Managing Catastrophic Risk: Lessons from Canada

by

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1. INTRODUCTION

Natural disasters are a serious threat to societies around the world. Death, injury and displacement affect hundreds of millions of people each year, while the frequency and severity of property damage is rising at an alarming rate. The UN's International Decade for Natural Disaster Reduction is a recent effort to promote better management of catastrophic risk; nevertheless, losses remain unacceptably high. The authors believe that the knowledge exists to better manage catastrophic risk, and the Canadian experience demonstrates a new approach to build resilient communities and reduce disaster losses.

Kunreuther has written extensively about a theoretical framework for public-private partnership in disaster management (Kunreuther 2001). He emphasizes the role that insurance, coupled with well-enforced standards, can play as a tool for reducing future disaster losses and provide funds for financial recovery after a catastrophic event. Kovacs has contributed to the international discussions about climate change, and adaptation to the changing risk of extreme events. He has also written about the Canadian approach to managing disaster risk, the role of insurance and options for prevention through the strengthening of community resilience (Kovacs 1999, 2001).

This paper brings the authors together to suggest a comprehensive framework for action to better manage the peril of natural hazards, and review how theory has been put into practice. The paper includes examples primarily from the Canadian experience, supplemented by some from the United States. Our principal purpose is to explore the major issues that have been raised with respect to catastrophic risk management and identify areas of potential further research and policy development in Canada and elsewhere.

2. THE PROBLEM

Nature's hazards – earthquakes, volcanoes, landslides, tsunamis, flooding, hurricanes and tornadoes – directly affect hundreds of millions of people each year. During the 1990s, 2,800 natural disasters killed more than 500,000 people and directly affected 1.3 billion people (International Federation of Red Cross and Red Crescent Societies 2000). The majority live in emerging economies where daily life is challenging during the best of times, and remarkably difficult when disaster strikes. Some die, others are injured, and many are displaced from their homes. For example, in 1989 Hurricane Hugo damaged or destroyed 98 percent of the homes on the Caribbean island of Montserrat (Benson and Clay 2000). Our long experience with Nature's fury continues to exact a toll that is unacceptable.

There has been a dramatic increase in property damage in recent decades, with most occurring in affluent regions including the United States, Japan and Europe. Since the early 1960s damage has been doubling every seven years or so, on average (Munich Re 2001). This represents a 14-fold increase over the past 40 years. If this alarming trend were to continue, then "around 2065 the world's wealth would be totally consumed by

the cost of natural disasters. Clearly such a 'limits to growth' projection is naïve… however, there is no room for complacency" (Dlugolecki 2001).

These losses have major financial implications. Worldwide natural disaster damage exceeded US$700 billion during the 1990s (International Federation of Red Cross and Red Crescent Societies 2000). The largest losses have been in the more developed nations because they own the majority, by financial value, of the world's buildings and other infrastructure. In Canada, the United States and most other affluent countries the insurance industry has assumed financial responsibility for most of the catastrophic damage to homes and businesses. Overland flood risk is often the only significant peril that is typically excluded from private insurance coverage. In Canada, the Flood Damage Reduction Plan was the primary program since the 1970s for managing flood risk, but during the 1990s Environment Canada withdrew its support for the program and no other level of government has effectively filed this void (Shrubsole 2000). In the United States, flood management includes the National Flood Insurance Program established as a governmental program with private delivery.

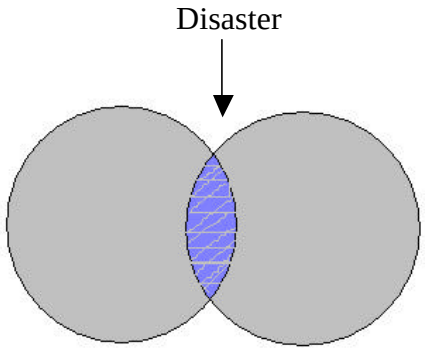
Schools, hospitals, bridges and other public structures are generally **not** covered by insurance for catastrophic damage, nor has there been much interest in disaster prevention investment programs. In part, this is because of budget constraints and a feeling that the disaster will not happen to our city. In the United States the principal reason for not investing in these protective measures is an assumption by municipal officials, borne out in reality, that much of the costs from disasters will be covered at the national level. More specifically the federal government provides funds to cover at least 75 percent of the costs of rehabilitating public facilities, but for catastrophic events, such as Hurricane Andrew in 1992 and the Mississippi Floods of 1993, it has covered the entire cost of public facility repairs. Ninety percent of these costs were covered after the Northridge earthquake, with the remainder financed by the State of California (Kunreuther and Roth, Sr. 1998).

In contrast, the role of the federal government in Canada is set out in the Disaster Financial Assistance Agreement that includes a sliding scale of assistance. Public relief is not to be provided to property owners when affordable private insurance is generally available. Federal assistance partially covers provincial disaster payments. Smaller events do not trigger any national disaster assistance funding. Yet the federal government likely covered 50 to 75 percent of the losses paid by provincial governments during the 1998 ice storm – Canada's most severe disaster loss – and funding could reach as high as 90 percent for even larger events, like a major urban earthquake (EPC 1999).

A number of organizations have assumed leadership for disaster issues in developing countries including the international Red Cross, World Bank, United Nations (UNDP, UNEP and ISDR), World Health Organization and Médecins Sans Frontières. Historically these organizations have focussed on response and recovery issues, and only recently have they begun to explore the potential for disaster prevention. This includes the World Bank's Disaster Management Facility and its focus development for prevention and mitigation, and the ProVention Consortium (Benson and Clay 2000).

Many extreme events occur in remote areas where there are very few people and little property at risk. This is most evident at sea, where our vast oceans have few people, ships or structures. These events are seldom described as a disaster. As shown below in Figure 1, hazards must converge with a vulnerable population to become a disaster, and cause significant loss of life and property damage. Accordingly, it is important to explore both the nature of hazards and also our vulnerability to Nature's perils.

FIGURE 1 HAZARDS CONFRONTING VULNERABLE COMMUNITIES CAUSE DISASTERS



There is strong agreement in the science community that the frequency and severity of earthquakes, volcanoes and other geological hazards has not changed in recent decades. Nor is the nature of these hazards expected to change over the next few decades. By definition, extreme events happen very seldom; however, they can inflict tremendous damage when they strike. Increasing earthquake damage in recent years is evidence of rising vulnerability and bad luck for the communities affected. More people with more valuable property are residing in earthquake-prone areas (Bruce, 1999).

Extreme weather events present a different story. The science community has demonstrated that the world's climate has changed in recent decades. Furthermore, additional and perhaps accelerating changes are predicted for the years ahead. These changes are complex, even if some summarize these developments with simple labels like "global warming". Some extreme weather risks are becoming less commonplace, including a reduction in the number of minor winter storms in several countries. The characteristics of other events are changing, like the expectation that spring flooding risk will peak earlier in the year. Many others perils are becoming much more dangerous, including the risk of sea surge in communities threatened by rising sea levels, increased periods of extreme rainfall and a growing risk of prolonged drought (IPCC 2001).

