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U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Institute of Standards and Technology

Office of Applied Economics
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Gaithersburg, Maryland 20899-8603

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Foreword

The National Institute of Standards and Technology (NIST) develops and promotes measurement, standards, and technology to enhance productivity, facilitate trade, and improve quality of life. In the aftermath of the attacks of September 11, 2001, NIST has taken a key role in enhancing the nation's homeland security. Through projects spanning a wide range of research areas, NIST is helping millions of individuals in law enforcement, the military, emergency services, information technology, the construction industry, and other areas protect the American public from terrorist threats.

NIST's Building and Fire Research Laboratory (BFRL) has as its mission to meet the measurement and standards needs of the building and fire safety communities. A key element of that mission is BFRL's commitment to homeland security. Specifically, the goal of BFRL's homeland security effort is to develop and implement the standards, technology, and practices needed for cost-effective improvements to the safety and security of buildings and building occupants, including evacuation, emergency response procedures, and threat mitigation. The strategy to meet this goal is supported by BFRL's:

- research and development (R&D) program to provide a technical foundation that supports improvements to building and fire codes, standards, and practices that reduce the impact of extreme threats to the safety of buildings, their occupants and emergency responders; and

- dissemination and technical assistance program (DTAP) to engage leaders of the construction and building community in implementing proposed changes to practices, standards, and codes. DTAP will also provide practical guidance and tools to better prepare facility owners, contractors, architects, engineers, emergency responders, and regulatory authorities to respond to future disasters.

This report, prepared for NIST by The Wharton School at the University of Pennsylvania, was funded by DTAP. It documents the need for linking risk assessment, risk perception, and risk management in order to develop meaningful strategies for dealing with extreme events. Cases where extreme events exhibit interdependencies, either among individual stakeholders or among stakeholder groups, are given special attention. Special attention is also given to the need for cooperation between the public and private sectors with the ultimate goal of generating sound strategies for reducing the risks of extreme events and reducing the damage should such catastrophes occur. These strategies will be fully informed by scientific assessments of risks and by an understanding of the population's perception of risks and their likely responses to alternative risk management programs.

The material presented in this report complements research being conducted by the Office of Applied Economics (OAE) under BFRL's homeland security R&D program. OAE's research focuses on developing economic tools to aid facility owners and managers in the selection of cost-effective strategies that respond to natural and man-made hazards. OAE's research has produced a three-step protocol for developing a risk mitigation plan for optimizing protection of constructed facilities (Chapman and Leng (2004)). This protocol helps decision makers assess the risk of their facility to damages from natural and man-made hazards; identify engineering, management, and financial strategies for abating the risk of damages; and use standardized economic evaluation methods to select the most cost-effective combination of risk mitigation strategies to protect their facility. This report covers key components of the first two steps of the three-step protocol.

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Abstract

This report discusses the need for linking risk assessment, risk perception, and risk management in order to develop meaningful strategies for dealing with extreme events, i.e., low probability-high consequence events. We give special attention to economic incentives and to extreme events exhibiting interdependencies, either among individual stakeholders or among stakeholder groups. We also give special attention to the need for cooperation between the public and private sectors with the ultimate goal of generating sound strategies for reducing the risks of extreme events and reducing the damage should such catastrophes occur.

We present a conceptual framework of how risk assessment, risk perception and risk management are linked with each other. Risk assessment evaluates the likelihood and consequences of prospective risks. Risk perception is concerned with the psychological and emotional aspects of risks. Risk management involves developing strategies for reducing the likelihood and/or consequences of extreme events. The discussion of risk assessment describes how the exceedance probability or EP curve is a convenient way of summarizing the nature of the risk and provides valuable input for different stakeholders to develop strategies for managing risk. The discussion of risk perception discusses how individual decisions on whether or not to adopt protective measures are influenced by psychological and emotional factors. Problems of coordination when facing interdependent security risks are also analyzed. In particular, we discuss the need for risk management strategies that involve both the private and public sectors for dealing with the negative externalities created by these interdependencies. The discussion of risk management strategies focuses on insurance and mitigation as two complementary strategies for reducing future losses and providing funds for recovery, and addresses the role of public-private partnerships in this regard. The use of controlled laboratory experiments to better understand household adaptive response to natural hazards is illustrated through an earthquake simulation that was tested with University of Pennsylvania undergraduate and graduate students.

Keywords

Economic incentives; extreme events; interdependency; interdependent security; laboratory experiments; risk analysis; risk management strategies.

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List of Acronyms

CEA	California Earthquake Authority
EP	Exceedance probability
FEMA	Federal Emergency Management Agency
IBHS	Institute for Business and Home Safety
IDS	Interdependent security
LP-HC	Low probability-high consequence
LRM	Loss reduction measure
MC1	Model City 1 (Oakland, CA)
NFIP	National Flood Insurance Program
RMM	Risk mitigation measures
WCL	Worst-case loss
WTP	Willingness to pay

1 Introduction

The tragic attacks of September 11th have raised a set of issues regarding how we deal with events where there is considerable ambiguity and uncertainty of the likelihood of their occurrence and their potential impacts. These low probability-high consequence (LP-HC) or extreme events include a wide range of hazards ranging from natural disasters to technological accidents. Extreme events often exhibit considerable interdependencies with respect to the risk.

By *interdependency* we mean the possibility of contamination or impact by one agent over another. In the context of natural disasters, if a homeowner in an earthquake-prone area has not strapped his water heater, an earthquake can cause the heater to topple over and cause a fire that may not only cause severe damage to the home but also spread to another dwelling. Even if that other house has taken appropriate preventive measures it may still suffer damage due to the non-actions of others.

The following questions should be addressed in order to develop meaningful strategies for dealing with these extreme events:

- What is the nature of the interdependencies associated with these risks and what impact do they have on the decisions by individuals to invest in protective measures?

- How can we use the tools of risk assessment and our knowledge of risk perception to develop risk management options that are likely to be successfully implemented, given the interdependencies associated with these risks?

- What type of economic incentives can encourage investment in cost-effective mitigation measures and how can these incentives be linked with other policy tools such as insurance, regulation, and building codes?

- How can we utilize lessons from dealing with past extreme events in helping to plan for the future?

1.1 A Conceptual Framework

Figure 1.1 depicts a conceptual framework for examining the above questions. The framework indicates the need for linking risk assessment, risk perception, and risk management in order to understand how to deal with extreme events. Two additional sources of complexity are not shown in Figure 1.1 but will be incorporated in our discussion applying the framework to extreme events. The first is that many extreme events exhibit considerable interdependencies with respect to their risk. That is, the fact that a particular event strikes one unit may also increase the risk that another unit experiences the same event. The second source of additional complexity is the need for cooperation between the public and private sectors (public-private partnerships) with the ultimate goal of generating sound strategies for reducing the risks of extreme events and reducing the damage should such catastrophes occur. These strategies will be fully informed by scientific assessments of risks and by an understanding of the population's perception of risks and their likely responses to alternative risk management programs.

Let us look at each of the elements of the framework depicted in Figure 1.1. *Risk Assessment* means evaluating the likelihood and consequences of prospective risks, either by the use of frequency data or on the basis of expert judgments, scenarios, and subjective probabilities. A risk assessment requires characterizing the forms of physical, social, political, economic, cultural, and psychological harms to which individuals and modern societies are susceptible. As one moves from events where considerable historical and scientific data are available (e.g. earthquakes and hurricanes) to those where there is greater uncertainty and ambiguity (e.g. terrorist attacks), there is a much greater degree of subjectivity in undertaking risk assessments.

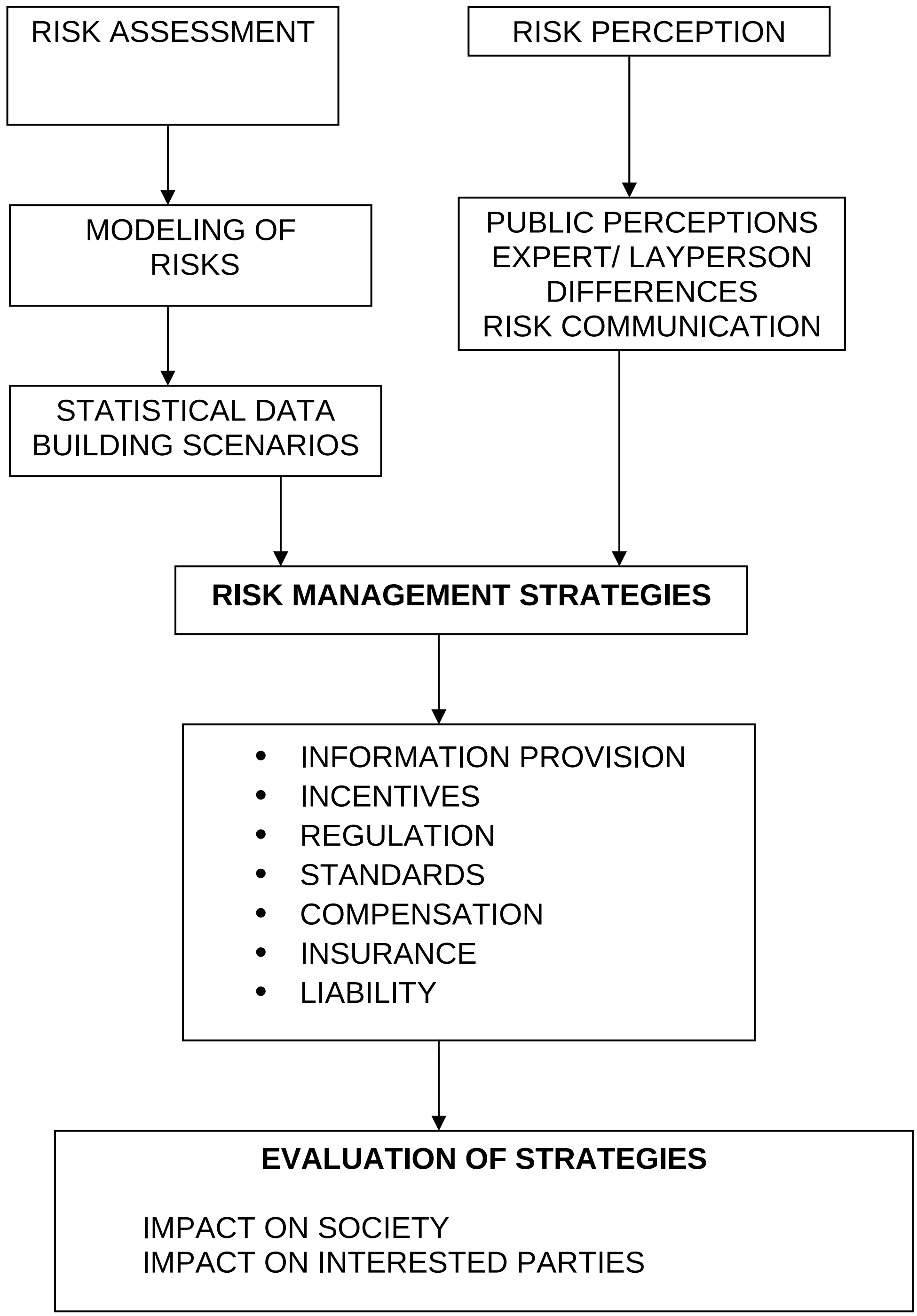

Figure 1.1. Conceptual Framework for Assessing and Managing Extreme Events

In highly interdependent systems characteristic of modern industrial societies, failures can propagate rapidly through the system in ways that are not always obvious ex ante. Constructing scenarios that may lead to the occurrence of specific events is a useful first step in assessing these risks. Such scenarios must take into account not only the possible initial security failures but also their ultimate consequences, which may be far removed in space and on occasion even in time. The consequences of an extreme event can be quite distant from the event itself, as in the case of last August's power failures in the northeastern US and Canada, where the initial event appears to have occurred in Ohio but the worst consequences were felt hundreds of miles away. The same was true of the 9/11/01 attacks, when security failures at Boston's Logan airport led to disaster at the World Trade Center. We will discuss the features of risk assessment and illustrate how it can be used in **Chapter 2**.

Risk Perception is concerned with the psychological and emotional aspects of risks, which have been shown to have an enormous impact on individual and group behavior. While traditional risk assessment focuses on objective evaluation of risks or expert evaluation in the absence of historical data, there is a growing body of evidence that one's choices are not simply based on the likelihood and consequences of different events, as normative models of decision-making suggest. Rather, individuals are also influenced in their choices by emotional factors such as fear, worry and love (Loewenstein et al. (2001); Slovic et al. (2002)). Studies by psychologists (Slovic (2002); Fischhoff (2002)) have shown that hazards that are least known, uncontrollable, have catastrophic potential, or are highly dreaded are perceived by the public as being the most risky. They are also the ones most likely to attract media and public attention.

Scientists, on the other hand, normally determine the risk of a hazard by weighing possible outcomes by their likelihood of occurrence. Therefore, laypeople and the experts from the scientific community are likely to see and react to risks quite differently. For technologies such as nuclear power, and activities such as storing radioactive waste, there is likely to be a wide disparity between the general citizens' and the experts' views of the risk. Risk perception has important implications for the effectiveness of alternative policies, most of which are intended to alter aspects of individual and corporate behavior. **Chapter 3** focuses on the decision processes of individuals and their (mis)perceptions of the risks they are facing.

Interdependent security principles, while not explicitly included in Figure 1.1, apply to risks from extreme events in the sense that the risk that one party faces depends on the actions of others. Heal and Kunreuther recently analyzed interdependent security (IDS) issues through a game-theoretic model (Kunreuther and Heal (2003); Heal and Kunreuther (in press)). Specifically, they have examined individuals or organizations who face security investment decisions, but whose ultimate risk is strongly dependent on the actions of those with whom they interact. We will illustrate the nature of the interdependencies in **Chapter 4** when we consider the decision by one homeowner to invest in protection given that his losses may be dependent on what his neighbor does.

Risk Management involves developing strategies for reducing the probabilities of negative events and/or their consequences should they occur. It therefore involves the full gamut of actions from preventing losses from natural disasters, technological accidents, or terrorist attacks to reducing damage in the event of an attack, to providing emergency response teams, to handling damage and providing insurance to compensate for financial losses. Risk management usually involves investment. The allocation of limited resources is guided by the assessments of risks and what we know of how people and firms perceive and react to them.

Risk management strategies normally involve the public and private sectors. For example, if one wants to develop economic incentives such as subsidies for mitigation measures to reduce the risk from earthquakes or hurricanes, then it may be necessary to institute well-enforced building codes to make sure that buildings are designed in a safer manner. Possible policy tools include risk communication strategies, economic incentives (e.g. subsidies and fines), insurance, third party inspections and audits, well-enforced regulations, and standards.

In a highly interdependent system where underinvestment in security is typical, an important aspect of risk-management is providing incentives to assure more appropriate levels of investment or, where this is not an option, mandating such investment through regulations. In **Chapter 5** we will examine risk management strategies for dealing with extreme events. More specifically, we will discuss how mitigation, insurance, and building codes can be linked together to reduce losses and provide funds for recovery should a disaster occur.

To better understand how well specific risk management strategies are likely to work in practice we have developed an earthquake/hurricane simulation model that has been used for undertaking controlled laboratory experiments. **Chapter 6** details the nature of a controlled set of experiments for understanding the decision processes of individuals who have an opportunity to invest in mitigation measures to reduce the losses from hurricanes and earthquakes. The broader context for designing these experiments will be outlined, the simulation will be described, and preliminary results will be presented. **Chapter 7** concludes with some suggestions for future research.

1.2 Key Stakeholders and Programs [1]

The above framework needs to be complemented with an understanding of the key stakeholders that are concerned with extreme events. In this section we examine a set of interested parties and illustrate the types of programs that can be considered for reducing future losses and providing funds for recovery. By examining the perspectives of these individuals and groups, one can develop more effective risk management strategies for reducing potential losses from extreme events.

