in Illinois. The Florida branch of Allstate, the other major player in the state at the time, paid approximately \$1.9 billion in claims. This loss exceeded by \$500 million the total profits that Allstate earned from all types of insurance they marketed in Florida during the 53 years the firm had been in business in the state.

Hurricane Andrew was a wake-up call for the insurance industry. Companies recognized that they were not well equipped to estimate the potential loss distribution from disasters and began to utilize catastrophic models to estimate the likelihood and consequences from specific hazards that might cause damage in specific locations (Grossi & Kunreuther 2005). Since that time, insurers have improved their underwriting processes against catastrophe risks. No insurance company declared insolvency as a result of the September 11, 2001, terrorist attacks, and only one insurer became insolvent after the series of hurricanes that devastated Florida in 2004 (U.S. Government Accountability Office 2005).

Extreme events have continued to inflict major losses on insurers. A new record was reached in 2004 with global insured losses of \$49 billion (Swiss Re 2005). This upward trend continued in 2005 with total insured losses from natural catastrophes of \$87 billion (which excludes \$17 billion in flood insurance claims paid by the U.S. National Flood Insurance Program). Hurricane Katrina alone cost insurers and reinsurers \$48.1 billion. Losses due to natural catastrophes and man-made disasters were far below the long-term trend in 2006. Of the \$48 billion in catastrophe-related economic losses worldwide, \$16 billion was covered by insurance (\$11 and \$5 billion for natural and man-made

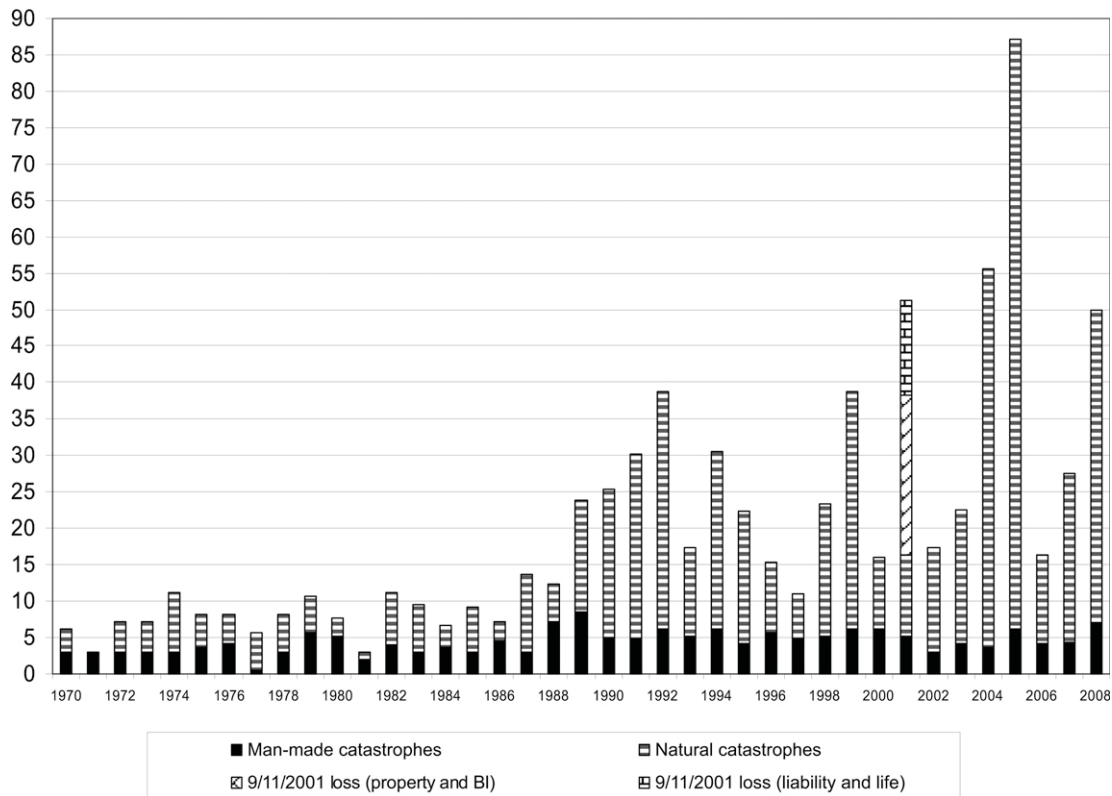


Figure 1

Worldwide evolution of catastrophe insured losses 1970–2008.

Note: Losses in dollars are indexed to 2008, which is in current dollars. Vertical axis measures US\$ billion, by which losses are measured.

Source: Wharton Risk Center with data from Swiss Re and Insurance Information Institute.

disasters, respectively). Insured losses were lower than in 2006 in only two years (1988 and 1997) during the period 1987–2006.

According to Munich Re, there were 950 natural catastrophes in 2007, the most since 1974, which inflicted nearly \$27 billion in insured losses. With Tropical Storms Fay and Hanna and Hurricanes Gustav and Ike¹ occurring in the North Atlantic in 2008 coupled with earthquakes in China, Japan, and Indonesia, and typhoons and floods in other parts of the world, total economic losses in 2008 were estimated to be \$200 billion, the third most expensive year on record after 1995 and 2005 (Munich Re 2008).

Figure 1 depicts the evolution of worldwide insured losses due to catastrophes between 1970 and 2008 (in 2008 indexed prices). The increased losses during the past 20 years (1989–2008) compared with the previous 19 years (1970–1988) are clearly displayed.

¹If preliminary estimates of damage from Hurricane Ike at \$25 billion are borne out, it would be the third-costliest hurricane in U.S. history.

2. REASONS FOR INCREASED LOSSES IN RECENT YEARS

What are the key drivers of the increase in these losses? More specifically, what role have socioeconomic factors played? How is a change in climate likely to affect the number and severity of catastrophes in the future? To answer these questions, we draw on material in Kunreuther & Michel-Kerjan (2009, ch. 1).

2.1. Increasing Urbanization and Value at Risk

The two socioeconomic factors that directly influence the level of economic losses from natural disasters are degree of urbanization and value at risk. In 2000, approximately 50% of the world's population (6 billion people) lived in cities, compared with only 30% (2.5 billion people) 50 years earlier. Projections by the United Nations show that by 2025 this figure will have increased up to 60% (i.e., 8.3 billion people). A direct consequence of this trend is the increasing number of so-called mega-cities with populations above 10 million. In 1950, New York City was the only mega-city. Forty years later, there were 12 such cities. By 2015, there are estimated to be 26, including Tokyo (29 million inhabitants), Shanghai (18 million), New York City (17.6 million), and Los Angeles (14.2 million inhabitants) (Crossett et al. 2004). **Figure 2** (see color insert) depicts the increase in population by county in the United States between 1990 and 2000. Coupled with the growth of urban areas has been a large movement of individuals to coastal areas that are subject to losses from hurricanes and flooding.