Much of the increase in disaster losses in recent years reflects society's growing vulnerability to Nature's hazards. Our public infrastructure is aging, and is increasingly incapable of managing the challenge of extreme events. Moreover, more people and

property are living in areas of risk. This includes rapid population growth, particularly in developing countries with most of the growth in very large urban centres. Disaster damage is frequently many times greater than it would have been in the past because the hazard strikes a community that now has many more people and so much more property. Dennis Mileti's "Disaster by Design" sets out in detail the changes in behavior, which have contributed to the growing disaster losses, and the enormous potential to better manage this risk (Mileti 1999).

To illustrate, the number of people living in the Vancouver area has more than doubled in the past thirty years (Statistics Canada 1997). Despite the severe earthquake risk evident in the area, the city has experienced one of the fastest rates of population and economic expansion in Canada. Similarly, each year approximately 130,000 new households are established in Florida and the coastal county population rose from 7.7 to 10.5 million between 1980 and 1993, a rate of sustained increase similar to that recorded in Vancouver. It is thus not surprising that the insurance industry suffered losses of over US$15 billion from Hurricane Andrew in 1992 – the single largest insured loss from any disaster – and the industry estimates that a major hurricane in this region could cause over US$50 billion in claims (Lecomte and Gahagan 1998).

3. FRAMEWORK FOR ACTION

Lowering expected future disaster damage requires focusing on the likelihood of the hazard and the vulnerability of the hazard-prone area. Reducing the frequency and severity of Nature's hazards has been explored frequently over the years but appears to hold less scope than efforts to reduce vulnerability. Table 1 suggests a framework for managing catastrophic risks.

Table 1: A FRAMEWORK FOR CATASTROPHIC RISK MANAGEMENT

Hazard Reduction	***Reducing Vulnerability***
controlling CO2 emissions	**disaster prevention**
weather modification	**emergency response**
other seismic/climate interventions	**community recovery**

A. Hazard Reduction – Changing Nature

The science community generally agrees that it is very difficult to materially reduce the frequency or severity of earthquakes and severe weather. The area of most active research is climate change and variability. Considerable diplomatic and research energy has been directed at establishing mechanisms to reduce greenhouse gas emissions as a means to stabilize the global climate, including climate extremes. Even optimistic forecasts, however, show that it will take many decades before this effort could meaningfully affect current climate trends (IPCC 2001).

Another area of study involves weather modification. Small-scale modification programs are in place in several countries around the world seeking to reduce hail damage. Cloud seeding is used to modify storms that appear likely to generate damaging hail, allowing the precipitation to fall in a form that is not expected to cause damage. The Canadian program is the only weather modification program currently in place which is funded entirely by the insurance industry. It has a mandate to reduce hail damage to vehicles and buildings. The science behind these programs continues to be debated, but in recent years the Canadian program has operated through a period of increased storm activity and this has coincided with a significant decline in hail damage insurance claims. The industry has experienced savings that are many-fold greater than the modest cost of the program.

Experiments to modify tropical cyclones by seeding began in 1947. The STORMFURY program was active in the late 1960s and 1970s. The program ended in the late 1970s because the results were not encouraging (Etkin et al 1998). There have also been a number of programs designed to enhance rainfall and reduce the risk of drought. For example, in 1997, a program aimed at mitigating the effects of drought in Northern Mexico was launched by the National Water Commission, Mexican Water Technology Institute, University of Colorado and the Coahuila state government.

The many small earthquakes provoked by nuclear testing have led to the first inadvertent experiments for earthquake control. In 1961, the US army drilled a deep well near Denver seeking to dispose of contaminated wastewater from chemical weapons manufacturing. The effort caused more than 700 earthquakes at magnitudes up to 4.3 on the Ritcher Scale. Between 1969 and 1970, the US Geological Survey carried out experiments to pressurize redundant oil wells near Rangely, Colorado causing 900 earthquakes. There is also a body of research studying reservoir-induced seismicity, including earthquakes of 5.0 to 6.5 magnitude in India, Greece, China, the United States, Zimbabwe, Yugoslavia and New Zealand (Alexander 1993).

In summary, there have been a number of prominent efforts to alter the risk of perils, but with a few exceptions, these have been viewed as largely unsuccessful, unpredictable and likely unwise. Spending on weather modification in the US largely began in the 1960s and peaked in the mid-1970s before dropping to current levels that are likely about 10 percent of the highest values (Cotton and Pielke 1995). Conventional wisdom warns not to fool with Mother Nature.

B. Reducing Vulnerability – Building Resilience

An essential element of preventing future disaster losses involves reducing vulnerability to hazards by building community resiliency. A strategy to build resiliency must begin with an assessment of the current vulnerability of the region. This requires information on the design of residential, commercial and public sector structures and infrastructure and their locations in relation to various hazards.

The use of geographic information systems (GIS) for incorporating natural conditions (e.g. geological data) and structural information for a region has enabled scientists and

engineers to estimate potential damage and losses from different disaster scenarios (King and Keremedjian in press). With respect to loss reduction activities, one should evaluate the costs and the expected benefits over time of adopting specific mitigation measures.

The quality of this essential planning information varies considerably from country to country, and from community to community. Frequently disaster management efforts for developing and emerging economies suffer from the absence of such foundational data. Detailed hazard assessments are a requirement for catastrophic risk management models.

Once a community's vulnerability has been assessed, what can be done to increase its resiliency to the consequences of natural disasters? Strategies for reducing losses and providing financial protection include well-enforced building codes, the use of warnings and evacuation plans to reduce loss of lives and damage at the onset of an event, and recovery strategies such as insurance and financial assistance following a disaster. These policy tools complement each other: well-enforced building codes reduce the need for financial assistance after a disaster; warning and evacuation procedures reduce the need for emergency hospital care in the affected region.

The full range of activities can be clustered into three critical elements of an effective emergency preparedness strategy – prevention, response and recovery:

Disaster Prevention

Adaptation involves investments before disaster strikes, actions designed to strengthen society's ability to resist the impact of future perils. Key elements of an adaptation or mitigation strategy for disaster prevention include the following:

- Public awareness – Informed families are best able to manage Nature's hazards, including the objective of establishing a culture of preparedness.
- Land use planning – Resilient communities keep people and structures away from areas where the hazard risk has been identified.
- Well-enforced building codes – Cost effective mitigation measures should be incorporated in design standards for existing and new structures, schools, hospitals and offices.
- Structural measures – Dams, levees, seawalls and other engineered structures can be effective mechanisms to protect communities.
- Non-structural measures – Plantings can reduce beach erosion, healthy marshes help manage flood risk and other natural elements can reduce disaster damage.