Property Owners

Owners of commercial and residential structures can choose from a range of risk management strategies to reduce losses. They can reduce their risk by retrofitting a structure to withstand wind or earthquake loading, transfer part of their risk by purchasing some form of insurance, and/or keep and finance their risk. They can also reduce their losses from natural disasters by adopting risk management plans.

The ways in which particular individuals decide to manage risk is often a function of their perceptions. As we discuss in Chapter 3, many homeowners do not take action even when the risk is abundantly clear and loss-reducing measures are available. It is often the case that many homeowners feel that a disaster will not affect them.

A commercial property owner's risk perception and strategies to manage risk are different from those of residential owners. A commercial establishment must concern itself not only with life safety and insolvency issues, but also with the impact of a disaster on the

[1] This section is based on Chap. 1 of Grossi and Kunreuther (eds.) (2005).

operation of its business. Often there are extra expenses as a business tries to remain viable after a catastrophe. The company is additionally concerned about business interruption loss—the loss or reduction of income due to the suspension of operations resulting from a disaster. Business owners in hazard-prone regions are normally quite interested in purchasing coverage against this type of risk.

Insurers

An insurer provides protection to residential and commercial property owners for losses resulting from natural disasters. Losses due to damage from fires (resulting from lightning during thunderstorms) and wind (resulting from tornadoes and hurricanes) are covered by a homeowner's insurance policy, normally required by lenders as a condition for a mortgage. Loss due to water damage (resulting from floods) is covered under the National Flood Insurance Program (NFIP), a public-private partnership between the federal government and the insurance industry. Losses due to damage from ground movement (resulting from earthquakes and landslides) are covered by a policy endorsement or by a separate policy issued either by the private sector or, in California, through a state-run, privately funded earthquake insurance company, the California Earthquake Authority (CEA).

Losses from natural disasters can have a severe impact on an insurer's financial condition. Therefore insurers want to limit the amount of coverage they provide to property owners in hazard-prone areas. An important concern for insurers is the concentration of risk. Those who cover a large number of properties in a single geographic area face the possibility of large losses should a natural disaster occur in the area. An insurer views a portfolio with this type of highly correlated (or interrelated) risks as undesirable. Subject to regulatory restrictions, an insurer limits coverage in any given area and/or charges higher premiums in order to keep the chances of insolvency at an acceptable level.

Other Private Sector Parties

Lenders play a vital role in managing risks of extreme events. Except for the uncommon case where the owner pays for property outright, banks and other financial institutions enable individuals in the United States to purchase a home or business by providing mortgages. The property is the collateral in the event that the owner defaults on the mortgage. Lenders thus have a vital stake in the risk management process, as they are unlikely to recover the full value of a loan on a piece of property destroyed by catastrophe.

Real estate agents, developers, engineers, contractors, and other service providers also play a supporting, yet important role in the management of risk from natural disasters. In hazard-prone regions, federal or state regulations require real estate agents to inform the new owner of potential hazards. Examples include the location of a home relative to an earthquake fault line or within a 100-year flood plain. Unfortunately, it is sometimes unclear how information on natural hazard risk is being used in the purchase process. A study of the impact of the California requirement that purchasers of residential property within a certain distance of a known earthquake fault be told about the hazard showed that most home buyers did not understand or recall the risk warning (Palm (1981)).

Engineers and contractors play a significant part in risk management in high hazard areas. Structures designed and built to high standards with inspections by reputable building officials can provide good protection against life and property loss in the next earthquake. Life and property loss are often attributable to inadequate design and construction practices. The problem of building and selling property in hazard-prone regions is exacerbated when disreputable building contractors bypass wind- and seismic-resistant designs.

Government's Role

Federal, state, and local government often take the lead in managing risk from natural disasters. Policymakers at all levels of government have developed a set of programs for reducing risks from these disasters. In addition, they prioritize funding following a severe earthquake, flood, tornado, or other extreme events.

At the national level, the Federal Emergency Management Agency (FEMA) coordinates many of the planning and response aspects related to catastrophes. FEMA has historically taken the lead in developing strategies for mitigation. For example, in December 1995, the agency introduced a National Mitigation Strategy 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)). One of its key features was to create disaster-resistant communities through the Project Impact program The program, begun in 1997, encouraged communities to "bring interested parties together to identify their potential natural hazards, assess the community's vulnerability, prioritize hazard risk reduction measures and communicate success to the residents" (FEMA (2000)). Over 250 communities have participated in Project Impact.

At the state level, an office of emergency services or a department of public safety promotes natural disaster preparedness. Additionally, seismic safety commissions have been established by earthquake-prone states to prioritize earthquake research and public policy needs. Building codes that include criteria for wind or earthquake resistance, and legislation for land use management, endeavor to reduce risk. Incentive programs have been instituted to reduce losses from disaster events, especially in hazard-prone states. A good example of such legislation is California's Proposition 127. Passed in November of 1990, the law states that seismic retrofitted improvements to property completed on or after January 1, 1991, and completed on or before July 1, 2000, will not increase the property tax for a homeowner until ownership changes. The state concluded that these improvements constitute such a significant reduction in the risks to life and safety, that they should be exempt from additional property tax.

At the local level, communities enforce building codes and have developed economic incentives, such as tax relief, for those who retrofit. Local communities have developed programs to promote awareness, provide training, and encourage self-help actions through neighborhood emergency response teams. The city of San Leandro, California has set priorities to retrofit both unreinforced masonry buildings and older wood-frame homes. The Home Earthquake Strengthening Program is a comprehensive, residential seismic strengthening program that provides homeowners with simple and cost-effective methods for strengthening their wood-frame houses for earthquake survival. The program includes earthquake-strengthening workshops for residents, a list of available earthquake contractors, as well as a tool-lending library for homeowners should they wish to do the work themselves.

Table 1.1 provides a set of examples of leadership activities at the different levels of government for defining and prioritizing risks, for alleviating risks through legislative means, and for encouraging reduction of earthquake risk. These programs bring together diverse groups of people around a common issue and provide needed encouragement and resources.[2]

Table 1.1 Government Leadership in Managing Earthquake Risk

	Define and Prioritize Risk	**Legislation to Alleviate Risk**	**Encourage Risk Reduction**
Federal Government	National Earthquake Hazards Reduction Program (NEHRP)	Robert T. Stafford Disaster Relief and Emergency Assistance Act	Federal Emergency Management Agency's Project Impact
State Government	State Seismic Safety Commissions California Earthquake Hazards Reduction Act	California Unreinforced Masonry Building Law	California Proposition 127
Local Government	Home Earthquake Strengthening Program (San Leandro, CA)	Earthquake Hazard Reduction Ordinance (Los Angeles, CA)	Tax Transfer Rebate (Berkeley, CA)

Source: Grossi and Kunreuther (2000)

1.3 Summary

This chapter introduced a conceptual framework for examining the interdependencies and developing strategies for dealing with extreme events where there is considerable uncertainty and ambiguity associated on their likelihood of occurrence and potential impact. The conceptual framework indicates how risk assessment, risk perception and risk management are linked with each other. Risk assessment evaluates the likelihood and consequences of prospective risks. Risk perception is concerned with

[2] See Grossi and Kunreuther (2000) for more details on earthquake programs and Moss (2002 Chap. 9) for a more general discussion of the role of the public sector in providing disaster assistance.

the psychological and emotional aspects of risks. Risk management involves developing strategies for reducing the likelihood and/or consequences of extreme events. The key stakeholders concerned with these extreme events range from property owners, insurers and other private sector groups to government organizations at the local, state and federal levels. Each of these interested parties is concerned with the nature of the risk, public perception and developing strategies for managing extreme events.

2 Risk Assessment Using Exceedance Probability (EP) Curves

The field of risk assessment involves estimating the chances of a specific set of events occurring and/or their potential consequences. Scientists and engineers need to provide the users of these data a picture of what we know regarding the nature of a particular risk and the degree of uncertainty surrounding these estimates. When doing so, experts in the field need to take special care not to provide these estimates through the filter of their values and biases about what constitutes a sizable loss or a sizable probability.

It is not uncommon for the public to hear Expert 1 say that there is "nothing to worry about" regarding a particular risk while at the same time learning from Expert 2 that this risk "should be on your radar screen." There may be many different reactions to these conflicting reports. One layperson may decide that they cannot rely on the judgment of any expert. Another individual may decide to focus on the expert supporting his or her own view of the risk. Someone else may seek out the views of other experts to see if there is a degree of consensus on the nature of the risk.

One way to convey to decision makers what experts know and do not know about a particular risk is to construct an exceedance probability (EP) curve. An EP curve specifies the probabilities that a certain level of losses will be exceeded. The losses can be measured in terms of dollars of damage, fatalities, illness, or some other unit of analysis.

2.1 Use of Exceedance Probability (EP) Curves

To illustrate with a specific example, suppose one were interested in constructing an EP curve for an insurer with a given portfolio of residential earthquake policies in Long Beach, California, of dollar losses to homes in Long Beach, CA from an earthquake. Using probabilistic risk assessment, one would combine the set of events that could produce a given dollar loss and then determine the resulting probabilities of exceeding losses of different magnitudes. Based on these estimates, one can construct a mean EP depicted in Figure 2.1. Suppose the insurer focuses on a specific loss L_i. One can see from Figure 2.1 that the likelihood that insured losses will exceed L_i is given by p_i. The x-axis measures the loss to the insurer in dollars and the y-axis depicts the probability that losses will exceed a particular level. A detailed discussion of how one constructs an EP curve appears in Section 2.2.

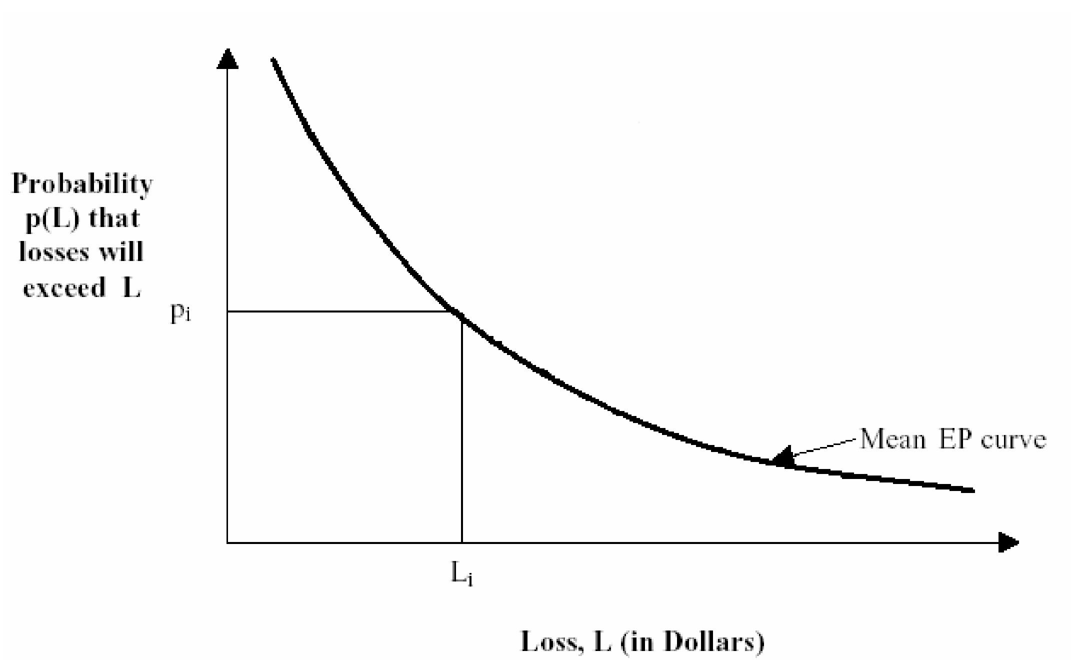

Figure 2.1 Sample Mean Exceedance Probability Curve

Each of the interested parties will construct EP curves to satisfy their needs and concerns. A company located in a hazard-prone area may need to determine how likely it will suffer direct dollar damage and indirect losses such as business interruption that exceed different magnitudes in order to determine how much insurance to purchase. A building owner may want to examine how specific protective measures will shift the EP curve downwards so they can see what impact these investments will have on future dollar losses to its structure.

Federal and state agencies may want to use EP curves for estimating the likelihood that losses to specific communities or regions of the country from natural disasters in the coming year will exceed certain levels. At the start of the hurricane season Florida could have used an EP curve to estimate the likelihood of damage exceeding $21 billion in 2004. This probability would have been extremely low even though we now know that a confluence of events (i.e. Charley, Frances, Ivan and Jeanne) produced an outcome that exceeded this dollar value.

By its nature, the EP curve incorporates uncertainty associated with the probability of an event occurring and the magnitude of dollar losses. This uncertainty is reflected in the 5 % and 95 % confidence interval curves in Figure 2.2.

The curve depicting the uncertainty in the loss shows the range of values, $L_i^{.05}$ and $L_i^{.95}$ that losses can take for a given mean value, L_i, so that there is a 95 % chance that the loss which will be exceeded with probability p_i. In a similar vein one can determine the range of probabilities, $p_i^{.05}$ and $p_i^{.95}$ so that there is 95 % certainty that losses will exceed L_i.

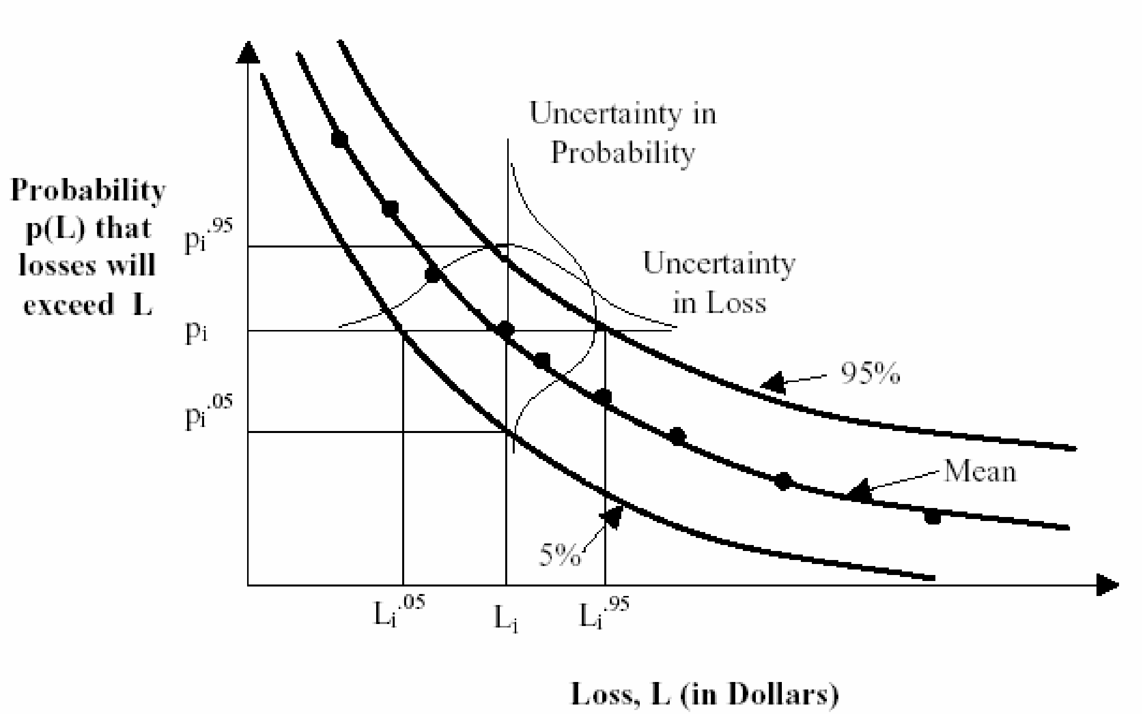

Figure 2.2 Confidence Intervals for a Mean Exceedance Probability (EP) Curve

It is much easier to construct an EP curve for natural disasters and chemical accidents than it is for terrorist activities. But even for these more predictable disasters or accidents, there may be considerable uncertainty regarding both the likelihood of the occurrence of certain risks and the resulting damage. For low probability-high consequence risks, the spread between the three curves depicted in Figure 2.2 shows the degree of indeterminacy of these events. Providing information on the degree of uncertainty associated with risk assessments should increase the credibility of the experts producing these figures.