In 2003, 53% of the nation's population (153 million people) resided in the 673 U.S. coastal counties (including near lakes), an increase of 33 million people since 1980, according to the National Oceanic Atmospheric Administration. And the nation's coastal population is expected to increase by more than 12 million by 2015 (Crossett et al. 2004).

The development of Florida as a home for retirees illustrates this trend. According to the U.S. Bureau of the Census, the population of Florida has increased significantly over the past 50 years: 2.8 million inhabitants in 1950, 6.8 million in 1970, 13.0 million in 1990, and a projected 19.3 million population in 2010 (an increase of almost 600% since 1950), increasing the likelihood of severe economic and insured losses unless cost-effective mitigation measures are implemented.

To understand more fully the implications of growing urbanization, one can calculate the total direct economic cost of specific disasters that occurred decades ago and see how much a similar catastrophe would cost today. A recent study by Pielke et al. (2008) normalizes to the year 2005 mainland U.S. hurricane damage during the period 1900–2005 by adjusting for inflation, population, and wealth. The data reveal that the 1926 hurricane that hit Miami, Florida, would have been almost twice as costly as Hurricane Katrina had it occurred in 2005 given the growth of the area. The Galveston, Texas, hurricane of 1900 would have had total direct economic costs similar to Hurricane Katrina if it had occurred in 2005. These findings suggest that, independent of changes in weather patterns, we are likely to see increasingly devastating disasters in the coming years because of the ongoing growth in population and property values in hazard-prone areas.

In summary, increased urbanization and an increase in real property values in hazard-prone areas will have a major impact on the level of economic and insured losses from future natural catastrophes. In low- and middle-income countries, many large cities have very high population densities compared to most North American and European cities.

This concentration poses a challenge with respect to timely evacuation and rescue operations for reducing the number of injuries and fatalities from a major disaster.

2.2. Impact of Climate Change

Is a change in climate likely to affect the number and severity of future weather-related catastrophes? Landsea et al. (2006) pointed out that subjective measurements and variable procedures make existing tropical cyclone databases insufficiently reliable to detect trends in the frequency of extreme cyclones. This conclusion is reinforced in a recent summary of articles on global climate change by Patrick Michaels, past president of the American Association of State Climatologists, who notes that all studies of hurricane activity that claim a link between human causation and the recent spate of hurricanes must also account for the equally active period around mid-twentieth century. 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 (Michaels 2006).

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 to come. The results to date raise issues for the insurance industry to the extent that an increase in the number of major hurricanes over a shorter period of time is likely to translate into a greater number hitting the coasts, with a greater likelihood of damage to a much larger number of residences and commercial buildings today than in the 1950s. For more discussion on this issue, see Mills (2005) and Höpfe & Pielke (2006).

Moreover, recent work by the Intergovernmental Panel on Climate Change (2007) indicates that one of the impacts of a change in climate will be an increase in weather extremes. We are likely to witness not only more intense storms, but also more intense heat waves, droughts, and flooding episodes. This will also translate into a much higher level of volatility from one year to the next and increased uncertainty by insurers. We turn to this aspect now.

3. CHALLENGES FACING INSURERS IN PROVIDING PROTECTION AGAINST CATASTROPHIC RISKS

Given the recent history of catastrophes, insurers and reinsurers are reexamining their ability to provide protection against catastrophic risks and are asking whether these events are still insurable and, if so, at what price (for details on which this discussion draws, see Kunreuther & Michel-Kerjan 2009, ch. 6). To understand the concept of insurability, consider a standard 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 the ability to identify and quantify, or estimate, the chances of the event occurring and the extent of losses likely to be incurred. The second is the ability to set premiums for each potential customer or class of customers at prices that provide a competitive return at the assumed level of risk.

If both conditions are satisfied, a risk is considered to be insurable. But it still may not be profitable. In other words, it may be impossible to specify a premium for which there is sufficient demand and incoming revenue to cover the development, marketing, operating, cost of holding capital, and claims processing costs of the insurer and yield a net positive profit over a prespecified time horizon. In such cases, the insurer will not want to offer coverage against this risk. In his study on insurers' decision making as to when they would

market coverage for a specific risk, Stone (1973) developed a model whereby firms maximize expected profits subject to satisfying a constraint related to the survival of the firm. Insurers satisfy their survival constraint by choosing a portfolio of risks that has a likelihood of experiencing total claim payments greater than some predetermined amount (L^*) that is less than some threshold probability p_1 .

In determining what premiums to charge for catastrophic risks, insurers must consider problems associated with the ambiguity of the risk and degree of correlation of the risk. We briefly examine each of these factors below.

3.1. Ambiguity of the Risk

Figure 3 illustrates the total number of loss events from 1950 to 2000 in the United States for three types of natural disasters: earthquakes, floods, and hurricanes. Events were selected that had at least \$1 billion of economic damage and/or more than 50 deaths. Looking across all the disasters of a particular type (earthquake, hurricane, or flood), for this 50-year period, the median loss is low while the maximum loss is very high. The 2004 and 2005 seasons have already dramatically changed the upper limits in Figure 3. Hurricane Katrina is estimated to have caused between \$150 billion and \$170 billion in economic losses, more than four times the most costly hurricane between 1950 and 2000. Given this wide variation in loss distribution, it is not surprising that insurers are concerned about the uncertainty of the loss in estimating premiums or about providing any coverage in certain hazard-prone areas.

The infrequency of major catastrophes in a single location implies that the loss distribution is not well specified. The ambiguities associated with both the probability of an extreme event occurring and with the outcomes of such an event raise a number of

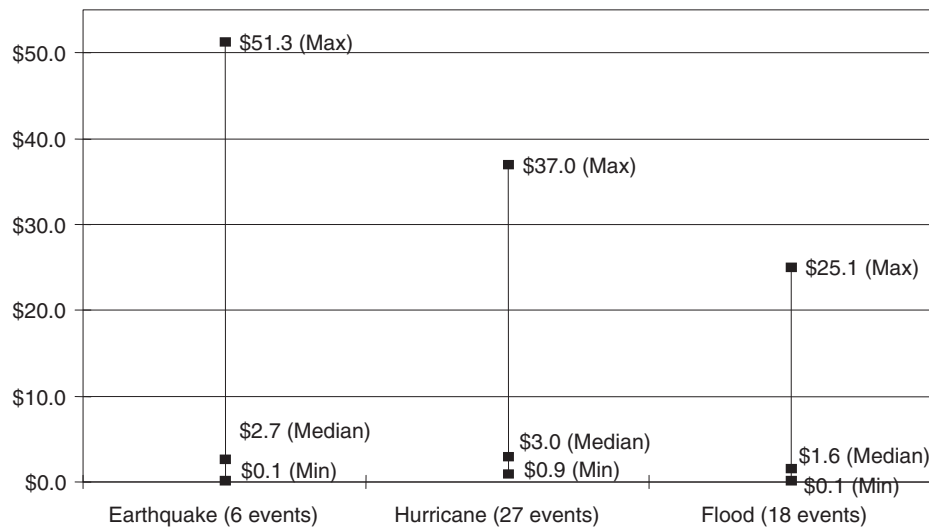


Figure 3
Historical economic losses in billions of dollars versus type of significant U.S. natural disasters for the 50-year period from 1950 to 2000.

challenges for insurers with respect to pricing 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 if these components of risk are well specified (Kunreuther et al. 1995).