Emergency Response

Response programs bring timely and comprehensive assistance to disaster victims. Effective emergency response is essential to reduce disaster losses and establish the basis for more rapid recovery. It includes the following elements:

- Hazard assessment – Community based hazard assessment is essential if local officials are to effectively formalize their disaster planning efforts.
- Disaster planning – Each community needs to establish a comprehensive disaster plan and develop the capacity of responsible officials to implement the plan.
- Warning systems – Doppler radar, hurricane tracking, seismic monitoring and other warning and information systems strengthen both prevention and response.
- Resource planning – Access to critical resources should be clarified before a hazard strikes, including food, power and communications.
- Interjurisdictional issues – Response requires coordination of police, ambulance, fire, local, regional, national and perhaps international agencies.

Community Recovery

A principal objective of catastrophic risk management is for a community to re-establish itself after disaster strikes, restoring functionality and a sense of normality. Disaster recovery takes time, funds and effective management including the following elements:

- Charities – The Red Cross has a long history of helping people in times of need.
- Disaster relief – All levels of government finance and help manage aspects of disaster recovery, including public building, infrastructure and uninsured risks.
- Private insurance – Insurance is the primary mechanism most homeowners and businesses use to secure funds to recover following most hazards.
- Public insurance – Some countries have established public insurance schemes, such as the National Flood Insurance Program in the United States.
- International aid – Developing and emerging nations finance their disaster recovery efforts primarily through international aid.

A challenge is to determine the appropriate mix of these different measures so as to balance equity and fairness concerns with efficient allocation of resources.

4. THE CANADIAN EXPERIENCE

Canada provides a nice example of the effective implementation of a comprehensive approach to disaster risk management. In this section we describe the key features of the Canadian model, with special attention to the components dealing with mitigation investments for disaster prevention, and financial recovery including the role of insurance and other risk transfer mechanisms.

A. Hazard Reduction – Changing Nature

Canada has played a leadership role in international scientific research on climate change, including the nature of climate variability and extremes. The country has also participated in all aspects of the international climate change negotiations. Canada has, however, been criticized by some because it has adopted a cautious policy approach on this issue that is seen to be similar to that of the United States and Japan, and much less aggressive that of the major countries in Europe. This is evident in the continuing increase in CO2

emissions despite Canada's commitment in Kyoto to reduce emission to 5 percent below 1990 levels.

Governments in Canada appear to have withdrawn from involvement in weather modification programs. Private insurers are now operating one program that was previously run by the government of Alberta to reduce hail damage. When the government ran the program it included a research component that was not continued when private insurers assumed financial responsibility. We are not aware of other active programs to directly influence severe weather and seismic risks in Canada, nor are any expected in the immediate future.

B. Reducing Vulnerability – Building Resilience

Nature's hazards have always been visible and evident in Canada, a vast nation with a challenging geography. Canadians experience earthquakes, landslides, hurricanes, tornadoes, hail, sea surge, flooding, drought, winter storms and much more. An active national effort has long been in place in Canada to reduce vulnerability to nature's hazards. Disaster experts regard the Canadian model as amongst the strongest in the world in terms of emergency response and community recovery, although there is need to improve prevention efforts. Below we characterize different elements of the program.

Disaster Prevention

During 1998, more than 500 disaster preparedness experts across Canada discussed the country's capacity to manage extreme events. There was a consensus that Canada should establish a national mitigation strategy (ICLR 1999). Disaster prevention investments have taken place over the years but they have not yet become part of an ongoing co-ordinated strategy. In particular, the 27-year-old agreement between senior governments in Canada provides a formal clarification of responsibilities with respect to emergency response and community recovery, but it presently does not expressly address disaster prevention and mitigation.

In recent years there has been a continuing effort to establish a national program of disaster prevention building on approaches applied in other countries, notably the United States and Australia. In the US, the Federal Emergency Management Agency (FEMA) introduced a National Mitigation Strategy in December 1995 with the objective of strengthening partnerships between all levels of government and the private sector to ensure safer communities. This strategy was developed with input from state and local officials as well as individuals and organizations with expertise in hazard mitigation (FEMA, 1997). The Australia program operates at the state level, again working with local officials. While the US program includes considerable direction and leadership from Washington, a significant difference in the Australian program is the support role of the national authorities to state officials who lead in emergency preparedness. Both these programs stress the importance of using local planning to identify key investments that significantly build community resilience to extreme events.

With respect to structural measures, Canada's most visible success in disaster prevention has been the construction of the Red River floodway in Winnipeg Manitoba (IJC 2000). A modest investment of $63 million established a structure to divert waters around the city of Winnipeg during times of flooding. The system has been used 18 times during its first 40 years of operation, and has contributed to the prevention of more than a billion dollars in property damage. There have been many other Canadian investments in dams, levies, sea walls and other mechanisms to reduce disaster damage, even if these are perhaps not as well known as the Red River floodway. Currently Canada does not have a formal strategy to support future investments in disaster safety, although the insurance community has been working with federal and provincial officials toward realizing this goal.

Land-use regulation has helped reduce disaster losses in Canada. To illustrate its success consider the major rainstorm passed across the Michigan/Ontario border in 1986. Property damage in the United States was 1,000 times greater than that in Canada. Adjustments for rain intensity, property values and other factors lead to the finding that almost all of the difference in the losses was due to more aggressive Canadian efforts to restrict development in the floodplain (Brown et al 1997). Indeed, following Hurricane Hazel in 1954, Ontario has become one of the most effective regions working to keep people and property from locating in areas of hazard risk.

With respect to warnings, during the 1990s Canada began investing in a national Doppler radar system. Soon the program will cover more than 95 percent of Canadians. When tornadoes and other extreme weather events threaten, this system provides earlier warning time. The system also strengthens traffic safety for airlines and road transport.

Canada has long operated a national building code. Every provincial government has adapted the national program to reflect regional concerns, while local officials are responsible for enforcement. The system works to include new ideas found in national and international construction research programs. Research in Florida before Hurricane Andrew struck, for example, provided warnings about the poor quality of code enforcement in that state. We are not aware of code enforcement research in Canada, but anecdotal evidence following disasters across North America, including the Red River Basin floods in 1997, suggest that more intense building code enforcement can improve community resilience to extreme events.

Emergency Response

Canada's emergency response system is based on the approach that individuals are primarily responsible for their own safety after a disaster. When a family is overwhelmed they should look to the local community for support. A community will, in turn, look to the provincial government, while the national government becomes involved only when asked to do so by provincial authorities (Hightower and Coutu 1996). The Emergency Preparedness Canada disaster database includes damage estimates for 450 events in Canada over the past century. 350 events included payments by government agencies. Almost 100 of these included federal payments to the provinces to partially offset their

costs. The remainder did not include any federal payments because the magnitude of the losses did not exceed the minimum threshold for participation. Hazard assessment and disaster planning at the local level is the key to success in the Canadian system.