The EP curve serves as an important element for evaluating risk management tools. It puts pressure on experts to make explicit the assumptions on which they are basing their estimates of the likelihood of certain events occurring and the resulting consequences. In fact, EP curves, such as those depicted in Figure 2.2, supplemented by a discussion of the nature of these assumptions, should enable the general public to gain a clearer picture as to why there is so much ambiguity surrounding estimates of some risks and much less uncertainty on others.

Here are a few questions to ponder with respect to the uncertainties associated with the following extreme events:

- What are the chances that Los Angeles will have an earthquake of Magnitude 7.0 or greater next year and what will be the resulting damage and indirect losses?
- What is the likelihood of a severe nuclear power accident somewhere in the United States and what would be the resulting impacts?
- What are the chances that there will be a terrorist-induced smallpox epidemic in the United States in the next five years and how many people would be affected?

When experts are asked to answer these questions they are likely to respond by asking for more precise information to help define the event. Take the question related to the chances of an earthquake of Magnitude 7.0 or greater in Los Angeles. The experts will normally require more precise information for defining the event. They are likely to ask: "What is the geographic area that defines Los Angeles?"; "What do you mean by next year (i.e. starting today or January 1, 2005)?"; and "What is an indirect loss?"[3] In order to obtain more accurate and useful risk assessments, laypersons need to define the terms of the analysis so that experts know what to do and users know what they have received.[4]

2.2 Generating Exceedance Probability (EP) Curves[5]

Given the importance of how insurers use catastrophe modeling and the EP curve to manage risk, it is essential to understand how the EP curve can be created from the loss output.

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[3] Our thanks to Robin Gregory who suggested that one needs to pose these types of questions when addressing issues of risk assessment.

[4] For a more detailed discussion of the interaction between laypersons and experts see National Research Council (1996) and Fischhoff (1994)

[5] This section is based on Chap. 2 of Grossi and Kunreuther (Eds.) (2005).

Suppose there is a set of natural disaster events, E_i (i: 1,…, I), which could damage a portfolio of structures. Each event has an annual probability of occurrence, p_i, and an associated loss, L_i. The number of events per year is not limited to one; numerous events can occur in the given year. Fifteen such events are listed in Table 2.1, ranked in descending order of the amount of loss.[6]

The events listed in Table 2.1 are assumed to be independent Bernoulli random variables, each with a probability mass function defined as:

$$\begin{aligned} P(E_i \text{ occurs}) &= p_i \\ P(E_i \text{ does not occur}) &= (1 - p_i) \end{aligned} \tag{2.1}$$

If an event E_i does not occur, the loss is zero. The Expected Loss for a given event, E_i, in a given year, is simply:

$$E[L] = p_i \cdot L_i \tag{2.2}$$

Assuming that only one disaster can occur during a given year, and assuming that we have indexed the events in reverse order of their losses (such that $L_i \geq L_{i+1}$), the exceedance probability for a given level of loss, $EP(L_i)$, can be determined by calculating:

$$EP(L_i) = P(L > L_i) = 1 - P(L \leq L_i) \tag{2.3}$$

$$EP(L_i) = 1 - \prod_{j=1}^{i} (1 - p_j) \tag{2.4}$$

The resulting exceedance probability is the annual probability that the loss exceeds a given value. As seen in equation (2.4) above, this translates into one minus the probability that all the other events below this value of loss have not occurred. The

[6] In order to keep the example simple and calculations straightforward, these events were chosen so the set is exhaustive (i.e., sum of the probabilities for all of the events equals one).

exceedance probability curve for the events in Table 2.1 is shown in Figure 2.3. More detail on how one can incorporate uncertainty about the EP curve into such a figure and into the analysis of risk management strategies will be discussed in Chapter 5.

Table 2.1 Events, Losses, and Probabilities

Event (E_i)	Annual probability of occurrence (p_i)	Loss (L_i)	Exceedance probability ($EP(L_i)$)	$E[L] = (p_i * L_i)$
1	0.002	25,000,000	0.0020	50,000
2	0.005	15,000,000	0.0070	75,000
3	0.010	10,000,000	0.0169	100,000
4	0.020	5,000,000	0.0366	100,000
5	0.030	3,000,000	0.0655	90,000
6	0.040	2,000,000	0.1029	80,000
7	0.050	1,000,000	0.1477	50,000
8	0.050	800,000	0.1903	40,000
9	0.050	700,000	0.2308	35,000
10	0.070	500,000	0.2847	35,000
11	0.090	500,000	0.3490	45,000
12	0.100	300,000	0.4141	30,000
13	0.100	200,000	0.4727	20,000
14	0.100	100,000	0.5255	10,000
15	0.283	0	0.6597	0

2.3 Use of EP Curves by Key Stakeholders

An EP curve is a vehicle for each key stakeholder to determine the nature of the risk that it is assuming and the impact that alternative strategies have on changing the risk. Homeowners can determine whether or not it is cost-effective to voluntarily adopt a specific mitigation measure. Governmental agencies such as FEMA can determine what types of building codes to enforce by examining the impact on the likelihood of losses of different magnitudes. Insurers can determine the size and distribution of their portfolios' potential losses and what premiums to charge for specific risks.

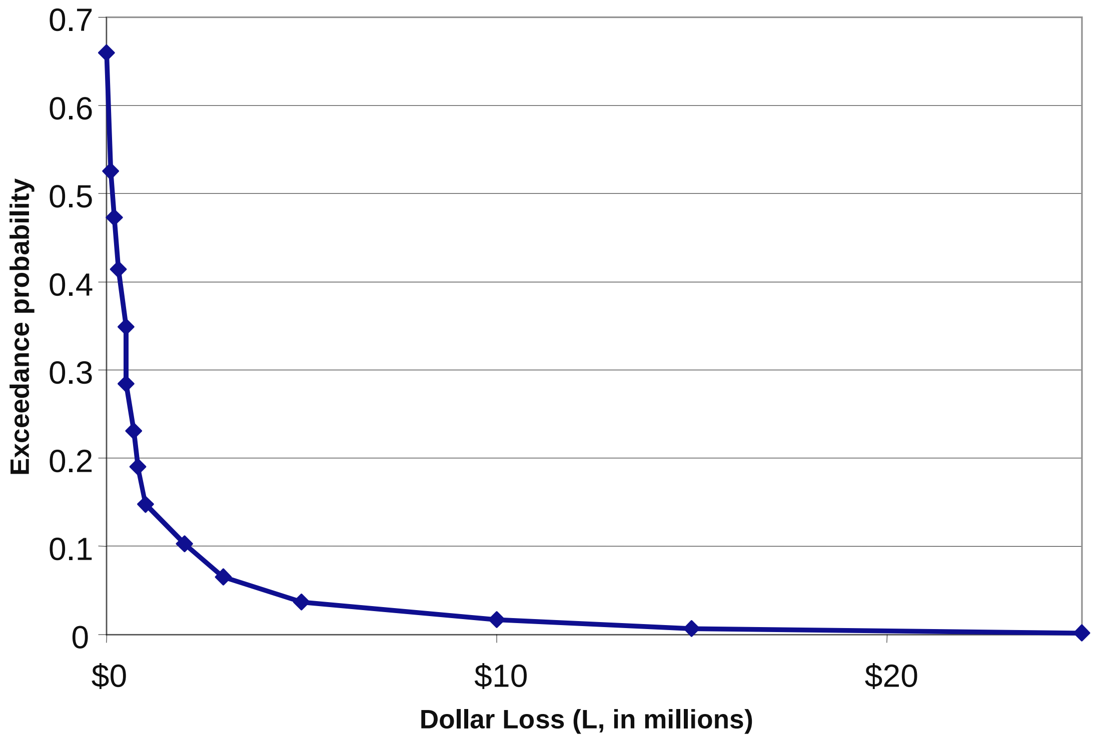

Figure 2.3 Mean Exceedance Probability Curve Based on Data in Table 2.1

To illustrate the role an EP curve can play in determining a stakeholder's strategy, consider an insurer who would like to specify a book of business[7] for earthquake insurance in Long Beach, CA. Based on the EP curve, they can determine the types and locations of buildings they would like to insure, what coverage to offer, and what price to charge to keep the probability of insolvency at an acceptable level. Insurers can also use an EP curve to determine what proportion of their risk needs to be transferred to either a reinsurer and/or the capital markets. For example, suppose the insurer's exceedance probability curve for its current portfolio of earthquake coverage is depicted in Figure 2.4

[7] A book of business for an insurer is the number of policies and total amount of coverage provided against a particular risk.

using data provided by EQECAT, one of the 3 largest modeling firms developing estimates of risks of losses from natural disasters.

Suppose the insurer specifies $10 million as an acceptable level of loss at a 1 % (1 in 100) probability of exceedance. From Figure 2.4, one can see that the loss profile of the current portfolio would be unacceptable since the 1 in 100 loss for the portfolio is $15 million. The insurer would need to look for ways to reduce its exposure, transfer $5 million of loss to a reinsurer, or purchase a catastrophe bond to cover it.

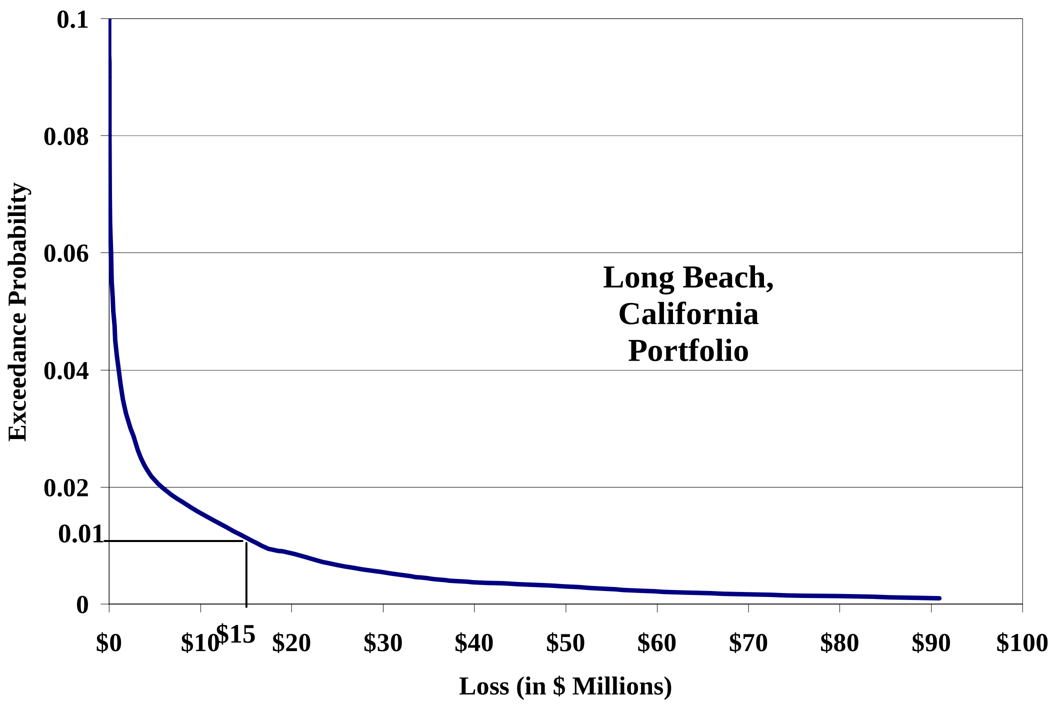

Figure 2.4 Catastrophe Model Output: "Right-hand Tail" of Exceedance Probability Curve Predicted by EQECAT for all Possible Events.

The curves depicted in Figures 2.3 and 2.4 are mean EP curves. As pointed out above, there is considerable uncertainty associated with the risks from natural disasters so that one would want to determine how sensitive the portfolio allocation and premium setting decisions are by adding EP curves reflecting the 90 % confidence interval (see Figure 2.2). More detail on how one incorporates uncertainty into the analysis of risk management strategies by different stakeholders will be discussed in Chapter 5.

2.4 Summary

This chapter highlights the importance of assessing the risk as inputs to developing risk management strategies. The EP curve is a convenient way of summarizing the nature of the risk and provides valuable input for different stakeholders to develop strategies for managing risk. Even if experts provide estimates of the risk, these estimates are only useful if those who have to make decisions find them helpful in determining whether to adopt protective measures. The next chapter examines the factors that influence individual and firm decisions with respect to these choices.

3 Factors Influencing Choices on Protective Measures[8]

This chapter focuses on the factors that are important to individuals when they adopt protective measures. After providing evidence in the next section on the reluctance of those in hazard-prone areas to invest in cost-effective mitigation measures, we develop a normative model of choice based on expected utility theory (Section 3.2) that indicates how these decisions should be made. Section 3.3 provides evidence on what factors are important to individuals' decision processes with particular emphasis on misperception of the risk and simplified choice rules. The chapter concludes by raising a set of questions for ways of improving individuals' decision processes (Section 3.4).

3.1. Empirical Evidence on Adoption of Protection Measures

The empirical data on studies of mitigation adoption in hazard-prone areas of the United States suggest that individuals are not willing to invest in mitigation measures despite the rather significant 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 natural 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 extent of damage from another storm. A July 1994 telephone survey of 1,241 residents in six hurricane-prone areas along the Atlantic and Gulf Coasts revealed that 62 % indicated that they had not installed hurricane shutters, used laminated glass in windows, installed roof bracing or made sure that sidewalls were bolted to the foundation either before or after Hurricane Andrew (Insurance Institute for Property Loss Reduction (1995)).

[8] This chapter is based on Kunreuther (2001) and Kunreuther (1996).

A 1989 survey of 3,500 homeowners in four California counties subject to earthquake hazards reported that only between 5 and 9 % of the respondents in each of these counties reported adopting any loss reduction measures (Palm et al. (1990)). This suggests that individuals do not believe that investing in such risk mitigation measures (RMMs) will increase their property value or that they have either short time horizons and/or severe budget constraints, which either reduce their perceived net benefits from RMMs or simply prevent them from making the investment.

Many residents in earthquake-prone areas are not even adopting mitigation measures that require only very minimal investment. Strapping a water heater with simple plumbers' tape, for instance, can normally be done by residents at a cost of under $5 in materials and one hour of their own time (Levenson (1992)). This RMM 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 do not invest in this RMM as much as one would expect.

Budget constraints and short time horizons alone are unlikely to be the sole barriers to adoption. We first discuss a normative model of adoption based on standard expected utility theory in Section 3.2, and then discuss several additional issues that are likely to affect people's mitigation decisions in Section 3.3.

3.2 A Normative Model of Choice: Expected Utility Theory

A decision by a homeowner on whether to adopt a protective measure involves comparing the upfront investment cost (C) with the reduction in property losses from future catastrophes. A key question that needs to be addressed is: "What is the maximum amount that a person would be willing to pay for this protection?" If the property owner focuses only on the benefits from the mitigation measure while residing in the structure, then the willingness to pay (WTP) depends on the magnitude of the loss reduction and the length of time that the person expects to live there.[9]

To illustrate how one would determine whether to invest in particular loss reduction measures (LRMs) consider the following hypothetical example. Suppose that scientific experts have estimated that the annual chance of a severe hurricane causing damage to homes in Miami, Florida is 1 in 25.[10] The Gale family has a one-story home in the area. If they reinforced the walls and foundations it would reduce the losses from such a hurricane by $10,000. In other words the expected *annual* benefit from investing in such a measure would be $400 (i.e. 1 in 25 x $10,000). The longer the time period T that the Gales expect to live in their house, the greater is the expected benefit from investing in such measures. Further, let B represent the expected present value of the benefit from LRMs over the entire time horizon T.[11] Also, let the cost to the Gales of these LRMs be C= $1200.