In a survey of 78 actuaries in France, Cabantous (2007) showed that the annual mean premium was 32% higher when the ambiguity came from an imprecise forecast than when the risk was well understood. A Web-based survey of U.S. actuaries and underwriters' decision making under risk in 2007 utilized nine different scenarios by crossing three different types of natural hazards (fire, flood, and hurricane) with three types of information about the probability of a disaster (precise probability, imprecise probability, and conflicting probability). For a one-year contract, mean annual premiums when the probability is ambiguous are 25% higher than when it is given precisely (Cabantous et al. 2009).

3.2. Correlated Risks

For extreme events, the potential for high correlation between risks will have an impact on the tail of the loss distribution. This requires additional capital for insurers to protect themselves against large losses. Insurers normally face spatially correlated losses from large-scale natural disasters. State Farm and Allstate paid \$3.6 billion and \$2.3 billion in claims, respectively, in the wake of Hurricane Andrew in 1992 owing to their high concentration of homeowners' policies in the Miami-Dade County area of Florida. Given this unexpectedly high loss, both companies began to reassess their strategies of providing coverage against wind damage in hurricane-prone areas (Lecomte & Gahagan 1998).

Hurricanes Katrina and Rita, which devastated the U.S. Gulf Coast in August and September 2005, had dramatic impacts on several lines of insurance, notably property damage and business interruption. Edward Liddy, chairman of Allstate, which provided insurance coverage to 350,000 homeowners in Louisiana, Mississippi, and Alabama, shortly after Katrina was quoted in the *Wall Street Journal* saying, "Extensive flooding has complicated disaster planning and the higher water has essentially altered efforts to assess 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 the most-devastated areas. It will be many weeks, probably months, before there is anything approaching reliable estimates" (Francis 2005).

4. DEALING WITH THE CHALLENGES OF CATASTROPHIC LOSSES

To protect themselves against the possibility of catastrophic losses, insurers have traditionally relied on reinsurance (this section draws on Michel-Kerjan & Morlaye 2008). Reinsurance provides protection to private insurers in much the same way that insurance provides coverage to policyholders. Reinsurers offer coverage against the catastrophic portion of a loss for which insurers do not want to be financially responsible. In this type of arrangement, the reinsurer charges a premium to indemnify an insurance company against a layer of the catastrophic losses that the insurer would otherwise be responsible for covering.

One of the key features of the reinsurance market is the lack of price regulation, which exists for insurance. Thus, there was a significant increase in reinsurance prices for catastrophic risks in the United States in the aftermath of the 2005 hurricane season (from +50% to +100% depending on the risk and insurer's characteristics). This provided an impetus for the expansion of alternative risk transfer instruments, such as insurance-

linked securities, that transfer part of the exposure to catastrophic losses directly to investors in the financial markets.

Since their inception more than a decade ago, insurance-linked securities have often been presented as a promising solution to address the capital needs of companies exposed to potential catastrophic risk. In a relative sense, the 2005–2007 period has been a clarion call for new investment opportunities, and we have witnessed historic records in catastrophe bond (cat bond) issuance and the development of a multibillion-dollar market for other innovative instruments. For a comprehensive discussion of alternative risk transfers markets at the beginning of the 2000s, see Lane (2002) and Dischel (2002). In the following sections, we discuss two types of insurance-linked securities instruments provided by the capital markets: industry loss warranties (ILWs) and cat bonds.

4.1. Industry Loss Warranties

The first ILWs were issued in the 1980s to cover airline industry losses. They were then developed in the property and casualty insurance industry in the aftermath of major natural disasters that occurred in the past 15 years. As the name indicates, an ILW (also known as original loss warranty, OLW) is a financial instrument designed to protect insurers and reinsurers from severe losses due to extreme events such as natural disasters. The ILW market today focuses almost exclusively on catastrophic risks, and it has increased significantly after Hurricanes Katrina, Rita, and Wilma.

ILWs operate as follows: The buyer who wants to hedge his risk pays the seller a premium at the inception of the contract. In return, the buyer can make a claim in the event of a major industry loss. The payout of an ILW can be structured in a simplified way such that the buyer can make a claim equal to the limit (L) of the ILW if a predefined industry loss index (IL) exceeds a threshold known as the trigger (T) for a particular state/region, regardless of the buyer's actual amount of incurred loss.²

$$\text{Claims} = L \text{ if } IL \geq T$$

$$\text{Claims} = 0 \text{ if } IL < T$$

For example, the buyer of a \$200 million limit U.S. wind ILW in New York in 2010 attached at \$20 billion will pay a premium to a protection writer (e.g., a hedge fund acting as a reinsurer) and in return will receive \$200 million if total losses to the insurance industry from a single U.S. hurricane in New York in 2010 exceed \$20 billion.

One of the main advantages of ILWs is that they involve relatively low transaction costs both for the buyers (insurers or reinsurers) and sellers (e.g., hedge funds). The sellers do not have to evaluate the expected loss to the (re)insured portfolio of a specific company from the trigger event; instead, they need to evaluate only the exceedance probability curve of the entire industry, which typically reduces the uncertainty and hence the cost associated with a higher level of volatility.

The ILW market has grown significantly in the aftermath of Hurricane Katrina, which indicates a strong appetite from insurers and reinsurers for access to sources of capital other than traditional reinsurance or retrocession. It is estimated that nearly \$4

²We give here the example of a derivative swap, which is the most commonly used ILW contract. But it does not have to be. There could be a first indemnity trigger (loss encounter by the buyers), then a second trigger based on industry loss. Several thresholds associated with different payments (L) could also exist.

billion in ILWs were issued between September 2005 and September 2006 (State Board of Administration of Florida 2006). However, because most of these transactions transpired directly between companies, and details of the deals are not necessarily made public, knowing the precise aggregate volume and prices is difficult.

4.2. Catastrophe Bonds

Cat bonds enable an insurer or reinsurer to access funds if a severe disaster produces large-scale damage, in a manner similar to ILWs. To illustrate how cat bonds work, consider an insurer or reinsurer, “SafeCompany,” who would like to cover part of its exposure against catastrophic losses. Suppose the losses from a disaster covered by the cat bond exceed a prespecified trigger. Then the interest on the bond, the principal, or both, are forgiven, depending on the specifications of the issued cat bond. These funds are then provided to SafeCompany to help cover its claims from the event.

In 2007, State Farm issued a jumbo cat bond: a \$1.2 billion risk capital bond, which as of June 2009 is the largest cat bond ever issued. (The original attempt had been to issue a \$4 billion bond, but it was scaled down to the \$1.2 billion note and term loan.) The bond is innovative in that it is cumulative: The company covers its portfolio in the case of cumulative losses due to a series of predefined events (e.g., hurricanes in the United States, earthquakes in Japan) over the three-year maturity of the bond.