In recent years the Canadian program of emergency response has been tested frequently, including the three most costly disasters – the 1996 Saguenay flood, 1997 Red River Basin flood and the 1998 ice storm. The people in Quebec have been severely tested, confronted with both the Saguenay flood and a major ice storm (Nicolet 1999). Comprehensive analysis of the Quebec system led the provincial government to table legislation last year requiring detailed hazard planning at the local level, ongoing community investments in disaster prevention, and that updated plans must regularly be filed with regional and provincial authorities. Using aspects of French disaster legislation and also the U.S. approach to flood risk management, the Quebec legislation ties the availability of potential future disaster relief to the requirement that comprehensive local disaster planning and loss prevention investments take place.

The federal government in Canada has played an important role supporting emergency response. This includes the operation of a disaster management training center. The government also provides much of the hazard assessment information needed for planning. In addition, the federal office of Emergency Preparedness Canada has directed Canada's response supporting a number of international relief efforts.

Community Recovery

Canada has experienced its three largest disaster losses in the years since 1996. Each event was followed by a period of rapid recovery. Insurance loss payments, public relief and charitable givings provided financial resources to support these recovery efforts. Following severe disasters there has been a positive response by the citizenry to provide critical supplies to those in need. Most notably, people from across the country, including flood victims of the 1996 Saguenay flood, were working in 1997 to support Red River Basin flood victims, and also to assist the many victims of the 1998 ice storm. This included filing sandbags and repairing power lines. There are aspects of the recovery process, however, that take many years despite the best efforts of all involved. For example, the 1998 ice storm destroyed or severely damaged millions of trees.

5. REFLECTIONS FROM THE LITERATURE – PREVENTION

The literature on catastrophic risk management is extensive and diffuse. This section summarizes key findings with respect to investments in loss prevention activities. Future damage can be reduced through cost-effective mitigation investments designed to strengthen society's ability to resist the impact of future perils. Significant damage would be averted if wind and seismic building codes were adopted and enforced, and if individuals took protective measures in advance of possible disasters.

The lack of interest in, and enforcement of these measures, coupled with the substantial growth in property investments in disaster-prone areas, has increased the probability that

losses will be severe when a disaster occurs. This section elaborates on these ideas with special attention to research findings related to risk assessment, decision processes and building codes. Observations from the Canadian experience draw out implications for further research and policy development.

Risk Assessment

A catastrophic risk management strategy requires the assessment of the probability and consequences of events of different magnitude. In the case of low probability-high consequence events there are limited past data on which to base these estimates so it is necessary to rely on scientific information to undertake these analysis. The exceedance probability curve is a key piece of information needed to undertake a detailed analysis of the problem (Kunreuther 2001).

A loss exceedance EP curve depicts the probability that a certain level of loss will be exceeded on an annual basis. Using probabilistic risk analysis, one combines the set of events that could produce a given dollar loss and determines the resulting probability of this loss occurring. Based on these estimates, one can construct the mean exceedance probability curve depicted in Figure 2. By its nature, the EP curve inherently incorporates uncertainty in event occurrence probability and magnitude of dollar losses. This uncertainty is reflected in the 5% and 95% confidence interval curves in Figure 2.

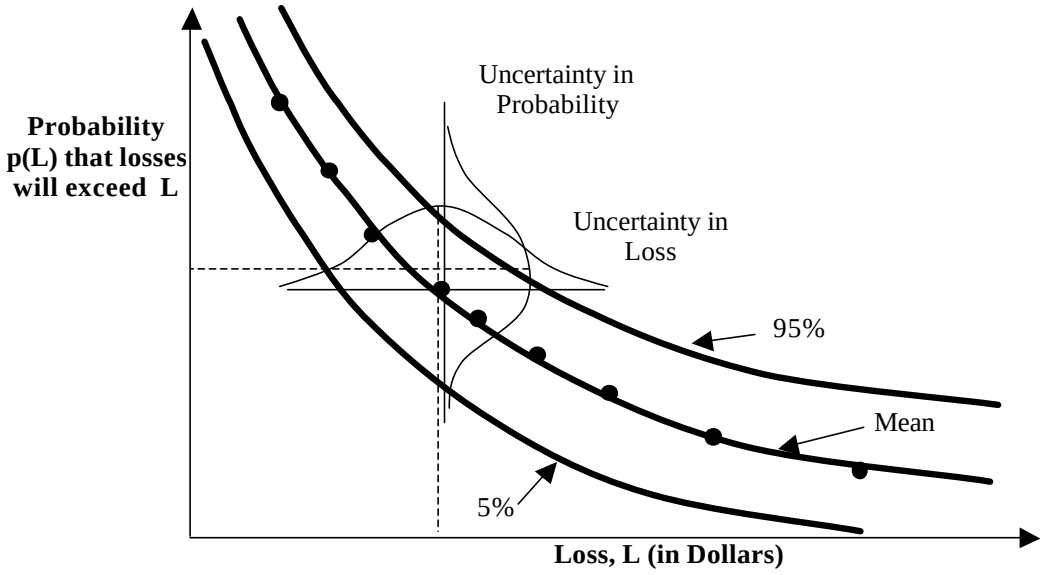


Figure 2. Example of Loss Exceedance Probability Curves

The loss EP curve is the key element for evaluating a set of risk management tools. The accuracy of the EP curves depends upon the ability of natural hazard experts, economists and structural engineers to estimate the impact of events of different probabilities and magnitudes on the performance of different structures.

Research that improves our understanding of both the probability of different events and the resulting damage is essential in reducing uncertainty and improving disaster management. Government agencies, communications and power utilities, insurers and others are involved in supporting this research. New scientific studies and engineering analyses provide estimates of the potential losses of future disasters more accurately than in the past. The development of faster and more powerful computers enables these data to be combined in ways that were not possible even five years ago. In particular, catastrophe models have proven useful for quantifying risks based on estimated probabilities and expected damage (Kunreuther 2001).

The literature raises questions concerning the best ways to combine scientific studies to model risk, and whether catastrophe models are sufficiently reliable to guide the insurance underwriting process. Questions about the best way to model the EP curve and how to improve the databases used in these models are two key areas where more research is needed.

Canada has developed extensive databases including geological/soil conditions, earthquake risks, landslides, ocean ice conditions, and severe weather information. These data have been incorporated into models developed by a number of private and public organizations.

The Canadian insurance industry is involved in supporting research to reduce the uncertainty in catastrophic loss estimates. Through the Institute for Catastrophic Loss Reduction, insurers sponsor ongoing research to improve understanding of both the probabilities associated with extreme events of different magnitudes, and damageability ratios. Both primary insurers and reinsurers also actively use catastrophe models to guide the underwriting process, particularly for earthquake risk. The models currently in use are not yet sufficiently refined to include individual risk rating for residential properties, but they are able to guide underwriting decisions for collections of properties. Models are also used in the regulatory process to monitor solvency risk for insurers.