Table 3.1 provides data for a variety of different estimates of the probability of a disaster and discount rate. Let T* represent the minimum number of years that the Gales must remain in their home for the loss-reduction investment to be cost-effective (i.e., the expected benefit/cost (B/C) ratio exceeds 1). This is denoted by a bold figure in each of the columns of Table 3.1. The second column depicts the expected B/C ratio as a function of T if the Gale's annual discount rate was 10 %. It is clear that if the family planned to live in their home for more than 4 years they should want to invest in these protective measures.

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[9] In theory, the value of the investment would be reflected in the resale price of the house. Hence restricting the expected benefits of the measure to the current owner is a conservative one.

[10] To simplify the story assume that hurricanes are the only extreme event that could affect Miami in the future.

[11] The net present value of the expected benefits are calculated under the assumption that the house will be occupied for the entire T periods and that if a hurricane occurred it would be at the end of each period. In reality the expected benefits in each year t are determined by weighting the reduction in losses by the probability that the house has not been damaged by a hurricane during the first t periods.

Table 3.1 Expected Benefit/Cost Ratio of Investing in Loss Reduction Measure as a Function of Time Horizon, Discount Rate and Perceived Probability (*p*)

Time Horizon	Discount Rate (10 %)		Discount Rate (20 %)	
	***p*=1/25**	***p*=1/75**	***p*=1/25**	***p*=1/75**
1	.30	.10	.28	.09
2	.58	.19	.51	.17
3	.83	.28	.70	.23
4	**1.06**	.35	.86	.29
5	1.26	.42	**1.00**	.33
10	2.05	.68	1.40	.47
15	2.54	.84	1.56	.52
20	2.83	.94	1.62	.54
25	3.03	**1.01**	1.65	.55

Source: Kunreuther (1996)

3. 3 Why Individuals Have Limited Interest in Protective Measures[12]

There are combinations of factors that appear to explain why individuals have *not* invested in cost effective LRMs**:**

Underestimation of Probability

Individuals may perceive the probability of a hurricane causing damage to their home as being sufficiently low that the investment in the protective measure is not justified. Suppose that the Gale family perceived the chances of a severe hurricane damaging their

[12] This material is based on Kunreuther (1996).

home to be 1 in 75 rather than the scientists' estimate of 1 in 25. As shown in Column 3 of Table 3.1, the value of T* is now more than six times as long as before, so that the Gales would have to expect to live in their home for at least the next 25 years in order to want to invest in these LRMs.

Some individuals may relate their perceived probability of a disaster (p) to a threshold level (p^*), which they may unconsciously set, below which they do not worry about the consequences at all. If their estimate of p is smaller than the threshold p^*, then they assume that the event "will not happen to me" and take no protective actions. This decision to ignore events when $p < p^*$ may be justified by individuals by claiming that there is a limited amount of time available to worry about protecting oneself against hazards facing us. By setting a threshold level p^*, individuals can devote their attention to events where p is sufficiently large that they are a source of worry and concern. Such a rule is also easy to explain and justify to others because of its simplicity.[13]

Several studies show that individuals rarely seek out probability estimates in making their decisions, and that low probabilities are inherently ineffective in eliciting reactions. When these data are given to them, decision makers often do not use the information (Camerer and Kunreuther (1989); Magat, Viscusi, and Huber (1987)). In one study, researchers found that only 22 % of subjects sought out probability information when evaluating several risky managerial decisions (Huber, Wider, and Huber (1997)). Even when another group of respondents was given precise probability information, less than 20 % mentioned the probability in their verbal protocols.

[13] Camerer and Kunreuther (1989) provide a number of examples of where threshold rules have been used by individuals, firms and government agencies.

When consumers are asked to justify their decisions about whether or not to purchase warranties for items such as stereos, computers and VCRs, they rarely list probability that the product needs repair as a reason for purchasing this protection (Hogarth and Kunreuther (1995)). This information should be relevant for deciding how much to pay for the warranty if one were utilizing a normative model of choice.

Why do people have such difficulty dealing with probabilistic information for small likelihood events? They need a context in which to evaluate the likelihood of an event occurring (Tversky, Sattath, and Slovic (1988); Hsee (1996); Hsee, Blount, Loewenstein, and Bazerman (1999)). People may have difficulty gauging how concerned to feel about a 1 in 100,000 probability of death without some comparison points. Most people just do not know whether 1 in 100,000 is a large risk or a small risk. In a laboratory experiment to determine how individuals judge low probabilities, Kunreuther, Novemsky, and Kahneman (2001) found that one must have available fairly rich context and information for individuals to be able to judge differences between low-probability events.

It is easy to see why the "it will not happen to me" strategy violates the tenets of expected utility theory or benefit-cost analysis. Instead of weighting the outcome from an event by its perceived probability of occurrence, individuals who utilize a threshold model treat low probability events as having a zero chance of occurrence. They do not even consider the consequences from events that they treat as impossible, when, in fact, they may actually occur. Homeowners who follow this decision process will have no interest in adopting loss reduction measures because they do <u>not</u> think about the consequences of a disaster.

High Discount Rates

Decision makers may have a very high discount rate so that the future benefits are not given much weight when evaluating the protective measure. As shown in Table 3.1 (Columns 4 and 5) if the Gale family's annual discount rate is doubled to 20 % and the family accepts the scientists' estimate of p = 1/25, then the critical time horizon increases from T^* = 4 to T^* = 5. However, if the Gales believe that the probability of a hurricane is p^* =1/75, then there is no value of T where the expected benefit/cost ratio is greater than 1.

Evidence for high annual discount rates for future savings have been observed in studies evaluating the reluctance of consumers to invest in energy-saving equipment (Hausman (1979); Gately (1980); Kempton and Neiman (1987)). A set of experiments by Lowenstein (1987) on willingness to pay for items whose receipt was delayed or speeded up revealed that the implied discount rates are considerably higher than market rates, particularly in situations where the expected savings over time are relatively small relative to the upfront expenditure.

Role of Emotions and Affection

There is now a growing body of evidence that affection and emotion play an important role in people's decision processes for choices when there are uncertain outcomes. For instance, one would expect that people living in countries with a strong uncertainty-avoiding culture would own more insurance products than people living in countries with a weak uncertainty-avoiding culture. Yet, the opposite appears to be the case. In a large-scale survey with respondents from 16 European countries, a country's average level of ownership of personal insurance and pension-related investments was correlated negatively with the country's uncertainty avoidance, i.e., the extent to which the members of a culture feel threatened by uncertain or unknown situations (de Mooij (1998)). This finding about insurance is rather paradoxical, and the same paradox may exist for mitigation measures. Uncertainty-avoiders who have the tendency to avoid negative emotions need not buy more protection but may prefer to avoid thinking about the need for protection and hence end up buying less. Though we are not aware of direct evidence of this effect, one should not ignore its potential existence.

Affection towards the property at risk is another type of emotion that may affect the propensity to engage in risk mitigation. That positive affect may increase the tendency to engage in protective measures is rather obvious. Less obvious is that it may also increase the tendency to purchase insurance. The expected utility model does not predict this behavior (at least when utility is equated with monetary outcomes). Rather, these findings appear to be explained by a "consolation hypothesis," according to which people perceive insurance compensation as a token of consolation.

Role of Friends and Neighbors

There is considerable empirical evidence that friends and neighbors play a key role in individuals' decisions on whether or not to adopt protective measures (Kunreuther et. al. (1978); Weinstein (1987)). Decision makers may also seek out friends and neighbors for information on where to buy coverage. If individuals use friends and neighbors to determine from which insurers to purchase coverage, then one would expect to find a clustering of policies with the companies who have successful regional agents. These insurers will face larger losses from a catastrophe than if a random search process had been utilized by consumers.

Framing of Information

Though the factors that determine the demand for protection are still not well understood, experimental studies provide some insight into consumer decision processes that apply to protection. For example, there is evidence that the format in which factual information is presented, i.e., its framing, affects how consumers determine whether to purchase insurance coverage and how much to pay. Some of these effects are the vividness of a projected event by the media, incorporating rebates so that the policyholder feels he has experienced a gain if he doesn't collect on his policy, and the status quo serving as a reference point for deciding between options. Data from insurance markets indicate that these same effects occur when actual insurance decisions are made (Johnson et al. (1993)). These findings clearly indicate that decision makers do not always behave according to the normative model presented in the previous section.

3.4 Improving the Decision Process[14]

Given how people make protective decisions and deviate from normative models, how can one improve the choice process? Some combination of the following options may be helpful in this regard:

Present Probabilities Using Concrete Comparisons

People have great difficulty evaluating low-probability risks, but they do a better job when these risks are presented in concrete form. They might not know what a one-in-ten-thousand risk means, but they can better interpret the figure when it is compared to the risk of an automobile accident. People need to see these decisions in the contexts of risks that they understand. Research indicates that comparisons of risks are much more

[14] This section is based on Kunreuther (2001).

effective in helping decision makers assess the risk than translating the risks into dollar values of insurance premiums.

Avoid Microscopic Numbers

People also are willing to pay considerably more to reduce the risk of some adverse events if the likelihood is depicted as a ratio rather than a very tiny probability (Stone, Yates, and Parker (1994)). For example, saying that the risk of an event occurring when one is protected is half of what it is when one is not protected elicits a far stronger reaction than saying the risk is reduced from .000006 without protection to .000003 with protection. Similarly, people are more willing to wear seatbelts if they are told they have a .33 chance of an accident over a 50-year lifetime of driving rather than a .00001 chance each trip (Slovic, Fischhoff, and Lichtenstein (1978)).

Adjusting the time frame also can affect risk perceptions. For example, if a firm is considering earthquake protection over the 25-year life of its plant, managers are far more likely to take the risk seriously if they are told the chance of an earthquake is 1 in 5 during the entire period rather than 1 in 100 in any given year (Weinstein, Kolb, and Goldstein (1996)). Studies have shown that even just rescaling the single-year risk and presenting it as 10 in 1,000 or 100 in 10,000 instead of 1 in 100 makes people more likely to pay attention to the event (Slovic, Monahan, and MacGregor (2000)). Most people feel that small numbers can be easily dismissed, while large numbers get their attention. One challenge for future research is to determine ways to present information to individuals so that they understand the meaning of low and high probabilities.

3.5 Summary

This chapter provided empirical data showing that relatively few individuals in hazard-prone areas adopted protective measures even if the costs are extremely low. Two of the principal reasons individuals do not invest in cost-effective loss-reduction measures include underestimation of the probability of a disaster and high discount rates coupled with short-term horizons. The chapter concluded by suggesting that people are more likely to view protection as attractive if probabilities are presented using concrete comparisons and are presented in a form that they are sufficiently large so that they will be taken seriously.

4 Dealing with Interdependent Risks

What economic incentives do individuals and organizations have for investing in protection when they are connected to and dependent on others whose failures may compromise anyone with whom they are connected? Kunreuther and Heal (2003) and Heal and Kunreuther (2004) recently introduced the concept of interdependent security (IDS) using game-theoretic models as a way of investigating how interdependence affects individual choices about security expenditures in interdependent systems. Specifically, this framework has been applied to evaluating investments by individuals and firms in the security of infrastructure operations, recognizing that any firm's risk is strongly dependent on the operational behaviors, priorities, and actions of others through interconnected networks or supply chains.

A characteristic of these interdependent security (IDS) problems that gives a unique and hitherto unnoticed structure to the incentives that organizations face to invest in mitigation is that the risk facing one agent is determined in part by one's own behavior (direct impacts) as well as the behavior of others (indirect impacts). At one extreme the expected damages are additive so that they are the sum of the direct and indirect impacts. At the other extreme the damages are non-additive which means that the indirect effects are conditioned on the direct loss not occurring. An IDS problem does not have the structure of a prisoners' dilemma game, even though it has some similarities (see Kunreuther and Heal (2003)). In an IDS problem, it is possible that a change in the behavior of one agent can tip the system from one equilibrium to another (see Schelling (1978)); a related phenomenon is cascading, when a change by one leads to a change by a second which provokes a change by a third, and so on (see Dixit (2002)). Neither tipping nor cascading is possible in prisoner dilemma problems.

In what follows we will assume that the damages are non-additive. As an example suppose that you own a house in an earthquake-prone area of California and are considering undertaking a mitigation measure such as bracing the cripple wall[15] and bolting the structure to the foundation. However, you know that the neighboring house has not invested in these protective measures, so there is some chance that if an earthquake occurs it will collapse and cause serious damage to your property even if you have adopted this mitigation measure. For this reason alone you will have less of an economic incentive to incur this cost since the expected benefits from taking this action are now reduced because there is some chance that you will have an indirect impact from your neighbor's home.

4.1 A Model of Interdependent Security

Consider a one-period model where there are *n* risk-neutral homeowners designated by H_i $i=1...n$. These are the primary actors who have to choose whether or not to invest in mitigation. This choice is taken to be discrete: invest or not invest. In the earthquake scenario, these are homeowners choosing whether or not to strengthen their homes so as to reduce the likelihood of damage resulting from an earthquake. Each homeowner faces the risk of a loss of magnitude *L*. There are two possible ways in which a loss can occur: it can either be initiated on the homeowner's own property or on the property of another homeowner.

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[15] The cripple wall is the wall/crawl space between the structure's foundation and its first-floor diaphragm.

The probability of a direct loss arising on the homeowner's own property if it has not invested in mitigation measures is p so that the expected loss from this event is pL. If it has invested in mitigation then this risk is zero.[16] The situation is completely symmetric and all agents are identical. If you have adopted a mitigation measure, your home could still sustain damage from an earthquake indirectly if the neighboring home has not been protected and suffered damage from a quake that then had an impact on your home. There is thus an additional risk of loss due to contagion from another agent who has not invested in loss prevention, denoted by q where $q \leq p$ since the likelihood of suffering an indirect impact can never be greater than the likelihood of a direct impact to the neighbor's house.

We assume throughout that the damages that result from multiple security failures are no more severe than those resulting from a single failure. In other words, damages are non-additive. The key issue is whether or not there is a failure, not how many failures there are. Indeed as the probabilities are so low, single occurrences are all that one can reasonably consider. One could think of the definition of a catastrophe as being an event so serious that it is difficult to imagine an alternative event with greater consequences. We focus first on the case of n=2 identical, risk neutral homeowners and then generalize the problem to n>2 homeowners, heterogeneous agents and endogenous probabilities.

4.2 The Two-Homeowner Problem

Assume that each homeowner has perfect information on the risks and costs of protection and has to make a choice between investing in mitigation (*Y)*, or not to do so (*N)*. Table 4.1 shows the payoffs to the homeowners for the four possible outcomes.

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[16] We make this simplifying assumption for ease of exposition. The qualitative results will not change if the probability of a loss when one adopts a mitigation is $p' < p$.