One advantage of cat bonds over traditional one-year reinsurance contracts is that they can typically offer longer term coverage—one to five years. Over time, the proportion of cat bonds with longer maturity has increased, an indication that these instruments are gaining trust within the reinsurance/finance community. **Table 2** specifies the maturity of cat bonds that were issued between 1997 and 2007. The average maturity is approximately three years: Some cat bonds have only a one-year maturity, whereas others have five or more years. In the context of highly volatile reinsurance prices that often occur after large catastrophes, cat bonds offer an important element of stability for insurers by guaranteeing a predefined price over several years, assuming that the entire capital of the bond is not triggered (in which case a new bond has to be issued under price conditions that are likely to differ). We believe that this stability has been largely undervalued so far.

Bonds do not have to cover only natural disasters, nor are they issued only to protect a commercial enterprise. For example, the first bond that insured against terrorism was issued in Europe in August 2003. The world-governing organization of football (soccer), the International Federation of Association Football (FIFA), which organized the 2006 World Cup in Germany, developed a \$262 million bond to protect its investment. Under very specific conditions, the cat bond covered losses resulting from both natural and terrorist extreme events that would have resulted in the cancellation of the World Cup final game without the possibility of it being rescheduled to 2007 (Kunreuther & Michel-Kerjan 2004). Moreover, through its FONDEN facility, the government of Mexico sponsored the \$160 million CAT-Mex transaction in May 2006, making it the first government to issue a cat bond.³

³The cat bonds were part of a \$450 million reinsurance transaction with European Finance Reinsurance, a wholly owned subsidiary of the reinsurance company, Swiss Re. Swiss Re retained \$290 million of the contract exposure and issued \$160 million in cat bonds with a three-year maturity through a special purpose vehicle, CAT-Mex.

Table 2 Maturity of cat bonds issued between 1997 and 2007^a

Maturity	1 year	2 year	3 year	4 year	5 year	10 year
1997	2	1	1	0	0	1
1998	7	0	0	0	1	0
1999	5	0	3	0	2	0
2000	3	1	4	0	1	0
2001	2	1	3	1	0	0
2002	0	1	4	2	0	0
2003	0	1	3	1	2	0
2004	1	2	1	1	2	0
2005	1	2	7	0	1	0
2006	2	4	12	1	1	0
2007	4	5	12	3	5	0
Total (91)	27	18	50	9	15	1

^aSource: Michel-Kerjan & Morlaye (2008).

An increasing number of cat bonds cover multiple events. In 2005, 2006, and 2007, over half of the capital at risk through cat bonds was for multievent bonds rather than single-event bonds. In terms of outstanding capital, U.S. earthquakes and hurricanes represented the largest volume in both 2006 and 2007, followed by storm exposure in Europe, then typhoons and earthquakes in Japan. Whether more companies, trade associations, and state and federal governments working in collaboration with experts in the field will diversify their coverage through insurance-linked securities shall be a key factor in developing these instruments.

Cat bonds have been on the market for approximately 10 years now, which enables one to make some comparisons about the evolution of issuances and outstanding capital. **Figure 4** (see color insert) illustrates the evolution of risk capital issued and outstanding, indicated by the number of bonds issued between 1997 and December 2007. At the end of 2004, nearly \$4 billion in cat bond principal was outstanding (including \$1.14 billion of new issuances that year). In 2007, 27 new cat bonds were issued for a total of \$7 billion in capital and an additional \$14 billion was outstanding.

The recent evolution of insurance-linked securities is promising. With more than \$25 billion of outstanding capital in 2007 for property/casualty coverage coupled with the annual rate of growth witnessed in recent years, we could continue to see an increasing volume of capital issued to cover catastrophes. As we write this paper, however, how the 2008–2009 financial crisis will impact this market remains unclear. On the one hand, investors might be more cautious by not investing in assets they can lose overnight. On the other hand, as investors look at a new class of assets that is not correlated with traditional financial markets, catastrophe insurance-linked securities may present some advantage (Cummins & Weiss 2008).

5. BEHAVIORAL CHALLENGES: THE DEMAND FOR INSURANCE AND MITIGATION

Although insurance, reinsurance, and financial instruments transfer the risk of catastrophes to other parties, they do not reduce the risk itself. In the case of natural disasters, one needs to focus on investments in measures that decrease the level of risk associated with the hazard.

How effective can mitigation be in reducing exposure to future disaster? To shed some light on this question, we undertook an analysis of the impact that mitigation would have on reducing losses from hurricanes that occurred in four states: Florida, New York, South Carolina, and Texas (Kunreuther & Michel-Kerjan 2009). In our analysis of the impact of mitigation, we considered two extreme cases: one in which no homeowners have invested in mitigation, the other in which all homeowners have invested in predefined mitigation measures for residential structures based on the latest building codes in these four states. In Florida, we used the requirements as defined by the Institute for Business and Home Safety (2009) to incorporate mitigation. From the U.S. Hurricane Model developed by the catastrophe modeling firm Risk Management Solutions, losses were calculated on a ground-up and gross basis, assuming an appropriate mitigation measure across the insured portfolio.

The analysis reveals that mitigation has the potential to provide significant cost savings in all four states, ranging from 61% in Florida for a 100-year return period loss to 31% in New York for a 500-year return period loss. In Florida alone, the use of mitigation leads to a \$51 billion savings for a 100-year event and \$83 billion for a 500-year event. These findings are important given the costly capital needed to cover the tail of the distribution of extreme events. Enforcing mitigation significantly reduces, if not eliminates, this tail.

The challenge, however, lies in making sure residents in hazard-prone areas adopt this mitigation measure. Indeed, many people tend not to invest in such protection until after a disaster has occurred, in what has been termed the natural disaster syndrome (Kunreuther 1996). There are a range of informal mechanisms that explain this syndrome. One relates to framing the problem imperfectly: Experts focus on likelihood and consequences as two key elements of the risk. Several studies show, however, that individuals rarely seek out probability estimates when making their decisions. When these data are given to them, decision makers often do not use the information. In one study, researchers found that only 22% of subjects sought out probability information when evaluating several risky managerial decisions (Huber et al. 1997). People have a particular difficulty dealing with probabilistic information for small-likelihood events. In one study, individuals could not distinguish the relative safety of a chemical plant that had an annual chance of experiencing a catastrophic accident that varied from 1 in 10,000 to 1 in 1 million (Kunreuther et al. 2001).

There is also evidence that firms and residents tend to ignore risks whose subjective odds are seen as falling below some threshold. Prior to a disaster, many individuals perceive its likelihood as sufficiently low that they argue, "It will not happen to me." As a result, they do not feel the need to invest voluntarily in mitigation measures such as strengthening their house or protecting themselves financially by purchasing insurance. It is only after the disaster occurs that these same individuals express remorse that they did not undertake protective measures.