Canada has not yet explored alternative ways of characterizing the uncertainties associated with determining the probability of disasters of different magnitudes and the vulnerability of structures from these events. Canada would also potentially benefit from continued improvement in the databases for assessing risks in different geographical areas and reducing uncertainty about the vulnerability of different types of structures to the natural hazards to which they are exposed.

Decision Processes

Public policy authorities are constantly seeking cost-effective risk mitigation measures. These are investments in disaster prevention where the discounted expected benefits over the life of the property are greater than the up front expenses associated with the measure. In theory, all of the parties concerned with natural disaster losses should view such measures favorably. The property owner should see this as an investment that increases the value of his or her residence or business. The insurer should charge a lower price or provide more generous coverage because of the knowledge that losses will be reduced should a disaster strike the area. The contractor and developer should find it easier to sell a property that is better designed against hazards, even if it costs more than one which is relatively unsafe. Public sector agencies at all levels should welcome the lower need for disaster assistance due to the reduced losses from future disasters.

The reality is quite different. Few property owners voluntarily adopt mitigation measures, nor do most insurers provide economic incentives for these investments through premium reductions. Housing values do not appear to reflect the benefits of mitigation measures, perhaps because people do not want to be reminded that they live in a hazard-prone area. As a result, developers and contractors have no economic incentive to build safer structures since it means incurring costs that they feel will hurt them competitively because the risk mitigation measures are undervalued by the potential buyers (Kleindorfer and Kunreuther 1999a).

Interviews with structural engineers concerned with the performance of earthquake-resistant structures indicate that they are not motivated to build structures that exceed existing codes because they have to justify these expenses to their clients and would lose out to other engineers who did not include these features in the design (May and Stark 1992). Hence the public sector has to bear a larger portion of the disaster losses than if these measures had been adopted.

The empirical data from studies of mitigation adoption in hazard-prone areas suggest that individuals are not willing to invest in mitigation measures despite the rather large damage that they and/or their friends and neighbors suffered from recent disasters. For example, after Hurricane Andrew in Florida in 1992 – the most severe disaster in the United States in terms of economic losses – most residents in hurricane-prone areas appear not to have made improvements to existing dwellings that could reduce the amount of damage from future storms.

With respect to earthquake damage, measures such as strapping a water heater to the wall with simple plumbers' tape can often be done by residents at a cost of under $5 in materials and one hour of their own time (Levenson 1992). This risk mitigation measure can reduce damage by preventing the heater from toppling during an earthquake creating gas leaks and causing a fire. Yet residents in earthquake-prone areas are not adopting these and other mitigation investments.

A 1989 survey of 3,500 homeowners in four California counties subject to the hazard reported that only between 5 and 9 percent of the respondents in each of these counties reported adopting any loss reduction measures (Palm et al. 1990). There appears to be an interesting correlation between insurance purchasing and mitigation activities. Palm and Carroll (1998) report that those who had adopted mitigation measures such as arranging heavy objects that were less likely to fall and invest in measures strengthening the house were more likely to have also purchased earthquake insurance.

In research to further probe individuals' willingness to pay for mitigation, Kunreuther, Onculer and Slovic (1998) found that a relatively small proportion of subjects behaved as if they made decisions based on benefit-cost comparisons using a reasonable discount rate. These results suggest that risk mitigation measures would need to be very cost effective to be adopted voluntarily through normal private choice.

Altogether, the research on individuals' behavior with respect to low probability/high consequence events suggests that some property owners are reluctant to invest in cost-effective risk mitigation measures because they do not make the implied tradeoffs between spending money now in return for potential benefits over time. Such non-adoption behavior may be further exacerbated by developers who may believe, perhaps correctly, that they are unable to recover the costs of risk mitigation measures in increased selling prices for the structures. Societies clearly need to provide additional incentives and or structures, such as well-enforced building codes, so that cost-effective risk mitigation measures that are in society's interest will be adopted. (Kleindorfer and Kunreuther 1999a).

The Canadian approach to risk mitigation measures has focused to date on encouraging investments in improving the durability of public buildings and infrastructure. It is interesting that the same decision processes that appear to limit individuals' investments in risk mitigation measures also appear to limit public investments in safety. Canadian involvement in encouraging individual choice to take loss reduction actions has to date included insurance industry and government public education campaigns.

If the empirical research from other jurisdictions is found to also hold in Canada, the prospect for affecting significant changes in consumer behavior solely through insurance premium incentives rates will not bear much fruit. It may be possible to combine premium reductions with other measures such as long-term loans tied to a mortgage. More specifically, if homeowners are reluctant to incur the upfront cost of a preventive measure due to short time horizons or budget constraints, then one way to make mitigation financially attractive to the property owner is for the bank to support this investment through a home improvement loan with a payback period identical to the life of the mortgage. If the mitigation measure is cost-effective and insurance premiums are risk-based, then the annual loan payment will be less than the reduction in the cost of insurance.

Well Enforced Building Codes

Building codes mandate that land developers adopt mitigation measures. Such codes may be desirable when property owners would otherwise not adopt cost-effective risk mitigation measures because they either misperceive the benefits from adopting the measure and/or underestimate the probability of a disaster. If a family, for example, is forced to vacate its property because of damage that would have been prevented if a building code had been in place, then this additional cost needs to be taken into account by the public sector when evaluating the cost-effectiveness of a risk mitigation measure from a societal perspective.

Cohen and Noll (1981) provide an additional rationale for building codes. When a structure collapses it may create externalities in the form of economic dislocations that are beyond the physical damage suffered by the owners. These may not be taken into account when the owners evaluate the importance of adopting a specific mitigation measure. For example, if a building topples off its foundation after an earthquake, it could break a pipeline and cause a major fire that would damage other structures not affected by the earthquake in the first place.

There are several key interested parties who can, in theory, enforce building codes. Banks and financial institutions could require an inspection of the property to see that it meets code before issuing a mortgage. Similarly, insurers may want to limit coverage only to those structures that meet the building code. Inspecting the building to see that it meets code and then providing it with a seal of approval provides accurate information to the property owner on the condition of the house. It also signals to others that the structure is disaster-resistant. This new information could translate into higher property values if prospective buyers took the earthquake risk into consideration when making their purchase decisions.

Canadian insurers already use building codes (year of building) in underwriting. The industry is fostering work with construction industry and public authorities regarding supervision of the implementation of the codes. The links among industries that have an interest in building codes, however, are not as strongly developed as they could be. For example, codes focus on preserving life rather than the broader social goal of preserving both life and property. Also, Canadian lenders and insurers do not directly participate in the development of codes or monitor enforcement. Fostering these relationships would potentially benefit the mitigation efforts in Canada.