Table 4.1 Expected Outcomes Associated with Investing and Not Investing in Mitigation

		Homeowner 2 (H_2)	
		Y	***N***
Homeowner 1 (H_1)	***Y***	*A-c, A-c*	*A-c-qL, A -pL*
	N	*A-pL, A-c-qL*	*A –[pL + (1-p) qL], A –[pL+ (1-p)qL]*

Here *A* is the assets of each homeowner before any expenditure on mitigation or any losses from the risks faced. The cost of investing in mitigation is *c*. If both homeowners invest in mitigation, then each incurs a cost of *c* and faces no losses so that their net assets are *A-c*. If H_1 invests and H_2 does not (top right entry) then H_1 incurs a cost of *c* and also runs the risk of a loss emanating from H_2. The probability of H_2 contaminating H_1 is *q*, so that H_1's expected loss from earthquake damage from his neighbor's house is *qL*. This cost represents the negative externality imposed by H_2 on H_1. H_2 incurs no mitigation costs and faces no risk of contagion from H_1, but it does face the risk of losses originating at home, *pL*. The lower left payoffs are just the mirror image of these. If neither agent invests in security, then both have an expected payoff of $A- pL - (1-p) qL$. Now that the outcomes have been specified, one can ask the natural question: under what conditions will the homeowners invest in mitigation if they are risk neutral? It is clear from Table 4.1 that for investment in security to be a dominant strategy, we need:

$$A-c>A-pL \quad \text{and} \quad A-c-qL>A-pL-(1-p)\, qL \qquad (4.1)$$

The first inequality just says that $c<pL$: the cost of investing in mitigation must be less than the expected loss, a natural condition for an isolated homeowner. The second inequality is more interesting: it reduces to $c<pL- pqL = pL(1-q)$. This is clearly a tighter inequality reflecting the possibility of contagion from the second homeowner. This

possibility reduces the incentive to invest in security. Why? Because in isolation, investment in mitigation buys the homeowner complete freedom from risk; with the possibility of contagion it does not. Even after investment there remains a risk of loss emanating from the other agent. Investing in security buys you less when there is the possibility of contagion from others.

In the two-homeowner problem with identical costs, one can determine the optimal behavior of each homeowner if they both make decisions simultaneously without any communication. In this non-cooperative environment if $c < pL(1-q)$, then both individuals will want to invest in protective measures (*Y,Y*); if $c > pL$ then neither homeowner will want to invest in protection (*N,N*). If $pL(1-q)<c<pL$, then there are two Nash equilibria (*Y,Y*) and (*N,N*) and the solution to this game is indeterminate.

The solution concept for two homeowners with identical costs and risks is illustrated below with a numerical example. Suppose that $p= .2$, $q=.1$, $L=1000$ and $c= 185$. The matrix in Table 4.1 is now represented as Table 4.2.

Table 4.2 Expected Costs Associated with Investing and Not Investing in Mitigation for Illustrative Example

		Homeowner 2 (H_2)	
		Y	**N**
Homeowner 1 (H_1)	**Y**	*A - 185, A - 185*	*A - 285, A - 200*
	N	*A - 200, A - 285*	*A - 280, A -280*

If H_2 invests in mitigation (*Y*), then it is worthwhile for H_1 to also invest in security, since without protection its expected losses will be $pL= 200$ and it will only have to spend 185 to eliminate this risk. If H_2 does not invest in security (N), then there is still a chance that H_1 will experience a loss even if it protects itself. The expected benefits to H_1 of investing in mitigation will now only be $pL(1-q) = 180$, which is less than the cost of the security measure. Hence H_1 will not want to invest in protection. In other words, either both agents invest in security or neither of them does so. These are the two Nash equilibria.

4. 3 Generalizing the Problem to More than Two Agents

The two-homeowner problem can be generalized to $n > 2$ agents in a straightforward manner to show that the incentive for investing in mitigation decreases as more other homeowners decide not to take this action. This result is intuitive. The greater your chances of being contaminated by others even if you take protective measures yourself, the less attractive it will be for you to invest in mitigation.

It is also possible to generalize the model so that the parameters (i.e. costs, risks) are heterogeneous. In this case some homeowners will want to invest in mitigation while others may not. Those who do have expected benefits that exceed the costs of mitigation even if they face some chance of being contaminated by others. Those who don't invest in mitigation may be reluctant to do so because of the negative externalities from others.

Heal and Kunreuther (2004) explore this more general case and show that a change of strategy by one agent or a small set of agents can shift the equilibrium radically by causing the other agents to follow suit. Tipping the equilibrium in this manner is in the spirit of Schelling (1978), Katz and Shapiro (1994), Watts (1999) (in the context of general networks), and more recently Gladwell (2000). For example, there may be a Nash equilibrium at which no homeowner invests in mitigation. Yet if one person changes strategy and invests – possibly in response to events or incentives outside the game – then all others will do the same.

One can also treat the case where the probabilities are endogenous as would be the case for terrorism. Terrorists are more likely to focus on targets which are less well protected, so that the p depends on the investment in security.[17] This is the phenomenon of displacement or substitution, documented in Sandler (2003) and Keohane and Zeckhauser (2003).

Consider the case of airline security. If some airlines are known to be more security-conscious than others, they are presumably less likely to be terrorist targets. An example illustrating this point is the Pan Am 103 crash in 1988. A bomb loaded onto Malta Airlines at Gozo, Malta, flown to Frankfurt and then transferred to PanAm in London destroyed the flight. The bomb was designed to explode above 28,000 feet, a height normally first attained on this route over the Atlantic Ocean. Malta Airlines and Gozo were presumably chosen because they were seen as having weak security procedures relative to Pan Am in London, and in the knowledge that for cost and logistical reasons inter-airline baggage is never screened.

It is important to distinguish between behavior when hazards are unintentional such as natural disasters and when they are premeditated such as sabotage, crime and terrorism.[18] In the case of an unintentional hazard the probabilities will be exogenous and there will be less incentive to invest in protection the larger the number of agents who do not take this action due to the higher negative externalities. With respect to

[17] There is a resemblance between this behavior by terrorists and that of burglars. If a house has a sign indicating that it has installed an alarm, those homes that are unprotected are more likely to be chosen as targets.

[18] See Appendix A of NISTIR 7073 (Chapman and Leng (2004)) for a more detailed discussion of these two types of hazards.

intentional hazards, there will be even more reason to invest in protection as others take this action if one believes that unprotected agents are more likely to be targeted for attack. Heal and Kunreuther (2004) show that it is easier to tip the system so that everyone invests in security in this situation than when the probabilities are exogenous.

4. 4 Policy Implications of IDS Models

There are important policy implications associated with problems with interdependencies among individuals, firms, and other agents. There will be a reluctance to invest in mitigation given the knowledge that others have also not taken this action. Not only is there a greater chance of being contaminated by others, which follows directly from the IDS model, but there also may be social norms that discourage one from taking this action. In particular, if friends and neighbors are an important source of choice, then their not investing in mitigation may lead you to follow suit.

The interdependency problem also compromises policy tools that are often used to encourage investment in protection through lower premiums, such as insurance. An insurer who provides protection to H_i is responsible for losses incurred by individual i no matter who caused the damage.[19] For this reason, if the insurer is aware that there is a relatively high chance that it will be responsible for claims to your property even if the damage was caused by a neighbor, then your insurer will be less likely to give you a premium reduction for undertaking mitigation measures on your own. As we discuss in Chapter 5, the problem of interdependencies argues for the public sector to play a role in dealing with risks through standards and regulations, such as well-enforced building codes.

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[19] If the damage from an insured risk is due to negligence or intentional behavior, then there are normally clauses in the insurance policy that indicate that losses are not covered (e.g. a fire caused by arson).

One way to convince n independent property owners that it would be in everyone's best interest to invest in protection is to organize some type of cooperative or coordinating mechanism for requiring or encouraging this action. In apartment buildings there is often a Council that specifies rules and regulations for all residents in the building. They could require investment in protective measures, such as smoke alarms to reduce the chances of fires, where there is a clear interdependency problem. A neighborhood association could encourage all homeowners to invest in protective measures to reduce the chances of damage from hurricanes and earthquakes to themselves and their neighbors. The organization could also make the case that property values would rise in the community by promoting their area as being safe against future disasters.

On a more informal level it might be possible to establish social norms that generate pressure to invest in protection (Sunstein (1996)). This is not easy to do since there are normally no visible benefits from protective investments until a disaster occurs. To the extent that opinion leaders can convince others in their community that these investments will yield expected benefits to everyone in the form of lower losses and higher property values, such a strategy may work.[20]

4.5 Multi-Period Considerations

A decision on whether or not to invest in security normally involves multi-period considerations since there is an upfront investment that needs to be compared with the benefits over the life of the protective measure. A homeowner who invests in mitigation knows that these measures promise to offer benefits for a number of years. Hence one

[20] See Ostrom (1990), particularly chapter 6 that deals with the conditions under which norms evolve governing the use of common property resources.

needs to discount these positive returns by an appropriate interest rate and specify the relevant time interval in determining whether or not to invest in these actions. There may be some uncertainty with respect to both of these parameters.

From the point of view of dynamics, one's own decision as to whether to incur the cost of protection depends on how many others have taken similar actions. Nash equilibria characterize what is likely to happen in the long run when there is the possibility of contamination but these solutions do not provide insight into the dynamics of the process. How does one get the process of investing in security started? Should one subsidize or provide extra benefits to those who are willing to be innovators in this regard to encourage others to take similar actions?

In order to answer these and other questions one needs to develop sequential models of decision-making. These models will need to consider the special characteristics of the hazard and the nature of the contamination effects. A dynamic model for mitigation against natural disasters will have a different set of interactions than one for protection against terrorism, immunization against specific diseases, or theft protection. The policy recommendations will also reflect these differences.

4.6 Behavioral Considerations

The IDS model discussed above assumes that individuals make their decisions by comparing their expected benefits with and without protection to the costs of investing in security. We label this a *rational model* of behavior.

There is a growing literature in behavioral economics that suggest that individuals make choices in ways that differ from the rational model of choice (Kahneman and Tversky (2000)). With respect to protective measures there is evidence from controlled field studies and laboratory experiments that many individuals are not willing to invest in security for a number of reasons that include myopia, high discount rates, and budget constraints (Kunreuther, Onculer, and Slovic (2000)). In the models considered above there were also no internal positive effects associated with protective measures. Many individuals invest in security to relieve anxiety and worry about what they perceive might happen to them or to others so as to gain peace of mind (Baron, Hershey, and Kunreuther (2000)).[21]

A more realistic IDS model that incorporated these behavioral features as well as people's misperceptions of the risk may suggest a different set of policy recommendations than would be implied by a rational model of choice. For example, if agents were reluctant to invest in protection because they were myopic, then some type of loan may enable them to discern the long-term benefits of the protective measure. A long-term loan would also help relieve budget constraints that may deter some individuals or firms from incurring the upfront costs of the risk-reducing measure.

4.7 Summary

This chapter develops a model of interdependent security where the actions of others could cause damage to your property in the event of a natural disaster. We showed using concepts of game theory that when there are identical agents, one can have two Nash equilibria—either everyone invests in mitigation or no one does. Standard policy tools such as insurance do not work well in this situation so it may be necessary to have public-private partnerships for reducing future losses. We explore this issue in more

[21] Of course, if these individuals become aware that substantial losses may be imposed on them or their firm from others who are unprotected, then this new knowledge may increase their anxiety by showing that investing in these protective measures has more limited benefits than they had initially assumed it would.

detail in Chapter 5, where we investigate risk management strategies by evaluating behavior of homeowners in a model city subject to natural disasters.

5 Risk Management Strategies for Reducing Losses: Role of Insurance and Mitigation[22]

In this chapter we focus on two complementary strategies for reducing future losses and providing funds for recovery: insurance and mitigation. We also will indicate the importance of well-enforced building codes given the reluctance of most property owners to invest in protective measures (See Chapter 3) and the interdependencies associated with disasters (See Chapter 4). The analysis is based on data provided to the Wharton Risk Management and Decision Processes Center by three modeling firms [Applied Insurance Research (AIR), EQECAT, and Risk Management Solutions (RMS)] so that one could undertake a detailed analysis of three model cities—Oakland, CA, Long Beach, CA and Miami/Dade County, FL. For illustrative purposes we will focus on one of the model cities (Oakland, CA), henceforth labeled Model City 1 (MC1), which is subject to earthquake losses.[23] Sections 5.1 through 5.4 present an illustration, while Section 5.5 discusses implications for public-private partnerships.

5.1 Construction of MC1

To evaluate the impact that mitigation will have on property losses of insurers and homeowners in MC1, we consider the measure of bracing a wood-frame structure's cripple wall and securing the structure to its foundation with additional anchor bolts. This measure only applies to wood-frame structures built prior to 1940 since most of these were built without adequate bracing to their cripple walls.

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[22]This chapter is based on Grossi and Kunreuther (2005) (Chap. 8).

[23] RMS provided the data to analyze earthquake mitigation measures in Oakland; EQECAT provided the information for Long Beach, CA which also faced an earthquake hazard. AIR provided the data for Miami/Dade County which faced a hurricane hazard.

A hypothetical insurance company provides earthquake coverage to residential property owners in MC1. It is assumed that each homeowner is willing to implement mitigation measures, desires earthquake insurance, and has the financial ability to incur these costs. If the insurer is concerned with the possibility of insolvency, the amount of coverage it provides may be limited so some property owners may be unprotected.

For MC1, 5,000 wood frame single-family residential structures were randomly selected to represent the maximum exposures that an insurance company could write. The distribution of structures is given in Table 5.1. In MC1, the structures were picked randomly from over 62,000 wood frame, single-family residences in the model city and all pre-1940 structures were considered eligible for mitigation. Structures whose age was unknown are assumed to fall into the pre-1940 or post-1940 category with the same likelihood as the known structures. Thus, based on the ratio of pre-1940 homes in the group of homes with known ages, it was assumed that 172 of the 259 structures with unknown age were constructed prior to 1940. Thus, 3,263 homes or 65.3 % of the structures were eligible for mitigation in MC1.

Table 5.1 Composition of Books of Business for Insurer in MC1

Structure by Year of Construction	
Unknown	259
Pre-1940	3,091
Post-1940	1,650
Total	**5,000**

Since insurers are concerned with insolvency, they focus on worst-case scenarios in determining the portfolio of risks they offer coverage to. For this analysis, a worst-case loss (WCL) is defined as a loss corresponding to a 1 % probability of exceedance. This implies that insurers would like to limit their book of business so that they have at least a 99 % chance of avoiding insolvency. The asset levels for the insurer is set at $57 million so its insolvency probability is *roughly* 1 % when mitigation is adopted by all residential structures in its portfolio and this portfolio comprises all 5,000 structures.

5.2 Constructing Exceedance Probability Curves

The variables that describe the nature of the earthquake hazard and characteristics of the buildings at risk are used in conjunction with a catastrophe model to generate an exceedance probability (EP) curve for the insurer's book of business. For an individual residential property owner, the EP curve is a function of the set of natural hazard events that are used in the model, the impact of mitigation (risk reduction) and the amount and structure of the residential insurance purchased (risk transfer). For the insurance company, the EP curve is a function of the amount and nature of insurance sold, the number and types of properties insured, overall adoption of mitigation measures, and the earthquake events that are used to generate loss exposures. The EP curves for the residential property owners and the insurance companies provide the foundation for evaluating expected and worst-case consequences of a set of scenarios, as well as the shares of the losses borne by each stakeholder.

In order to incorporate uncertainty into the study, two parameters are varied from each mean estimate and the sensitivity of the resulting losses to these variations is presented. For the earthquake hazard, the annual recurrence of seismic events and the vulnerability of the building inventory are subjected to variation. Specifically, high and low estimates of these parameters are determined such that they encompass a 90 % confidence interval for each parameter in question. In other words, these high and low estimates are selected so that they cover the true estimates of the model parameters with a probability of 90 %. The high estimate (95th percentile) is conservative since it produces a parameter estimate that will be exceeded only 5 % of the time. The low estimate (5th percentile) is optimistic in that it produces a parameter estimate that will be exceeded 95 % of the time. Figure 5.1 depicts an EP curve for the insurer in MC1 with its portfolio of 5,000 residential earthquake policies along with the 5 % and 95 % confidence bands reflecting the uncertainty in estimating these risks.