Another reason that individuals do not invest in protective measures is that they are highly myopic and tend to focus on the returns over only the next couple of years. In addition, there is extensive experimental evidence showing that human temporal discounting tends to be hyperbolic, where temporally distant events are disproportionately discounted relative to immediate ones. As an example, people are willing to pay more to have the timing of the receipt of a cash prize accelerated from tomorrow to today, than they are to have it accelerated from the day after tomorrow to tomorrow (Loewenstein & Prelec 1991).

There is extensive evidence that residents in hazard-prone areas do not undertake loss-prevention measures voluntarily. A 1974 survey of more than 1000 California homeowners in earthquake-prone areas revealed that only 12% of the respondents had adopted any protective measures (Kunreuther et al. 1978). Fifteen years later, there was little change despite the increased public awareness of the earthquake hazard. In a 1989 survey of 3500 homeowners in four California counties at risk from earthquakes, only 5–9% of the respondents in these areas reported adopting any loss-reduction measures (Palm et al. 1990). Burby et al. (1988), and Laska (1991) found a similar reluctance by residents in flood-prone areas to invest in mitigation measures.

Even after the devastating 2004 and 2005 hurricane seasons, a large number of residents had still not invested in relatively inexpensive loss-reduction measures with respect to their property, nor had they undertaken emergency-preparedness measures. In May 2006, a survey of 1100 adults living along the Atlantic and Gulf coasts revealed that 83% of the respondents had taken no steps to fortify their home, 68% had no hurricane survival kit, and 60% had no family disaster plan (Goodnough 2006).

Homeowners who do not invest in cost-effective mitigation measures if they are not required to do so should not simply be considered irrational. There are a number of reasons that people have for not taking these actions until after the next disaster occurs. We thus turn to the need for long-term contracts to address these issues.

6. AN INNOVATIVE MARKET-BASED SOLUTION: LONG-TERM RISK FINANCING CONTRACTS

To address the problem of the volatility of homeowners' failure to protect their property against disaster, we propose a new approach to providing homeowners' coverage: long-term insurance (LTI) contracts rather than the usual annual policies on residential property (information in this section is based in part on Jaffee et al. 2008). For an LTI policy to be feasible, insurers would have to be able to charge a premium that reflects their best estimate of the risk over a given time period (say, 10 or 25 years). The uncertainty surrounding these estimates could be reflected in the premium as a function of the length of the insurance contract in much the same way that the interest rate on fixed-rate mortgages varies among 15-, 25-, and 35-year loans.

The obvious advantage of an LTI contract from the point of view of policyholders is that it provides them with stability and an assurance that their property is protected for as long as they own it. This has been a major concern in hazard-prone areas where insurers have canceled policies following severe disasters such as those that occurred during the 2005 hurricane season. With an LTI policy in place, homeowners in hazard-prone areas would be protected from one disaster to the next, providing them with financial resources for recovery and reducing the need for liberal disaster assistance.

6.1. Benchmark from the Mortgage Industry

The mortgage market in the United States provides a useful benchmark for developing LTI. Although home loans today typically have maturities of 20 or 30 years, until the Great Depression, such long-term mortgages were rare. For instance, U.S. bank mortgages were commonly short term (maturities 1 to 4 years) with the full principal due at maturity. As house prices fell under dire Depression conditions, the loan balances of most homes began to exceed the house value, giving the borrower further incentive to default. A vicious circle then ensued, as falling house prices begot more mortgage defaults and mortgage defaults begot greater declines in house prices. To curtail this process, the Federal Home Owners Loan Corporation (HOLC) was created in 1933 to recycle the failing home mortgages (reminiscent of government programs now being proposed to deal with subprime mortgages). The HOLC also expanded the use of long-term, fixed-payment, and fully amortizing mortgages in the United States. Having concluded its objectives, the HOLC was closed by 1935, a notable achievement. It was replaced by the Federal Housing Administration, established under the National Housing Act of 1934, to oversee a program of home mortgage insurance against default and which continued to promote the use of long-term mortgages (Aaron 1972).

6.2. Encouraging Adoption of Mitigation Measures

LTI provides economic incentives for homeowners to invest in mitigation, whereas current annual insurance policies (even if they are risk based) are unlikely to do so. To illustrate this point, consider the following simple example where insurance premiums reflect the actuarial risk. Suppose that the “Lowland” family could invest \$1500 to strengthen the roof of its house so as to reduce the damage by \$30,000 from a future hurricane with an annual probability of 1 in 100. An insurer charging a risk-based premium would be willing to reduce the annual charge by \$300 ($1/100 \times \$30,000$) to reflect the lower expected losses that would occur if a hurricane hit the area in which the policyholder was residing. If the house was expected to last for 10 or more years, the net present value of the expected benefit of investing in this measure would exceed the up-front cost at an annual discount rate as high as 15%.

Under current annual insurance contracts, many property owners would be reluctant to incur the \$1500 expenditure, because they would get only \$300 back next year and are likely to consider only the benefits over the next few years when making their decisions. If they underweigh the future, the expected discounted benefits would likely be less than the \$1500 up-front costs. In addition, budget constraints could discourage them from investing in the mitigation measure. Other considerations could also play a role in a family’s decision not to invest in these measures. For example, the family may know how long they will reside in the house, or their insurer might not reward them again when their policy is renewed.

Suppose a 20-year required insurance policy were tied to the property rather than to the individual. The homeowner could then take out a \$1500 home-improvement loan at an annual interest rate of 10%, resulting in payments of \$145 per year. If the insurance premium was reduced by \$300, the savings to the homeowner each year would be \$155. Alternatively, this loan could be incorporated as part of the mortgage at an interest rate below 10%.

These mitigation loans would constitute a new financial product. A bank would have a financial incentive to provide this type of loan, because it is now better protected against a

catastrophic loss to the property. In addition, the insurer knows that its potential loss from a major disaster is reduced. Moreover, the general public will now be less likely to have large amounts of their tax dollars going toward disaster relief (Kunreuther 2006)—a win-win-win situation for all!

There is an additional benefit to insurers in having banks encourage individuals to invest in cost-effective mitigation measures. The cost of reinsurance, which protects insurers against catastrophic losses, should now decrease. If reinsurers know that they are less likely to make large payments to insurers because each piece of property in a region now has a lower chance of experiencing a large loss, then they will reduce their premiums to the insurer for the same reason that the insurer is reducing its premium to the property owner.

Suppose that an insurer had 1000 identical insurance policies in a particular area and that each would expect to make claims payments of \$40,000 following a hurricane if homeowners had not strengthened their roofs. The insurer's loss from such a disaster would be \$40 million. Suppose also that the insurer would want to have \$25 million in coverage from a reinsurer to protect its surplus. If the hypothetical hurricane has a 1-in-100 chance of hitting the region where these families reside, the expected loss to a reinsurer would be \$250,000 and the premium charged to the insurer would reflect this. If the bank required that all 1000 homes had their roofs mitigated to meet the local building code and each homeowner's loss were reduced to \$10,000, then the insurer's total loss would be \$10 million should all 1000 homes be affected, and it would not require reinsurance. These savings would be passed on by the insurer to the homeowner in the form of a lower premium.