Open Questions and Suggestions for Further Research

- While some effective risk mitigation measures have been researched and identified (e.g. bolting frames to foundations and strapping water heaters), more research could be done to identify cost-effective mitigation measures for residential as well as commercial and public buildings and infrastructure.
- What are the most effective ways to evaluate the benefits (direct and indirect) from disaster prevention investments? What empirical studies are necessary for

determining the magnitude of the social costs and externalities that could be reduced through well-enforced building codes?

- What role can the insurance industry play in encouraging mitigation through incentives and what changes in institutional structure are needed for this to take place? How can other parties like financial institutions, construction and real estate industry aid the process of disaster prevention?
- What are the processes affecting public decisions to invest in loss reduction activities? How can these be affected through different strategies?
- What are the challenges in enforcing building codes and ways to improve this? Can community based programs play a key role in encouraging mitigation including retrofitting? Is the community rating system associated with the U.S. National Flood Insurance Program a model that one can build on for other perils?

6. REFLECTIONS FROM THE LITERATURE – RECOVERY

This section focuses on a key aspect of physical property recovery – financial recovery. This includes a review of the literature on the role of insurance – exploring the sources of capital available for disaster recovery as well as issues in the demand and supply of insurance. Observations from the Canadian experience provide implications for future research and policy development.

Sources of Recovery Funds

There are many parties concerned with recovery following natural disaster damage. The insurance industry, capital markets and public agencies all have a role to play with respect to providing financial protection against catastrophic losses. In most countries a national emergency management agency has the responsibility for championing loss reduction or mitigation investments as well as providing disaster financial assistance to local governments to deal with public property losses following a natural disaster.

Reinsurers relate to insurers in the same manner that insurers do to property owners. They provide protection to primary insurers by insuring a portion of their claims in exchange for a premium. Reinsurance is a prerequisite to offering insurance against natural disasters when there is a potential for catastrophic losses. Recently, the capital markets have provided private insurers access to funds in the form of catastrophe bonds. The insurer borrows from investors or an institution at higher than normal interest rates to cover extreme losses that exceed a trigger amount. If this amount is exceeded then the interest on the bond, the principal or both are forgiven.

Primary insurance companies provide direct insurance coverage to residential and commercial property owners for losses due to natural disasters, such as compensation for damage due to an earthquake. Primary insurance companies offer this coverage through the standard homeowners' policies normally required as a condition for a mortgage and through commercial multiperil policies. In some jurisdictions, but not in Canada, a public insurance facility also offers insurance protection in complement or competition with the private insurance industry.

While all these stakeholders potentially play a role in the financial recovery from a disaster, many jurisdictions have not developed coherent strategies for coordinating the roles of these various parties. A critical question that must be addressed concerns the appropriate roles of the private and public sectors in financing the cost of recovery from large-scale natural disasters. This question is likely to be answered differently from jurisdiction to jurisdiction depending on its unique historical and social context, and the relative roles of the public and private sectors in the economy and other public policy issues.

Canada has addressed the question of the appropriate roles of the private and public sectors in financing the cost of recovery from large-scale disasters. This is set out in the federal Disaster Financial Assistance Arrangements that have been largely unchanged since 1975, and in equivalent provincial legislation. Private insurance industry provides protection for private property against most catastrophe risk, with flood representing the most significant uninsured risk. Governments are responsible for protection and preparedness for uninsured losses, and historically this has primarily included damage to public property and flood management. The Canadian system illustrates creative public-private partnerships with respect to insurance. The governments provide limited tax deferral for insurer earthquake capacity building through premium reserves. The insurance industry provides insurance and reinsurance to governments – particularly municipal governments – for some public property exposed to catastrophic losses.

The Role of Insurance – Insurance Supply

Two conditions must be met before insurers are willing to offer coverage against an uncertain event. The first, is the ability to identify and estimate the chances of the event occurring, and the extent of losses likely to be incurred when providing different levels of coverage. The second, is the ability to set premiums for each potential class of customers. This requires some knowledge of the customer's risk in relation to others in the population of potential policyholders. It is here that difficulties, including ambiguity of risk, adverse selection, moral hazard and correlated risk, can interfere to increase insurers' potential exposures, leading to insurance premiums that considerably exceed the expected loss or to decisions to not offer coverage.

The higher the ambiguity regarding the probability of a specific loss and its magnitude, the higher the premium will be. As shown by a series of empirical studies, actuaries and underwriters are so averse to ambiguity and risk that they tend to charge much higher premiums than if the risk were well specified (Kunreuther, Hogarth and Meszaros 1993).

If the insurer sets a premium based on the average probability of a loss, using the entire population as a basis for this estimate, those at the highest risk for a certain hazard will be the most likely to purchase coverage for that hazard. In an extreme case, the poor risks will be the only purchasers of coverage, and the insurer will lose money on each policy sold. This situation, referred to as adverse selection**,** occurs when the insurer cannot distinguish between good- and poor-risk categories.

Providing insurance protection to an individual may lead that person to behave more carelessly than before he or she had 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 too low to cover losses. Moral hazard refers to an increase in the probability of loss caused by the behavior of the policyholder. Obviously, it is extremely difficult to monitor and control behavior once a person is insured. How do you monitor carelessness? Is it possible to determine if a person will decide to collect more on a policy than he or she deserves by making false claims?

Correlated risk refers to the simultaneous occurrence of many losses from a single event. Natural disasters such as earthquakes, floods, and hurricanes produce highly correlated losses: many homes in the affected area are damaged and destroyed by a single event. If a risk-averse insurer faces highly correlated losses from one event, it may want to set a high enough premium not only to cover its expected losses but also to protect itself against the possibility of experiencing catastrophic losses. An insurer will face this problem if it has many eggs in one basket, such as providing earthquake coverage mainly to homes in the Vancouver area, for example, rather than diversifying across the entire country.

Even if the insurer is able to set premiums which take into account problems of ambiguity, adverse selection, moral hazard and correlated risks, it might not be economic for the firm to market coverage. More specifically, it may not be possible to specify a rate for which there is sufficient demand and incoming revenue to cover the development, marketing and claims costs of the insurance and yield a net positive profit. In other words the risk would satisfy the two conditions for insurability, but not be profitable.

Recent legislation and earthquake activity in California convinced the insurance industry in that jurisdiction that the earthquake risk was not an insurable risk if left to the private sector alone. A public-private partnership, the California Earthquake Authority (CEA), formed in 1996, offers homeowners in the state earthquake coverage as a separate policy. Private insurers can still offer coverage against earthquake risks but the California Earthquake Authority is the principal form of coverage that is being supplied to homeowners. For commercial structures, earthquake protection for property damage coverage is still included as part of a multi-peril policy provided by the private sector (Roth, Jr. 1998).