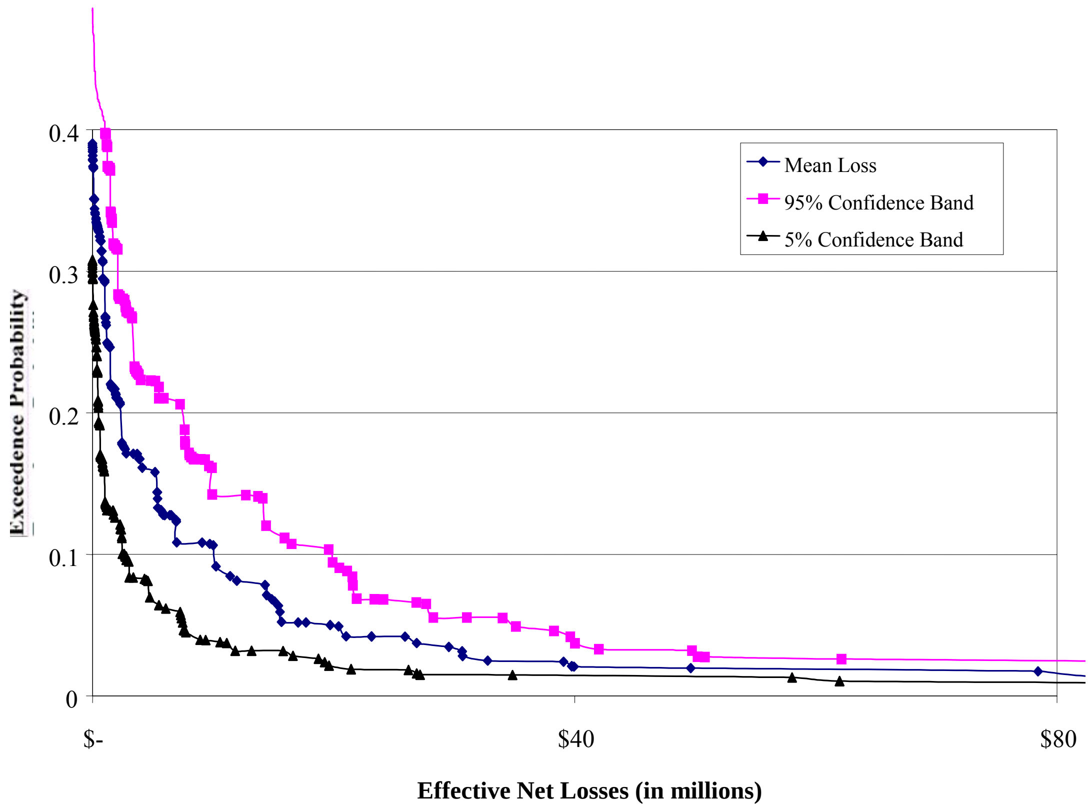


Figure 5.1 EP Curve for Insurer in Oakland, CA with 5 % and 95 % Confidence Bands

5.3 Impact of Mitigation on Losses and Insurer Behavior

Table 5.2 presents the insurer's expected loss $E(L)$, worst-case loss [WCL], and probability of insolvency for levels of mitigation of 0 % and 100 % assuming coverage was offered to all 5,000 residential property owners in MC1. The mean values of these losses (Mean) are displayed along with the values at the confidence bounds, denoted as Low (5th percentile) and High (95th percentile).

Table 5.2 Effects of Mitigation on Insurer in MC1($ in $1000s)

	0 % Mitigation			100 % Mitigation		
	Low	Mean	High	Low	Mean	High
E(*L*) ($1,000s)	$769	$1,679	$3,142	$463	$987	$1,744
WCL ($1,000s)	$40,020	$92,940	$141,580	$25,080	$58,660	$85,460
Probability of Insolvency (%)	0.74 %	1.35 %	1.84 %	0.70 %	1.00 %	1.57 %
Properties Insured (%)	100.00 %	66.1 %	42.8 %	100.00 %	100.00 %	70.9 %
Expected Profits ($1,000s)	$2,590	$1,100	$90	$1,510	$1,000	$160

The mean expected losses are the losses borne by the insurer after the deductible is applied to each policy. In MC1 this deductible level is 10 %. The worst-case losses are those at the 1 % probability of exceedance level. Finally, the Probability of Insolvency is the likelihood that the insurer's losses will exceed the sum of its premiums and assets if all of the 5000 residential structures were insured. Thus if the mean EP curve were utilized with 0 % mitigation, then the likelihood of the insurer becoming insolvent is 1.35 %. This probability drops to 0.74 % if the EP curve is the one depicted in Figure 5.1 as the 5 % confidence band and rises to 1.84 % if the 95 % confidence band is used.

Two other statistics are shown in Table 5.2: the percentage of properties insured and the expected profits of the insurer. Properties Insured is the percent of the full book of business that each insurer can cover without having its probability of insolvency exceed 1 %. Thus only 3,305 of the 5,000 residential structures would be insured if there was no mitigation and a mean EP curve were utilized. With the same EP curve and 100 %

mitigation all 5,000 houses could be insured and the probability of insolvency would be exactly 1 %. Expected profits equal the sum of the premiums minus the expected losses and administrative costs while still meeting an insolvency probability constraint of 1 %.

As expected, the analysis shows that mitigation reduces losses to the insurer in MC1 with a more pronounced impact on worst-case loss than for the expected annual loss. The reduction in mean annual expected losses is $700,000 or 41 %. A principal reason for investigating the impact of mitigation on the worst-case loss is to understand how mitigation reduces the probability of insolvency when all residential structures are insured. Based on Table 5.2 one can see that for MC1 for the mean scenario, the probability of insolvency is reduced from 1.35 % to 1.00 %.

A graphical description of the impact of mitigation on the EP curve for an insurer is depicted in Figure 5.2. Benefits from a particular mitigation measure vary along different parts of an insurer's EP curve (low-end, mid-range, or right hand tail). The precise location of these effects will determine the impact of deductible levels, coverage limits, and premium structures on the insurer's retained risks, profitability, and solvency. In addition, the net benefits to the insurer of mitigation measures will depend on the cost of the various risk bearing and risk transfer methods the insurer uses for each part of the EP curve.

The following interdependent issues arise from these observations. First, it is not a foregone conclusion that policyholders will adopt mitigation measures even when they are shown to be effective and properly priced by the insurer. Since mitigation shifts the EP curve downward, it will also increase the percentage of structures for which the insurer can provide coverage and still maintain an annual probability of insolvency of

1 %. In other words, insurers can provide coverage to more homes if each homeowner is required to adopt mitigation as a condition for insurance.

Consider the expected or mean scenario in Table 5.2. When no mitigation is adopted, the insurance company in MC1 will only be able to provide coverage for 66 % of those property owners who would like to buy a policy. As the percentage of homes adopting mitigation increases, so does the percentage of homes for which the insurer can provide coverage. When all of the homes have adopted the mitigation measure, the insurer is willing to provide coverage to all of the structures, a significant increase over the percentage covered when no mitigation is in place.

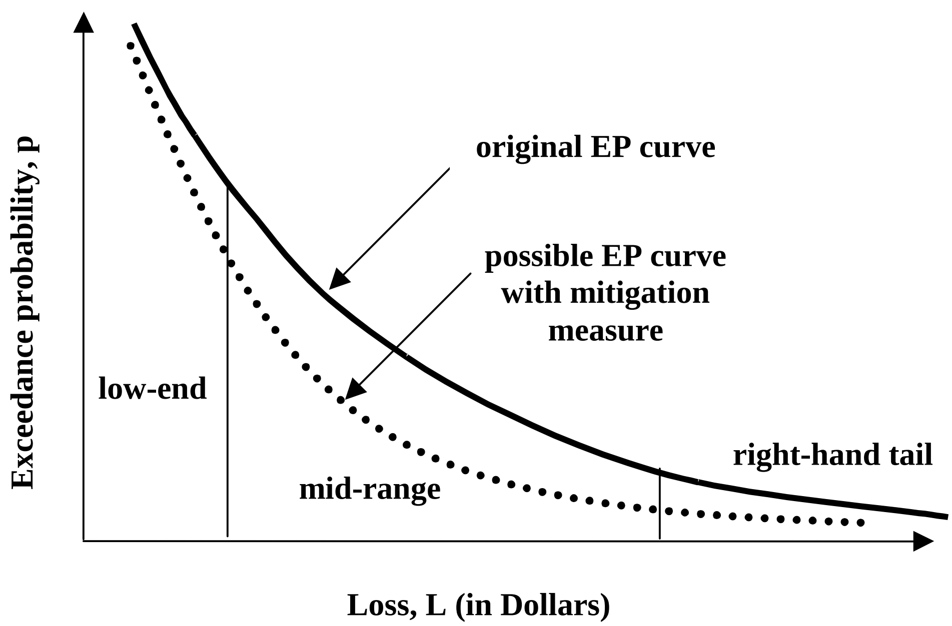


Figure 5.2 An Insurer's Exceedance Probability Curve with Mitigation

5.4 Impact of Mitigation on Homeowners' Performance

As discussed in Chapter 3, field surveys and controlled experiments indicate that most individuals are not willing to invest funds for mitigation even if they are residing in highly hazard-prone areas. In analyzing a homeowner's decision to mitigate or not to mitigate, the fixed mitigation costs are converted to an annual expenditure based on a time horizon of 30 years so these costs are comparable with annual insurance premiums and expected annual losses to the homeowner. In this way, the robustness of the mitigation measure can be viewed in terms of an average homeowner's decision process.

Table 5.3 presents the results for the homeowners in MC1 when no insurance is purchased. The expected loss is the expected annual (or mean) loss to the average property owner based on the scenario events considered in the analysis. This expected loss does not include the cost of mitigation. The worst-case loss is the average homeowners' loss at the 1 % probability of exceedance level. The cost of mitigation is the annual average cost discounted at a 7 % rate over a 30-year time horizon. This cost is applicable only to those 3,263 homeowners in MC1 who mitigate.

From Table 5.3 it can be seen that mitigation reduces losses in MC1, but it is not cost-effective except for the case of High loss. More specifically, when one adds the annualized costs of mitigation to the expected losses with mitigation for the low and mean cases, the total is larger than the expected loss without mitigation. For the High loss case, the potential loss to the homeowner is $1,553 without mitigation. With mitigation, the total potential cost is lower and equal to $1,475 (including the cost of mitigation). These results imply that for the eligible structures in MC1 the disaster risk is not serious enough to justify investing in mitigation based solely on the mean potential loss and the costs of the measure combined.

A basic point to recognize from these results is that it is not a foregone conclusion that a homeowner will view particular mitigation measures as worth adopting. It requires a detailed assessment of the costs and benefits under various hazard scenarios. It is important to note as well that only the direct property losses are evaluated in this analysis. Mitigation could have additional real and perceived benefits for homeowners in reducing the risk of fatalities, stress and interruption of home life. These are not considered here, but are discussed in more detail in a Heinz Center (1999) report.

Table 5.3 Average Homeowner losses for MC1 (No Insurance)

MC1 (No Insurance)	**0 % Mitigation**			**100 % Mitigation**		
	Low	Mean	High	Low	Mean	High
Expected Loss	$430	$910	$1,550	$310	$640	$1,070
Worst-Case Loss	$14,850	$30,100	$40,700	$11,280	$20,390	$27,170
Cost of Mitigation	--	--	--	$410	$410	$410

Turning to the relationship between insurance and mitigation, some interesting findings emerge from recent surveys undertaken by Palm and Carroll (1998). They report that individuals who adopt mitigation measures were also more likely to buy earthquake insurance. This raises the question as to whether certain types of individuals want protection for reasons that have less to do with their perception of the risk than their intrinsic worries and concerns.

In analyzing the impact of mitigation on a homeowner having insurance in MC1, the time horizon is once again set at 30 years with a discount rate of 7 %. Total expected loss and worst-case losses for insured homeowners are computed for the property owners under the assumption that the insurer is providing coverage to the full book of business. In this case, each homeowner has full coverage against losses except for a 10 % deductible. Worst-case losses are those borne by the homeowner at the 1 % exceedance probability level. Costs of mitigation are the same as those noted in Table 5.3.

The results of this analysis are presented in Table 5.4. The expected deductible loss is based on the mean loss across all homeowners. To illustrate how this figure is calculated suppose that all homes in MC1 were valued and insured at $100,000 so that the 10 % deductible was $10,000. If 95 % of the homeowners suffered 0 losses from an earthquake and 05 % of the homeowners suffered losses greater than $10,000, then the expected deductible loss would be $500 (i.e. .95 ($0) +.05 ($10,000).

Table 5.4 also reveals that when insurance is purchased, the earthquake mitigation measure is cost-effective for both the mean and high scenarios in MC1. By lowering the cost of insurance, mitigation becomes a financially feasible option even for the mean scenario. As can be seen from the table, the total expected annual costs are $1,250 and $1,240 with and without mitigation, respectively.

Table 5.4 Average Homeowner Losses for MC1 with and without Mitigation (All Homeowners Have Insurance)

MC1 (10 % Deductible)	**0 % Mitigation**			**100 % Mitigation**		
	Low	Mean	High	Low	Mean	High
Expected Deductible Loss	$280	$580	$920	$220	$440	$720
Insurance Premiums	$670	$670	$670	$390	$390	$390
Cost of Mitigation	--	--	--	$410	$410	$410
Total	$950	$1250	$1,590	$1,020	$1,240	$1,520
Worst-Case Loss	$6,850	$11,510	$12,390	$6,630	$8,660	$10,080

5.5 Implications for Public-Private Partnerships

Suppose homeowners were to voluntarily adopt mitigation measures and insurers were to set premiums that reflected the reduction in losses resulting from the mitigation. Under these ideal conditions, there would be a reduction in both losses to residents and the probability of insolvency for the insurers.

In reality most property owners have limited interest in investing in these measures. Furthermore, insurers have little reason to encourage mitigation in hazard-prone areas if they are not forced to provide coverage and the rates they are allowed to charge are inadequate. Furthermore given the interdependencies of risks discussed in Chapter 4, the insurer may be responsible for losses to their policyholder that may have been caused by their neighbor's home. For these reasons, insurers would want to do everything they could to reduce their exposure and encourage the policyholder to seek coverage from another insurer.

Insurers may have an interest in mitigation if they have no choice but to provide coverage to individuals in hazard-prone areas. If rates in these hazard-prone areas were based on risk and adequate, insurers would want to encourage mitigation, reduce overall losses and charge lower premiums for those who adopted the measures. The magnitude of the premium would be determined by how many neighboring homes also adopted mitigation measures due to the interdependency of the risk.

In this section two types of public-private partnership programs that can encourage mitigation are explored: (1) building codes and other legislation and (2) premium reductions linked with long-term loans for mitigation. In evaluating these programs, it is assumed that there has already been an attempt to use market-based mechanisms to encourage the different interested parties to take action.[24]

Role of Building Codes

Building codes require property owners to meet standards on new structures but normally do not require them to retrofit existing structures. Often such codes are necessary, particularly when property owners are not inclined to adopt mitigation measures on their own due to their misperception of the benefits resulting from adopting the measure, their inclination to underestimate the probability of a disaster occurring and/or their recognition that their neighbors have not adopted these measures.