In addition to all these benefits, LTI would also reduce transaction costs from the consumer's and insurer's point of view. More specifically, an insurer who offers an LTI policy has reduced marketing costs because this is incurred only at the time the contract is offered rather than every year. Similarly, consumers with one-year policies whose contracts are canceled at the end of the year are able to avoid the search costs of looking for another policy by buying an LTI policy. The expected social welfare benefits to the consumer based on a long-term policy can be quite substantial.

6.3. Why Does a Market for Long-Term Insurance Not Exist Today?

To move forward in developing a market for LTI, it is important to consider some of the reasons why this market does not exist today. In his seminal work on uncertainty and welfare economics, Kenneth Arrow defined "the absence of marketability for an action which is identifiable, technologically possible and capable of influencing some individuals' welfare. . . as a failure of the existing market to provide a means whereby the services can be both offered and demanded upon the payment of a price" (Arrow 1963). Here we discuss several factors that have contributed to the nonmarketability of LTI for protecting homeowners' property against losses from fire, theft, and large-scale natural disasters. We discuss elements that affect both the supply and demand sides.

6.3.1. Supply side. Insurance rates in the United States are frequently restricted to be artificially low in hazard-prone areas. The result is that the risks most subject to catastrophic losses also become the most unattractive for insurers to market. A second stumbling block, derived from premium regulation, is that insurers are unclear as to how much they will be allowed to charge in the future.

Uncertainty regarding costs of capital and changes in risk over time may also deter insurers from providing LTI. In principle, insurers could add a component in their premium quotes to account for the costs created by these factors. The problem is that the insurance regulator presumed to be representing consumer interests may not allow these costs to be embedded in the approved premiums. Furthermore, it is unclear what the voluntary demand for coverage will be, given the resulting premium. In a real sense, a new and less intrusive format for government regulation of insurance markets may be required if the private markets are to be successful in dealing with time-varying risks and capital. Impediments to risk spreading across insurance firms is another source of market failure.

6.3.2. Demand side. Some homeowners may worry about the financial solvency of their insurer over a long period, particularly if they have the feeling they would be locked-in if they sign an LTI contract. Consumers might also fear being overcharged if insurers set premiums that reflect the uncertainty associated with long-term risks. Furthermore, those who have not suffered a loss for 10 years but have a 25-year LTI may feel that the premiums are unfairly priced. It is thus essential that the design of an LTI contract anticipates these concerns. The policy may also include specific features that allow contract terms to change over time.

6.3.3. Open issues. There are many issues that have to be addressed in the development of long-term property insurance contracts:

- Could insurers offer adjustable rate policies similar to these types of mortgage contracts?
- Could property owners change their insurance policy over time in a manner similar to refinancing a mortgage?
- What role would the modeling companies and the scientific community studying climate science play in providing estimates for developing risk-based premiums and for suggesting a rationale for changes over time as new information becomes available from the scientific community?
- What types of risk-transfer instruments would emerge from the reinsurance market as well as from the capital markets to protect insurers against catastrophic losses?
- What role would the federal government play in providing such protection?
- Should property owners be required to purchase insurance or would this be at the discretion of the banks issuing a mortgage?

Although these issues will have to be resolved before such policies are marketed, we feel that the idea should be introduced as a way of dealing with the issue of myopia that often discourages individuals and firms from investing in cost-effective mitigation measures.

7. CONCLUSION: LESSONS FROM NATURAL DISASTERS TO OTHER EXTREME EVENTS

Our analysis in this article deals with one type of catastrophe (natural hazard) and one country (the United States), but we believe the findings apply to a broader set of extreme events and extend to other countries (see also Kunreuther & Michel-Kerjan 2009, ch. 15). We expand on this point below by focusing on the myth of low-probability events and

suggesting ways of linking risk assessment and risk perception with risk management for catastrophic events as part of a more coherent strategy for dealing with extreme events.

7.1. The Myth of Low-Probability Events

Conventional wisdom holds that major accidents and disasters are low-probability events. From the viewpoint of any individual or any community these events may indeed have a small chance of occurring. However, when one expands the lens to a state, country, or the global community, the likelihood of a catastrophic event increases.

It is somewhat sobering, for instance, to learn that the probability that at least \$10 billion of insured properties will be destroyed by hurricanes in Florida next year is one in six. This is equivalent to the chance of getting the number three when one tosses a die—hardly a low probability. If we extend the time horizon from 1 year to 10 years while keeping the population of Florida constant, the likelihood of damage exceeding this amount is greater than five in six.

With more economic development in coastal areas and the possible increased intensity of hurricanes due to global warming, we are almost certain to experience a disaster of \$10 billion or greater in Florida in the next decade. If one extends the event space to include all natural disasters and the sample space to encompass the globe, then it should be clear that we have to modify our definition of a low-probability event. In other words, we expect large-scale catastrophes to unfold at an accelerating rhythm in the coming years. What should be done to meet this new challenge?

7.2. Risk Management Strategies for Extreme Events

Catastrophic risk management strategies should be based on assessments of the risk, recognize interdependencies, and address behavioral biases and heuristics used by decision makers who can influence the risk. The capabilities of the private sector should be utilized to develop risk management strategies in combination with public sector initiatives that address the aforementioned pitfalls.

In the context of natural disasters, we propose the development of long-term contracts such as multiyear insurance policies with premiums reflecting risk and multiyear financial loans to encourage homeowners to invest in cost-effective loss-reduction measures. Given the vulnerability associated with poorly designed structures, there is a need for well-enforced building codes for new structures in hazard-prone areas.

Turning to other extreme events, we believe that similar risk management strategies may be appropriate for reducing future losses. Rather than assuming that an event will not happen, one should develop worst-case scenarios to determine whether there are steps that can be taken to reduce the impact. For example, with respect to the recent financial crisis, there has been extensive documentation as to how the subprime mortgage crisis could have easily been predicted had the industry developed scenarios where housing prices fell nationally by a large amount. Similarly the *New Orleans Times Picayune* (2002) had a series of articles predicting Hurricane Katrina and the *National Geographic* published an article (Bourne 2004) characterizing the devastation that a disaster such as Katrina could do to the city. The disaster occurred 10 months later. The challenge is to develop economic incentives to reward individuals and organizations for taking these scenarios seriously, as there are often competing interests to be satisfied immediately.

There are also opportunities for developing long-term contracts that take the behavioral biases and heuristics utilized by decision makers into account. For example, presenting probabilities of extreme events in the context of a multiyear horizon may also lead individuals to pay attention to the resulting outcomes. To illustrate, rather than providing information in terms of a 1-in-100 chance of an event occurring next year, one could indicate that the chance of at least one of these events occurring in the next 25 years is greater than one in five.