The situation in California presents an interesting contrast to that in Canada and many other countries where there is a ready supply of earthquake insurance for residential and commercial property risks. This suggests that potential problems of adverse selection and highly correlated risks are not significant for insurers providing policyholders with earthquake coverage. Research conducted by the Insurance Bureau of Canada suggests that the current earthquake premiums are in fact representative of the underlying risk. Accordingly, in Canada it appears as though there is capacity within the industry to provide coverage based on risk-based rates.

Formal public-private partnerships, such as the California Earthquake Authority, have not been pursued in Canada. As in the United States, the industry earlier proposed a role for the federal government providing a form of excess of loss reinsurance. This proposal was later dropped. The Canadian government does provide excess reinsurance of a sort through its liability for damage to public property in the event of the next earthquake. The size of the catastrophe seems to be an important factor in determining whether the private sector can insure the risk, as in Canada, or whether there is a need for public sector involvement as in the US with the California Earthquake Authority or the National Flood Insurance Program.

The capital markets are another source of funds for providing coverage against catastrophic events. In the past five years investment banks and brokerage firms have shown considerable interest in developing catastrophe bonds (cat bonds) for protecting insurers and reinsurers against large-scale disaster losses. Their objective is to find ways to make investors comfortable trading these new instruments covering catastrophe exposures, just like the securities of any other asset class. In other words, catastrophe exposures would be treated as a new asset class (Insurance Services Office 1999).

The insurance company USAA issued the first catastrophe bond in June 1997 when they floated act-of-God bonds that provided them with protection should a major hurricane hit Florida. This cat bond would be considered an indemnity contract, similar to reinsurance, since it was directly tied to the magnitude of the losses experienced by USAA. More recently there have been indexed-based contracts developed where the amount paid out to the firm (*i.e.* the ceding company) is tied to a disaster-severity index (*e.g.*, covering damage from a certain earthquake magnitude event within a specified region). Since these parameters are independent of the firm's actual losses, payments can be made to the firm immediately after the disaster occurs rather than being subject to the time delay necessary to compute actual losses, as in the case of insurance or reinsurance.

For example, a parametric-based contract to cover the loss from an earthquake was purchased in May, 1999 by Oriental Land, a Japanese company that is best known as the owner and operator of Tokyo Disneyland. This cat bond provides $100 million to the company should an earthquake of a specific magnitude occur in the vicinity of Tokyo. The Japanese Meteorological Agency provides the measurement of event magnitude. The magnitude which qualifies a given quake for payments to Oriental Land is higher as the locations of its epicenter becomes more remote from Tokyo Disneyland. These bonds represent the first direct access of the capital markets by a corporation seeking catastrophe risk financing (Standard & Poors 2000).

The capital markets do not play a role in the Canadian model at this time, although there is provision for insurers to include capital market financing among their regulator-approved methods of demonstrating capacity to meet earthquake claims. Traditional reinsurance is readily available for Canadian insurers at a cost that is affordable.

The Role of Insurance – Insurance Demand

The demand for earthquake insurance in California has evolved over the past thirty years. In the mid 1970s, fewer than 5 percent of homes were insured against earthquake damage. By 1995 over 40 percent of the homes in many areas in hazard-prone areas were insured against this risk. Kunreuther (1996) found that homeowner's principal reasons for not choosing to purchase insurance is that they feel the chances of a future disaster are so low that it is not worth worrying about and/or because of budget constraints. In a study of homeowners residing in earthquake-prone areas of California, Palm (1995) concluded that the most important motivating reason for those who purchased insurance was that "I worry that an earthquake will destroy my house or cause major damage in the future".

Other factors that motivated homeowners to purchase coverage were "the fear that they would have lost an important part of their equity from the earthquake" and that "they would not have funds to rebuild their damaged home." Insurance purchases appear, then, to be motivated by anticipated losses, fear that government aid will be unavailable or insufficient, and an estimate of likely damages as opposed to the cost of premiums. The influence of family, friends, real estate agents or mortgage lenders was negligible.

This marks a distinct change from the factors influencing the purchase decision in the early 1970s when earthquake insurance was purchased by relatively few residents of California and hence could be considered a novel way to protect oneself even if it had been available since 1916. With few people having this type of coverage, Kunreuther et al (1978) found that knowing someone with insurance and talking about insurance with someone were among the most influential factors in causing the household to consider and buy earthquake coverage.

By international standards, the demand for earthquake insurance is strong in Vancouver and Victoria, the region in Canada most likely to experience a severe urban earthquake. A study last fall by the British Columbia government found that 96 percent of homeowners have fire insurance and 63 percent purchase earthquake cover (McIntyre & Mustel 2000). The Insurance Bureau of Canada (1994) estimates that 80 percent of businesses in the area purchase insurance coverage that includes earthquake insurance. Nearby Seattle residents are vulnerable to similar seismic risks but only 12 percent of homeowners purchase earthquake insurance (Shuster 2001). An interesting research opportunity would be the exploration of the pronounced difference in attitude between the high use of insurance protection in Vancouver and Victoria relative to the low use in Seattle and other parts of the Western United States.

Insurance and Regulation

Insurance is a heavily regulated industry. Solvency regulation seeks to protect policyholders against the risk that insurers fair to meet their financial obligations. Market regulation work to ensure fair and reasonable insurance prices, products and trade practices. A key challenge facing any regulatory commission charged with rate

supervision is to determine what is considered to be a fair rate. If the insurer can justify a high rate by showing that it is based on risk, and a regulator feels that it is too high on other grounds (e.g. for political reasons) then this may undermine the role of insurance as a means of encouraging loss reduction as well as protection against events. In addition, there are challenges on how regulators determine what is a rate based on risk.

In the past 10 years new advances in information technology have led to the development of catastrophe models that have proven very useful for quantifying risks based on estimated probabilities and expected damage. A model is the set of databases and computer programs designed to analyze the impact of different scenarios on hazard-prone areas. Catastrophe models combine scientific risk assessments of the hazard with historical records to estimate the probabilities of disasters of different magnitudes and the resulting damage to affected structures and infrastructure.

Specifically, these models combine the characteristics of the disaster with characteristics of the property in the affected region to determine a damageability matrix. This matrix provides information on the potential losses from disasters of different magnitudes to the structures at risk. Depending on the type of insurance coverage available, one can then estimate the insured loss per property.[1]

Given the complexity of catastrophe risk assessment and modeling, some regulators have been reluctant to accept the results of these model-based analyses without considerable scrutiny. Florida, for example, established a Commission on Hurricane Loss Projection Methodology to evaluate the details of the models on which the expected losses from future hurricanes are estimated. There was also considerable debate in California on the basis of the premiums to be charged within the state using model-based losses as a key input for setting rates. In these jurisdictions, it has been found to be critical to find ways to increase public confidence in the use of the best scientific methods to support adequate insurance prices.