One way to encourage the adoption of mitigation measures is for banks and financial institutions to provide a seal of approval to each structure that meets or exceeds building code standards. Under the Institute for Business and Home Safety's (IBHS) "Fortified for Safer Living" program, structures that meet predefined criteria receive a certificate of disaster resistance. Upon receipt of that certificate, the structure qualifies for incentives provided by banks (e.g., lower mortgage rates), contractors, and insurers. The success of such a program requires the support of the building industry and a cadre of qualified inspectors to provide accurate information as to whether existing codes and standards are being met. Such a certification program can be very useful to insurers who may choose to provide coverage only to those structures that are given a certificate of disaster resistance.[25]

Cohen and Noll (1981) provide an additional rationale for building codes. When a building collapses, it may create externalities in the form of economic dislocations and other

[24] See the report issued by the Earthquake Engineering Research Institute (1998), which indicates the challenges facing property owners in improving the seismic performance of their structures and suggests ways to encourage cost-effective investments.
[25] For more details on ways to make communities disaster-resistant, see CUSEC 1997.

social costs that are beyond the economic loss 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 homes not structurally damaged by the earthquake in the first place. Additionally, if a family is forced to vacate its property because of damage that would have been prevented had a building code been in place, then avoiding relocation costs is an additional benefit of mitigation.

The latest effort to encourage individuals to adopt mitigation measures is the Earthquake Loss Reduction Act of 2001. Under the provisions of this Act[26], the government would offer incentives for commercial and residential property owners to adopt mitigation measures. Residential property owners would receive a 50 % tax credit for a qualified seismic retrofit expense (limited to $6,000 per year). Further, businesses will be allowed to depreciate expenses associated with earthquake mitigation over a period of five years.

Long-Term Loans for Mitigation.

If homeowners are reluctant to incur the upfront cost of mitigation due to budget constraints, then a long-term loan may provide a financial incentive for adopting cost-effective measures. The bank holding the mortgage on the property could provide funds for this purpose through a home improvement loan with a payback period identical to the life of the mortgage. For example, a 20-year loan for $1,500 at an annual interest rate of 10 % would result in payments of $145 per year. If the annual insurance premium reduction due to the adoption of the mitigation measure were greater than $145 per year,

[26] As of this writing this legislation is still under review in the Senate finance committee.

the insured homeowner would have lower total payments by investing in mitigation (Kunreuther, 1997). By tying mitigation and insurance to a loan, one makes small payments each month and avoids the possibility of a much larger loss should an earthquake occur and the damage exceed the coverage limits because the house was not mitigated.

One additional factor to consider is that many poorly constructed homes are owned by low-income families who cannot afford the costs of mitigation measures on their existing structure, or the costs of reconstruction should their house suffer significant damage from a natural disaster. Social considerations suggest providing this group with low interest loans and grants for the purpose of adopting mitigation measures or to relocate them to a safer area. Such subsidies can be justified from an economic perspective as well since low-income victims are more likely to receive federal assistance after a disaster.

5.6 Summary

This chapter examined the impact of mitigation on the disaster losses to residential structures provided to the Wharton Risk Management and Decision Processes Center by three modeling firms. Insurers providing coverage to residential structures in Oakland, CA (MC1) were able to reduce their worst case losses and book of business by requiring mitigation on all homes in the city. Homeowners who did not purchase insurance reduced their expected costs by mitigating their structures. Even when they did purchase insurance, their total costs were less with mitigation than without for the mean and high EP curves characterizing earthquake losses. The chapter concluded by highlighting the importance of public-private partnerships and stressing the importance of building codes and long term loans for mitigation.

6 Designing Controlled Laboratory Simulations to Better Understand Household Adaptive Response to Natural Hazards: An Illustration

If there is a saving grace to natural hazards such as earthquakes, fires, and hurricanes, it is that they are far more often avoided by households than encountered. For most individuals, the risks they pose are thus abstract, learned from images of damage seen in remote news accounts, or tables of actuarial odds read in government preparedness brochures.

Yet, while this rarity of natural hazards is unambiguously positive, it also has a paradoxical downside: it implies that when such threats do arise they are imposed on populations that have had little opportunity to train for them. Moreover, it also hinders the ability of governments to know what policies will be most effective for helping the public prepare in the event that hazards are realized. If a community has never faced an imminent threat from a hazard, it is difficult to know how it will respond to different kinds of preparedness measures (e.g., evacuation orders), or how a close-call might affect the community's willingness to respond to measures instituted in the future.

The 2004 hurricane season in Central Florida provided a rare case study in these dynamics. Although Florida is historically the most hurricane-prone state in the nation, people born in inland central Florida area after 1960 would have grown to adulthood without ever directly experiencing one—an incidental quirk of climatology and chance. Hence, when Hurricane Charley approached the region overland from the southwest in August of that year, the severity of its damage caught many central-Floridians by surprise, many having been lured to the complacent belief that their inland location made them immune from the destruction of hurricanes typically seen along the coast.

But Floridians turned out to be quick learners—or so it seemed. When the same area was threatened by yet another hurricane just two weeks later—Frances—the threat was met by an almost panic-like response, as residents depleted gas stations of fuel supplies and thousands crowded storm shelters to wait out the next blow. But this new-found respect for the risk posed by hurricanes proved short-lived. As it turned out, Frances weakened before hitting the region and the damage was far less than that wrought by Charley, leading many to believe—particularly those who had evacuated to shelters—that they probably had over-prepared. Hence, when hurricane Jeanne—the state's fourth hurricane of the season—threatened the state three weeks later following the same path as Frances, the response was far more subdued, with many eschewing evacuation orders even when forecasters warned of the possibility that Jeanne could be an order of magnitude stronger than Frances on impact. As it was, Jeanne did not strengthen as forecast and the feared disaster never materialized—but not without leaving emergency management officials worrying that some Floridians may have learned the wrong things from their recent experiences.

How does the experienced frequency of natural hazards affect the heuristics households use to respond to them? While the above case study suggests some clues, the fact remains that we know little of a generalized nature about this question. The reason is simple: in the same way that the rarity of natural hazards makes it difficult for individuals to learn how to respond to such risks, their rarity also precludes field researchers from efficiently studying how these responses are formed and adapt to experience. Even when natural opportunities for studying learning arise—such as above—the insights they afford are often limited. The heightened awareness to the threat of Hurricane Frances illustrates, for example, how highly reactive risk attitudes can be to experienced losses, and the more subdued response to Jeanne indicates how these same attitudes can change again given near-misses. But it remains uncertain to what degree one should interpret these as isolated anecdotes versus general phenomena, or whether undesired leaning outcomes can be counteracted through policy, such as arrays of economic incentives designed to heighten hurricane-risk awareness and investments in mitigation.

In this chapter we illustrate how insights such as these might be gained outside of field settings through the use of real-time experimental computer simulations. In these simulations human participants play "virtual hazard games" in which they live in a hypothetical region that is prone to the risk of a given class of natural hazard—such as earthquakes or hurricanes. Participants are endowed with a real wealth at the start of the simulation, and their goal is to make a continuous series of decisions about whether to spend this wealth on devices that protect their home against the threat of hazards, or not invest and take the chance that their home will not be damaged by any hazardous events that arise. The simulations thus form a laboratory for testing a large number of possible hypotheses about how individuals learn responses to hazard risk, including the effects of the frequency and timing of experienced hazards, the role of social influences on mitigation behavior, and the effects of policy incentives.

We first describe in detail the structure of and findings of a prototype simulation set in the context of individual and group response to earthquake risks. We then discuss the implications of the method for future descriptive and prescriptive research on mitigation responses to low-probability, high-consequence events.

6. 1 The Earthquake Simulation: A Laboratory Prototype

Overview

The purpose of this investigation was to explore the viability of using computer simulations to test a fundamental assumption about the economic rationality of individual decisions whether to invest in mitigation to protect against the risk of natural hazards. The focal issue was this: while normative theory outlines a precise method by which rational households should make mitigation-investment decisions by maximizing long-run expected utility, the information needed to make such calculations is rarely available. Objective information about hazard probabilities, for example, is commonly ambiguous owing to short and/or incomplete historical data records, and even when it does exist there will be uncertainty about how to apply it to an individual household location.

In addition, few households will be certain what their length of tenure will be in a household, and just how effective different investments will be in precluding damage in the event that a hazard strikes. Consistent with this, research in mitigation decision making has routinely shown that decisions are made by processes that seem to bear little resemblance to that prescribed by economic theory; probability information is ignored, investments are temporally myopic, and, in some cases, no decisions are made at all, as households simply imitate the actions of others (Kunreuther (1996)).

Yet, none of these observations preclude the possibility that normative economic theory might nevertheless emerge as a tenable *as-if* model of decision making as long as decision makers have an opportunity to learn from experience—be it either directly or by observing the experiences and actions of others. Specifically, one of the core findings of behavioral economics is that all that is required for naïve decision makers to exhibit optimal or near-optimal behavior is that a decision environment be conducive to trial-and-error learning. Specifically, the following four conditions exist:

1. The optimal policy has the potential of being imagined and tested by a decision maker;
2. Decision makers can observe the outcomes of a given policy (e.g., whether a protective investment works or not);
3. Policies that yield positive outcomes are more likely to be repeated than negative outcomes (positive actions are reinforced); and
4. Decisions and outcomes are observed with sufficient frequency and variance to allow convergence to equilibrium.

The problem with applying these principles to mitigation decisions is that principle (3) will fail in many circumstances by the rarity and complexity of the effects caused by hazards. For example, if a Florida resident erects storm shutters and finds that they successfully protect a home's windows during a hurricane, it will be impossible to know how much credit should be given to the shutters; the windows might well have been fine without them. Likewise, if a decision is made *not* to make an investment in a certain mitigation device and damage is suffered, there will be uncertainty about whether the investment would have prevented the loss. In addition, principle (4) presumes that decision makers are innately good experimental observers; in the event that they personally do not experience a hazard, that they are good at applying learning principles to the experiences of others.

We tested this assumption of optimal learning by observing the repeated investment behavior of experimental subjects engaged in a computer simulation set in the context of earthquakes. The goal of the simulation was to test the extent to which participants would learn the optimal level of investment in a set of mitigation instruments whose effectiveness was initially uncertain, but that could be learned by experience. In this case two forms of learning from experience were available: that of observing the amount of damage suffered by a home conditional on a given level of mitigation, and that of observing the investments and damage levels experienced by a pool of other decision makers.

Participant and Procedure

Experiments were run on a small-group basis in the behavioral lab of the Wharton School with 109 undergraduate and graduate students from the University of Pennsylvania who volunteered to participate in response to a cash incentive. In return for participating all subjects received a $10 show-up fee plus a chance to win a $200 cash reward depending on their performance in the simulation.

The experiment centered on a real-time earthquake simulation programmed with assistance of the Alfred West, Jr. Learning Laboratory of the University of Pennsylvania's Wharton School. The simulation was a web-based networked game that allows multiple players to make decisions about whether to invest in improvements that potentially lower the chance that their home will suffer the damaging effects of an earthquake, as well as observe the decisions being made by other players and their damages, if any.

The instructions to the simulation began by asking participants to imagine that they had just moved into a home in a hypothetical country that was prone to periodic earthquakes. Participants were told that each had a starting wealth of $50,000, $40,000 of which was reflected in the value of the home and $10,000 in cash that could either be invested at a 10 % rate of return (compounded and paid a fixed number of times during the course of the simulation) or used to purchase improvements in their home that could potentially lower the damage it would suffer in the event of an earthquake. Their goal was simple: to end the game with as large a total wealth value as possible.

The central simulation interface is shown in the screen shots in Appendix 1. The interface consisted of six major aspects:

1. A map showing the location of the player's home, that of each other player, and, when there was an earthquake, its epicenter and size (depicted by a set of concentric rings)
2. A home-improvement panel which the player could use to upgrade the quality of the construction of their home in an effort to make it more resilient to the effects of earthquakes. Added construction value was measured on a 0-100 percentage scale, and could be achieved by paying for improvements in the chimney, door frame, foundation, landscape, roof, walls, and/or windows.
3. A house-condition panel that showed the upgraded condition of the player's house as well as that for each other player. This information was displayed through house icons whose various features (e.g., roof, landscaping) changed color depending on the degree of upgrading that had been purchased.
4. A research button that a player could click to gather information about the likely frequency of earthquakes and expert opinions about the value of mitigation investments; and
5. A "messages" box that alerted players when a interest payment on their cash had been made; and
6. A time line that recorded the number and time of historical earthquakes during the simulation.

A critical feature of the simulation was that the game was played in *real time* rather than in terms of a fixed number of lock-step moves. As such, participants could make decisions about investing in mitigation at any time they wished during the simulation (regardless of what other players did), and earthquakes could arise at any time. In addition, whenever any player elected to purchase mitigation and/or suffered losses due to an earthquake these events were immediately posted to the screens of all players.

As noted above, when an earthquake occurred it was manifested on the screen by an animation that showed a set of concentric circles emanating from its epicenter, as well as a text message indicting its strength. There were four levels of earthquake strength, with stronger earthquakes having damage zones that covered a larger area and having greater damage potential. In the simulation the administrator controlled the frequency and timing of the quakes but not the intensity, which was a random draw from a skewed distribution that made minor quakes more likely.

Given that an earthquake occurred, the damage it imposed on a given home (*D*) was computed using the deterministic formula

$$D=(exp\text{-}a(dist(Q)))*S*V*(1-P*E), \tag{6.1}$$

where *dist(Q)* was the Euclidean distance between the quake epicenter and the player's home, *S* was the scalar measure of the quake's strength, *V* was the value of the player's home, *P* was the fraction of possible home improvements purchased by the player, and *E* was a continuous scalar parameter bounded by the range [0,1] that captured the marginal effectiveness of improvements (the higher E, the more effective a given level of purchased protection). In the simulation participants were able to view graphs that showed the implications of damages computed according to equation (6.1) for an unprotected home for varying quake strengths and distances. They were not told the effectiveness parameter, which, as we will describe below, was a central experimental manipulation.

The simulation was administered by having all groups play three 10-minute rounds of the simulation. These replications gave participants an opportunity to make up for early mistakes made due to unfamiliarity with the simulation structure. All 10-minute games utilized the same parameters, and involved an average of 5 earthquakes per game.

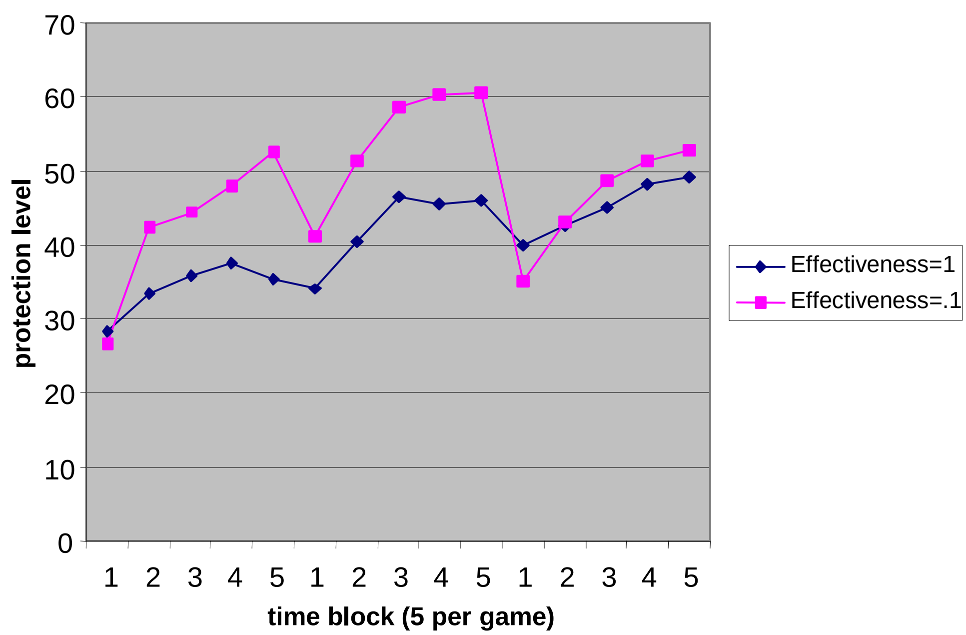
The Effectiveness Manipulation

In the current experiment the focus centered on a manipulation of the parameter *E* in (6.1), the marginal effectiveness of investments in mitigation. Specifically, in half the games this value was set to .1, implying that investments in mitigation would do little to limit losses against earthquakes, while in the other half this value was set to 1, implying that investments were maximally effective. Given full knowledge of these parameters participants were thus posed with one of two extreme optimal policies: either buy as much protection as possible (*E=1*) or buy none at all (*E=.1*)

Results

In Figure 6.1 we plot the average percentage level of protection as measured at 2-minute intervals over each of the three successive simulations. The data yield a striking result: not only is it the case that subjects did not seem to converge toward the rational equilibrium investment levels in each game, but the mean level of investment was directionally *opposite* of the normative value. Specifically, all mean investment levels oscillated over a range between .25 and .65, with greater investment in settings where it was least effective.