At the end of the day, the paradox in waging a war against the weather and other extreme events is that we are our own worst enemy. As individuals, we may decide to build in risky areas. As decisions makers in the public sector, we may permit millions of people to live in these high-hazard areas without requiring them to adopt appropriate risk-reduction measures. In refusing to take steps in a proactive manner to reduce our vulnerabilities, we plant seeds for future disasters that will affect our future well-being and social welfare.

DISCLOSURE STATEMENT

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LITERATURE CITED

- Aaron H. 1972. *Shelter and Subsidies: Who Benefits from Federal Housing Policies*. Washington, DC: Brook. Inst.
- Arrow K. 1963. Uncertainty and the welfare economics of medical care. *Am. Econ. Rev.* 53(5):941–73
- Bourne JK Jr. 2004. Gone with the water. *Natl. Geogr. Mag.* 206:88–105
- Burby R, Bollens S, Kaiser E, Mullan D, Sheaffer J. 1988. *Cities Under Water: A Comparative Evaluation of Ten Cities' Efforts to Manage Floodplain Land Use*. Boulder, CO: Inst. Behav. Sci. Univ. Colo.
- Cabantous L. 2007. Ambiguity aversion in the field of insurance: insurers' attitude to imprecise and conflicting probability estimates. *Theory Decis.* 62:219–35
- Cabantous L, Hilton D, Kunreuther H, Michel-Kerjan E. 2009. *Is imprecise knowledge better than conflicting expertise? The impacts of imprecise and of conflicting probabilities on insurance pricing*. Work. Pap., Wharton Risk Manag. Decis. Process. Cent., Wharton Sch., Univ. Pa.
- Crossett KM, Culliton TJ, Wiley PC, Goodspeed TR. 2004. *Population Trends Along the Coastal United States: 1980–2008*. Silver Spring, MD: Natl. Ocean. Atmos. Admin.
- Cummins JD, Weiss MA. 2008. *Convergence of insurance and financial markets: hybrid and securitized risk transfer solutions*. Work. Pap., Temple Univ.
- Dischel RS. 2002. *Climate Risk and the Weather Market, Financial Risk Management with Weather Hedges*. United Kingdom: Risk Books
- Francis T. 2005. After Katrina, insurance costs to rise. *Wall Street Journal*, Sept. 5: C1
- Goodnough A. 2006. As hurricane season looms, states aim to scare. *New York Times*, May 31: A16
- Grossi P, Kunreuther H, eds. 2005. *Catastrophe Modeling: A New Approach to Managing Risk*. New York: Springer
- Höppe P, Pielke R, eds. 2006. *Workshop on climate change and disaster losses: understanding and attributing trends and projections*. SPARC Workshop Rep., Univ. Colo., May 25–26, Hohenkammer, Germany
- Huber O, Wider R, Huber O. 1997. Active information search and complete information presentation in naturalistic risky decision tasks. *Acta Psychol. (Amst.)* 95:15–29

- Institute for Business and Home Safety. 2009. *Fortified... for safer living*. http://www.ibhs.org/property_protection/default.asp?id=8
- Intergovernmental Panel on Climate Change. 2007. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. S Solomon, D Qin, M Manning. Cambridge, UK: Cambridge Univ. Press
- Jaffee D, Kunreuther H, Michel-Kerjan E. 2008. *Long term insurance (LTI) for addressing catastrophic market failure*. Work. Pap. 14210, NBER
- Kunreuther H. 1996. Mitigating disaster losses through insurance. *J. Risk Uncertain.* 12:171–87
- Kunreuther H. 2006. Disaster mitigation and insurance: learning from Katrina. *Ann. Am. Acad. Polit. Soc. Sci.* 604:208–27
- Kunreuther H, Ginsberg R, Miller L, Sagi P, Slovic P, et al. 1978. *Disaster Insurance Protection: Public Policy Lessons*. New York: Wiley & Sons
- Kunreuther H, Meszaros J, Hogarth R, Spranca M. 1995. Ambiguity and underwriter decision processes. *J. Econ. Behav. Organ.* 26:337–52
- Kunreuther H, Michel-Kerjan E. 2004. Policy-watch: challenges for terrorism insurance in the United States. *J. Econ. Perspect.* 18(4):201–14
- Kunreuther H, Michel-Kerjan E. 2009. *At War with the Weather: Managing Large-Scale Risks in a New Era of Catastrophes*. New York: MIT Press
- Kunreuther H, Novemsky N, Kahneman D. 2001. Making low probabilities useful. *J. Risk Uncertain.* 23:103–20
- Landsea CW, Harper BA, Hoarau K, Knaff JA. 2006. Can we detect trends in extreme tropical cyclones? *Science* 313:452–54
- Lane M, ed. 2002. *Alternative Risk Strategies*. London: Risk Waters Grp.
- Laska SB. 1991. *Floodproof Retrofitting: Homeowner Self-Protective Behavior*. Boulder, CO: Inst. Behav. Sci. Univ. Colo.
- Lecomte E, Gahagan K. 1998. Hurricane insurance protection in Florida. In *Paying the Price: The Status and Role of Insurance Against Natural Disasters in the United States*, ed. H Kunreuther, R Roth. Washington, D.C: Joseph Henry Press
- Loewenstein G, Prelec D. 1991. Negative time preference. *Am. Econ. Rev.* 81(2):347–52
- Michaels P. 2006. *Is the sky really falling? A review of recent global warming scare stories*. Policy Anal. 576, Cato Inst.
- Michel-Kerjan E, Morlaye F. 2008. Extreme events, global warming, and insurance-linked securities: how to trigger the “tipping point.” *Geneva Pap. Risk Insur. Issues Pract.* 33:153–76
- Mills E. 2005. Insurance in a climate of change. *Science* 308:1040–44
- Munich Re. 2008. *Catastrophe figures for 2008 confirm that climate agreement is urgently needed*. Munich Re Press Release, Dec. 29
- New Orleans Times Picayune*. 2002. *Special report: washing away*. Five-part series June 23–27. <http://chss.montclair.edu/english/furr/essays/tpnoseries02.pdf>
- Palm R, Hodgson M, Blanchard RD, Lyons D. 1990. *Earthquake Insurance in California: Environmental Policy and Individual Decision Making*. Boulder, CO: Westview
- Pielke R Jr, Gratz J, Landsea C, Collins D, Saunders M, Musulin R. 2008. Normalized hurricane damage in the United States: 1900–2005. *Nat. Hazard Rev.* 9:29–42
- State Board of Administration of Florida. 2006. *A Study of Private Capital Investment Options and Capital Formation Impacting Florida’s Residential Insurance Market*. Tallahassee, FL: SBA Florida
- Stone J. 1973. A theory of capacity and the insurance of catastrophe risks: part I and part II. *J. Risk Insur.* 40:231–43, 339–55
- Swiss Re. 2005. *Natural catastrophes and man-made disaster in 2004: more than 300,000 fatalities, record insured losses*. Sigma Study 1, Swiss Re
- U.S. Government Accountability Office. 2005. Catastrophe risk: U.S. and European approaches to insure natural catastrophe and terrorism risks. Appendix III. *GAO Rep.* GAO-05-199, Washington, DC