The solvency role of regulation poses additional constraints on the insurer. Higher capital requirements for the insurer may force them to raise rates. Regulation can play an important positive role by protecting the consumer against fly-by-night companies through solvency regulation. On the other hand, price regulation may discourage companies from offering coverage and mitigation incentives if rates in hazard-prone areas are highly supressed.

Insurance in Canada is supervised for solvency purposes primarily at the federal level, with market conduct regulation primarily a provincial government responsibility. Many provincial governments, however, have some provincially registered insurers, for which they are also responsible for supervising for solvency purposes. Federal and provincial regulators in Canada use a common solvency form. This provides for uniformity in treatment for all insurers in Canada irrespective of the government responsible.

[1] For more details on catastrophe models see Insurance Services Office (1996).

Market conduct regulation in Canada generally includes supervision of policy forms to ensure clarity for consumers in terms of coverage in force. Rate supervision only applies to automobile insurance, and then, to varying degrees in different provinces. There is no rate supervision of property insurance, although there are regulatory provisions pertaining to basic consumer protection and information issues.

Canada's earthquake supervisory regime, includes six components:

- Common basic information is required for the management of catastrophic risk. Uniform data standards allow the comparisons among companies, and can support development of industry-wide measures of exposure and capacity.
- During the 1990s the use of models and other formal risk management tools became standard practice in organizations with material exposure. The regulations set out means to ensure that the models are relevant.
- Policy terms and conditions vary considerably across this competitive industry so regulators can regularly check that practices are in compliance with relevant legislation and regulations.
- Procedures for the management of catastrophic reinsurance coverage are central to the overall management of earthquake risk.
- Clear procedures were established to supervise insurers who may use new financing mechanisms like cat bonds.
- Clear procedures have been set out to establish the extent of earthquake exposure that can be retained by the primary insurer.

Federal and provincial regulations are based on a single, common model that is applied to all insurers with material earthquake exposure. A level playing field has been established in terms of minimum practices, and the inclusive and transparent process used to develop these standards is expected to permit regular review and update of the standards when appropriate. Insurers are required to have an earthquake risk management system in place that meets these needs. Each company must have an approved plan to maintain data that will support modeling and other risk measurement activities. Also, senior management and board members must be regularly informed about earthquake risk management practices. The objective is to implement formalized risk management processes.

The Canadian regulatory regime for earthquake insurance includes a primary role for catastrophe models. Rather than embarking on a Florida-type review process, the Canadian system includes an explicit decision to rely on competition in the model-making industry to produce quality models. The modeling community is supported, in turn, by sponsoring research through the Institute for Catastrophic Loss Reduction and other channels to improve base data and understanding.

Open Questions and Suggestions for Further Research

- It would appear that demand for insurance and perhaps individual mitigation actions could be increased in Canada by an insurance industry/government consumer campaign aimed at educating consumers about earthquake risks and the relative roles

of private insurance and government assistance after a disaster. What kind of public education campaign would be most effective in reaching property owners?

- What is the potential role of the capital markets in offering protection against catastrophic losses? Are there unique institutional arrangements particular to involving this sector in Canada?
- What are the most effective routes for the private insurance industry assist the public sector with managing catastrophic risks?
- Can regulation of rates be used in combination with other policy tools such as building codes to encourage mitigation?

7. CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

This paper stresses the importance of private insurance as a catalyst for reducing losses in the future and covering much of the losses from catastrophic risks such as natural disasters. Such a strategy takes advantage of recent developments in information technology and the emergence of new capital market instruments to deal with non-diversifiable catastrophic risks. These two major changes open up opportunities for residents and firms to undertake cost-effective loss protection measures, while at the same time providing a financial cushion to insurers concerned with the possibility of insolvency. Insurers should thus be able to play a more important role in the future in helping to manage catastrophic risks.

The success of a disaster management program requires the active involvement of a number of interested parties from the private sector such as insurers, banks and financial institutions, realtors, and builders and contractors. It also requires that government officials enforce building codes. Public sector agencies have a role in providing assistance to low-income families so that they can adopt cost-effective mitigation measures, and so that they can recover after a disaster. The federal government may want to provide catastrophic reinsurance to insurers if the private sector does not offer sufficient coverage.

One way of developing the specifics of such a catastrophic risk management program involves analyzing the impact of disasters of different magnitudes on property and infrastructure. Long-term simulations could help in estimating expected losses from these events and in projecting the maximum probable losses arising from worst-case scenarios. In order to undertake these simulations one needs to determine exceedance probability (EP) curves based on risk assessments of the particular hazard. Studies, such as the assessment of risk due to fire following earthquake in British Columbia (Scawthorn and Waisman 2001) provide the necessary ingredients for construct these EP curves.

By constructing simulations of large, medium, and small *representative* insurers with specific balance sheets, types of insurance portfolios, and premium structures, one could examine the impact of different events on the insurers' profitability, solvency, and performance under different scenarios regarding future losses. This simulation exercise

would enable one to evaluate how mitigation measures and the provision of funds against catastrophic losses by reinsurers and the capital markets affect insurers' profitability and likelihood of insolvency. An example of the application of such an approach to a model city in California facing an earthquake risk can be found in Kleindorfer and Kunreuther (1999b). It should be feasible to undertake a similar analysis for Vancouver, BC.

Such an analysis may also enable one to compare how index-based cat bonds perform relative to indemnity instrument, such as reinsurance, for different types of insurers who have specific risks in place. The data from the simulations could also be used to determine the return an investor would require to provide capital for supporting each instrument. The selling prices of different types of capital market instruments would reflect both the expected loss and variance in these loss estimates to capture risk aversion by investors.

This type of simulation modeling must rely on solid theoretical foundations in order to delimit the boundaries of what is interesting and implementable in a market economy. Such foundations will also apply to research on the traditional issues of capital markets and the insurance sector, and to research on the processes by which insurance and reinsurance companies, public officials, and property owners determine levels of mitigation, insurance coverage, and other protective activities. In the area of catastrophic risks, the interaction of these decision processes, which are central to the outcome, seem to be considerably more complicated than in other economic sectors, perhaps because of the uncertainty and ambiguity of the causal mechanisms underlying the events themselves and their mitigation.

Finally, public sector damage from catastrophic events such as natural disasters often results in a substantial cost to taxpayers. Government officials should be encouraged to purchase insurance for public structures and invest in cost-effective mitigation measures. With respect to natural disasters one way to do this is to change legislation so that recovery funds would not be available unless municipalities implemented cost-effective mitigation measures. Another alternative is to levy property taxes on all community residents to cover losses to public structures from catastrophic losses. This is a form of community-based insurance, with all residents paying a share in proportion to the value of their property.

This is a very exciting time for the insurance and reinsurance industry to explore new opportunities for dealing with catastrophic risks. If insurance can be used as a catalyst to bring other interested parties to the table, it will have served an important purpose in helping both the industry and society deal with the critical issue of reducing losses and providing protection against damage from earthquakes, floods, hurricanes, and other natural disasters.

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