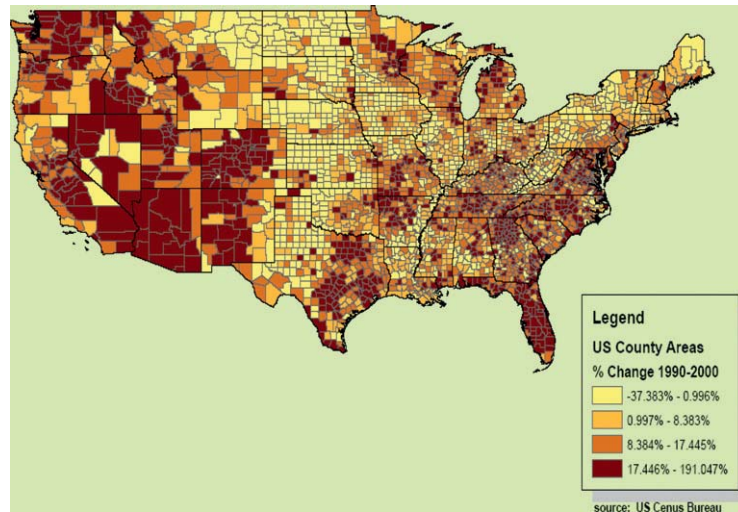


Figure 2
Evolution of the U.S. population between 1990 and 2000.

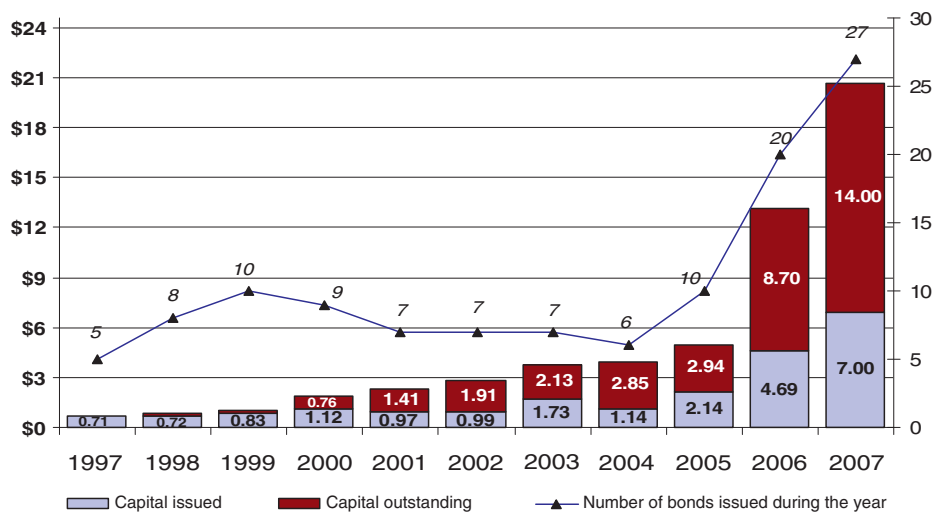


Figure 4
Natural catastrophe bonds: capital risk issued and outstanding 1997–2007 (in billions of dollars, left vertical axis). Years are noted in the right vertical axis. Bonds for natural disasters in the United States and abroad are combined; also included is the first liability cat bond (Avalon Re) issued by Oil Casualty Company in 2005 for \$405 million. Sources: Data from Swiss Re Capital Markets, Goldman Sachs, and Guy Carpenter.



Contents

Prefatory Article

- An Amateur Among Professionals
Robert M. Solow 1

Policy Analysis and Design

- Agriculture for Development: Toward a New Paradigm
Derek Byerlee, Alain de Janvry, and Elisabeth Sadoulet 15

- Governance Structures and Resource Policy Reform:
Insights from Agricultural Transition
Johan F.M. Swinnen and Scott Rozelle 33

- Distortions to Agricultural Versus Nonagricultural
Producer Incentives
Kym Anderson 55

- Public-Private Partnerships: Goods and the Structure of Contracts
Gordon Rausser and Reid Stevens. 75

- Environmental Regulations and Economic Activity:
Influence on Market Structure
Daniel L. Millimet, Santanu Roy, and Aditi Sengupta. 99

- The Development of New Catastrophe Risk Markets
Howard C. Kunreuther and Erwann O. Michel-Kerjan 119

- The Curse of Natural Resources
Katharina Wick and Erwin Bulte 139

- Experiments in Environment and Development
Juan Camilo Cárdenas 157

- Behavior, Environment, and Health in Developing Countries:
Evaluation and Valuation
Subbrendu K. Pattanayak and Alexander Pfaff. 183

Resource Dynamics

Irreversibility in Economics <i>Charles Perrings and William Brock</i>	219
Whither Hotelling: Tests of the Theory of Exhaustible Resources <i>Margaret E. Slade and Henry Thille</i>	239
Recent Developments in the Intertemporal Modeling of Uncertainty <i>Christian P. Traeger</i>	261
Rent Taxation for Nonrenewable Resources <i>Diderik Lund</i>	287
Land Use and Climate Change Interactions <i>Robert Mendelsohn and Ariel Dinar</i>	309
Urban Growth and Climate Change <i>Matthew E. Kahn</i>	333
Reduced-Form Versus Structural Modeling in Environmental and Resource Economics <i>Christopher Timmins and Wolfram Schlenker</i>	351

Ecology and Space

Integrated Ecological-Economic Models <i>John Tschirhart</i>	381
Integrating Ecology and Economics in the Study of Ecosystem Services: Some Lessons Learned <i>Stephen Polasky and Kathleen Segerson</i>	409
The Economics of Urban-Rural Space <i>Elena G. Irwin, Kathleen P. Bell, Nancy E. Bockstael, David A. Newburn, Mark D. Partridge, and JunJie Wu</i>	435
Pricing Urban Congestion <i>Ian W.H. Parry</i>	461
The Economics of Endangered Species <i>Robert Innes and George Frisvold</i>	485
On the Economics of Water Allocation and Pricing <i>Yacov Tsur</i>	513

Technology and Innovation

The Economics of Agricultural R&D <i>Julian M. Alston, Philip G. Pardey, Jennifer S. James, and Matthew A. Anderson</i>	537
--	-----

Supply and Demand of Electricity in the Developing World <i>Madhu Khanna and Narasimha D. Rao</i>	567
Energy Efficiency Economics and Policy <i>Kenneth Gillingham, Richard G. Newell, and Karen Palmer</i>	597
Recent Developments in Renewable Technologies: R&D Investment in Advanced Biofuels <i>Deepak Rajagopal, Steve Sexton, Gal Hochman, and David Zilberman</i> . . .	621
Fuel Versus Food <i>Ujjayant Chakravorty, Marie-Hélène Hubert, and Linda Nøstbakken</i> . . .	645
The Economics of Genetically Modified Crops <i>Matin Qaim</i>	665

Errata

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