Figure 6.1 Protection by Time and True Effectiveness



What makes this finding particularly striking is that while each individual had only limited opportunities for *personal* learning in each game, they had ample opportunity for learning from observing the decisions and experiences of other players.

What caused this result? The most likely explanation is that it is a consequence of two forces:

1. A tendency to set protection levels through an anchor-and-adjustment heuristic; and

2. A tendency for adjustments to be flawed in the face of highly ambiguous decision feedback.

Specifically, most participants appeared to make decisions by buying a modest amount of protection at the start of each game, and then adjusting that amount depending on the experienced effects of earthquakes. In the case where mitigation was ineffective, subjects appeared to attribute the high levels of experienced damage to insufficient investment rather than ineffective protection, hence, paradoxically, increased rather than decreased investments. In the case where mitigation was effective, however, an opposite attribution seems to have been made: the fact that limited damage was encountered when an earthquake arose triggered the attribution that the threat posed by earthquakes was limited, not that the mitigation was effective. Hence, we see little effort made to increase investment levels.

The fact that this result was observed in a setting where the decisions of all players could be observed, of course, makes the result all the more curious. In this case the social setting of the simulation may have reinforced rather than corrected the biased nature of responses.

6. 2 Future Directions

The purpose of this experiment was to illustrate the potential value of dynamic laboratory simulations as a tool for gaining a better understanding of how households make decisions about whether to invest in protective measures against the threat of natural hazards. We observed that the rarity of hazards makes developing this knowledge difficult using traditional field survey data, and, of course, nature rarely lets us run policy experiments. On the other hand, we have now reached a point of computing sophistication where many of these answers can come from experiments run in laboratories, using highly realistic computer simulations of natural hazards.

In this illustration we focused on the degree to which households might be expected to optimize decisions about when to invest in protective mitigation. The answer is not an encouraging one: left to their own wits, individuals seem prone to under-invest when mitigation is cost-effective and over-invest when it is ineffective. Moreover, contrary to the expectations based on economic theory, allowing individuals to learn from others does little to move people toward optimality; if anything, it may reinforce sub-optimality.

How does one correct this? In our view, the greatest potential value of simulations lies in addressing this question. A logical next step in this work is to test the effectiveness of different kinds of incentives either to encourage individuals to become more effective experimenters or to encourage a particular social optimum in terms of investments. For example, note that in this experiment subjects could easily have discovered the true effectiveness of mitigation simply by observing an extreme test point—what happened to a household that suffered a quake under 100 % protection. Yet, few participants elected to undertake such an experiment (we observed only rare instances of respondents purchasing 100 % protection, and none in the first round of the simulation), and few seemed to attend to the insights latent in the variance in investment levels that did exist. An interesting point for future work would be to identify conditions under which individuals could be trained to be more effective inductive learners.

Finally, although simulations such as this form a potentially powerful tool for empirical analysis in a wide range of hazards settings, it should be stressed that there may well be substantial differences between responses to events in the real world versus the laboratory. As realistic as the simulation may be, it cannot hope to re-create the depth of emotion that often drives decision-making in real hazard situations. It is for this reason that we see simulations as being a *companion* to traditional field survey work—work needed to both calibrate laboratory findings as well as identify potential future foci of laboratory investigations.

7 Suggestions for Future Research

This chapter discusses future research directions for reducing losses from extreme events while at the same time providing financial protection should a disaster occur. This report has stressed the need to identify the nature of interdependencies between agents and the importance of developing risk management strategies for encouraging the adoption of cost-effective protective measures that take into account the uncertainties associated with risk assessment as well as people's risk perceptions. We also need to undertake empirical studies to understand more clearly how individuals behave with respect to adopting loss reduction measures. The controlled laboratory experiments described in Chapter 6 using computer simulations address this issue. It is important to determine what individuals learn from past experience and from others' actions in making their choices under uncertainty.

7.1 Dealing with Interdependencies

Future research should address the appropriate strategies for dealing with situations where there are interdependencies between agents (persons, organizations, countries). In these situations, there may be a need for the public sector to play a role with respect to providing protective measures because the private sector may have few economic incentives to take these steps on their own.

The 9/11 events and the anthrax attacks during the fall of 2001 also demonstrated a new kind of vulnerability. Terrorists can use the capacity of a country's critical infrastructures to have an immediate large-scale impact on the nation by reversing the diffusion capacity of the networks and turn them against the target population so that every aircraft and every piece of mail now becomes a potential weapon (Michel-Kerjan (2003)).

The emerging vulnerabilities in critical infrastructures raise challenging questions related to strategies for mitigation given the large operating networks associated with the water supply, electricity, transportation networks, telecommunications, banking and finance, energy, emergency, and defense services. The social and economic continuity of a nation's activities critically depend on their operation (OECD (2003); Michel-Kerjan (2003); White House (2003)). Future research should examine the nature of these interdependencies as well as the appropriate role of regulations, standards, third party inspections, and insurance to encourage individuals and firms to take protective actions. Without some type of coordinating mechanism, or economic incentives such as a fine, subsidy or tax, it may be difficult to convince individuals or firms to invest in mitigation because they know others may contaminate them.

To better understand these interdependencies at a managerial level, it would be meaningful to organize international strategic debriefings after an extreme event or a large-scale threat occurred between involved senior executives and academic experts. Every threat offers an opportunity to learn and be prepared collectively (Lagadec and Michel-Kerjan (2004)).

While launching such initiatives requires expertise and commitment by the top-management of organizations, it would help to learn more about these emerging risks and to examine more adequate global security strategies given limited resources. By developing trusted public-private partnerships to deal with interdependencies associated with extreme events substantial benefits can be provided to the affected individuals and firms as well as improving the social welfare.

7.2 Risk Management Strategies

There are a range of risk management strategies that can be pursued by the private and public sectors for encouraging agents to invest in cost-effective protective measures while at the same time providing financial relief to the victims of a disaster. Here are a few of them:

Information Gathering: Collecting information on the risk and costs. For example, one could construct scenarios so that one can estimate relevant probabilities, outcomes and costs with greater accuracy.

Economic Incentives: Designing incentive systems (e.g. subsidies or taxes) to encourage investment by agents in protective measures.

Insurance: Developing insurance programs for encouraging investment in protective measures when firms are faced with contamination.

Government Protection: Introducing federal reinsurance or state-operated pools to provide protection against future losses from terrorist attacks to supplement private terrorist insurance

Liability: Structuring the liability system to deal with the contamination effects of interdependent systems

Regulations and Standards: Carefully designed standards (e.g. building codes for high-rises to withstand future terrorist attacks) that are well-enforced through mechanisms such as third-party inspections.

It may be desirable to integrate several of these measures through public-private risk management partnerships. For example, banks and financial institutions could require that firms adopt security measures as a condition for a loan or mortgage. To ensure that these measures are adopted there may be a need for third party inspections or audits by the private sector. Firms who reduce their risks can be rewarded through lower insurance premiums. If there are federal or state reinsurance pools at reasonable prices to cover large losses from a future terrorist attack, then private insurers may be willing to provide terrorist coverage at affordable premiums

7.3 Controlled Laboratory Experiments

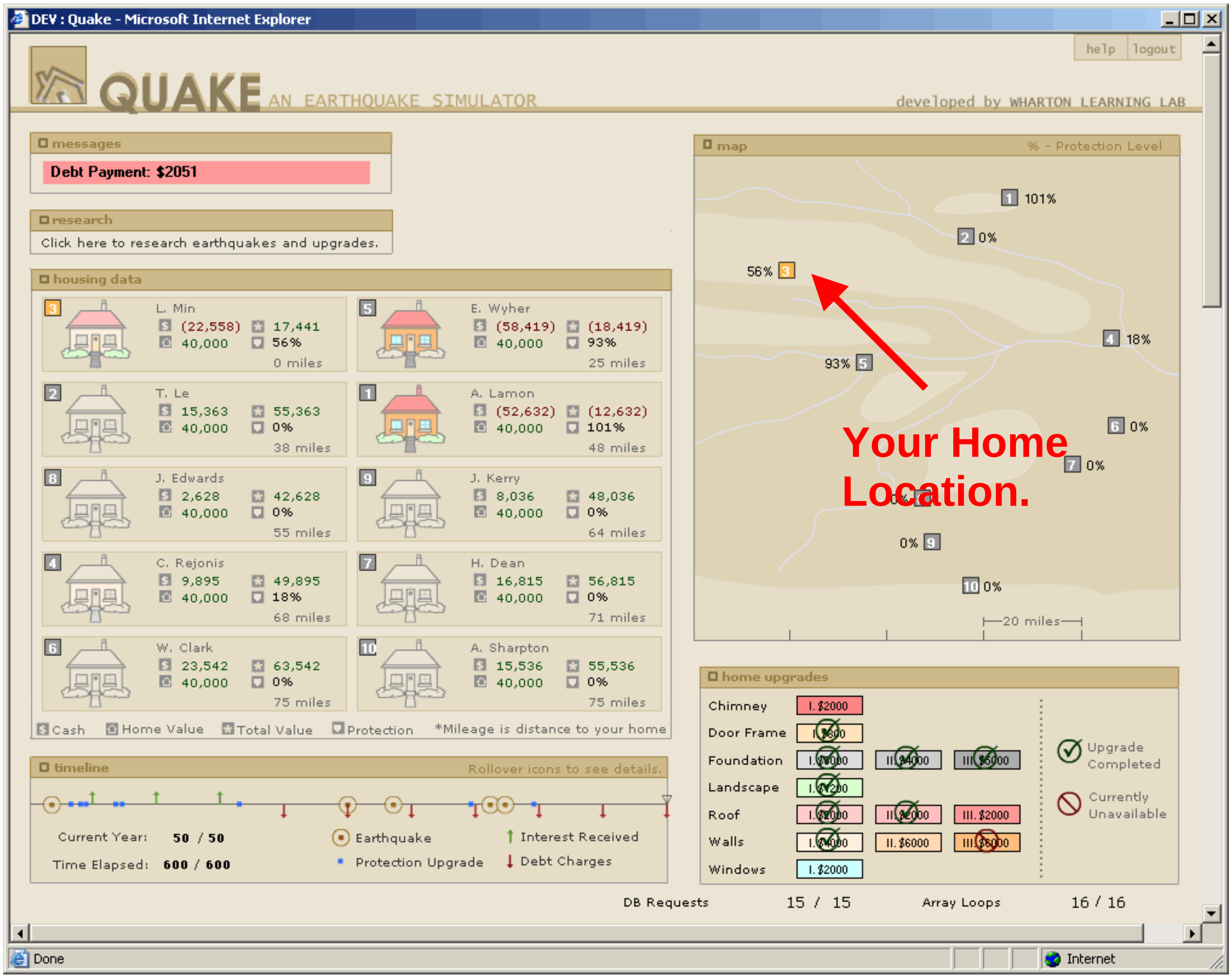
In the laboratory experiment we reported on, we focused on the degree to which decision makers optimized their decisions about whether to invest in protective mitigation. We found that left to their own wits, individuals seem prone to under-invest when mitigation is cost-effective and over-invest when it is ineffective. Moreover, allowing individuals to learn from others did little to move people toward optimality. Future experiments may provide insights on how one can best correct this.

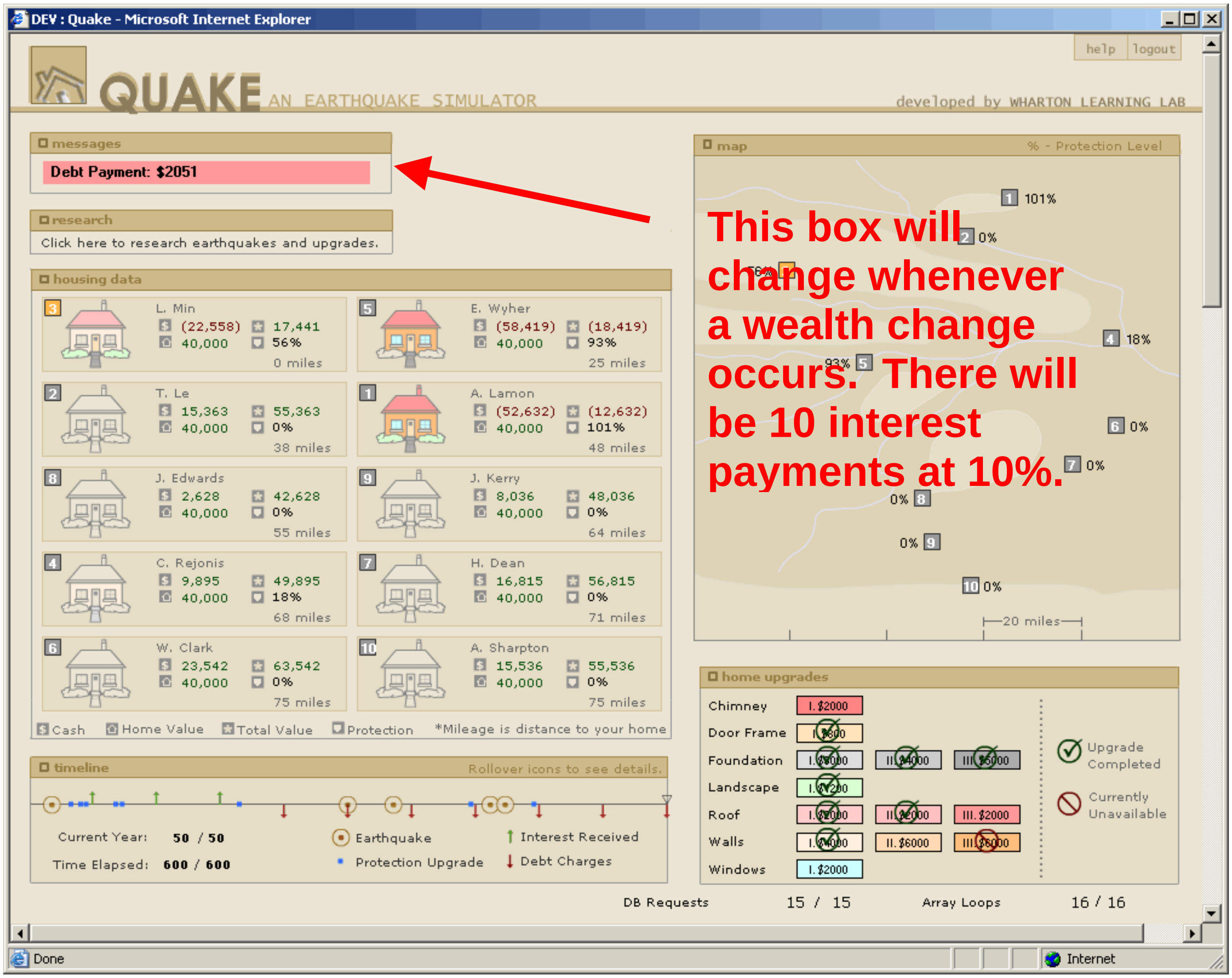
A logical next step in this work is to test the effectiveness of different kinds of guidelines and incentives either to encourage individuals to become more effective learners or to encourage a particular social optimum in terms of investments.

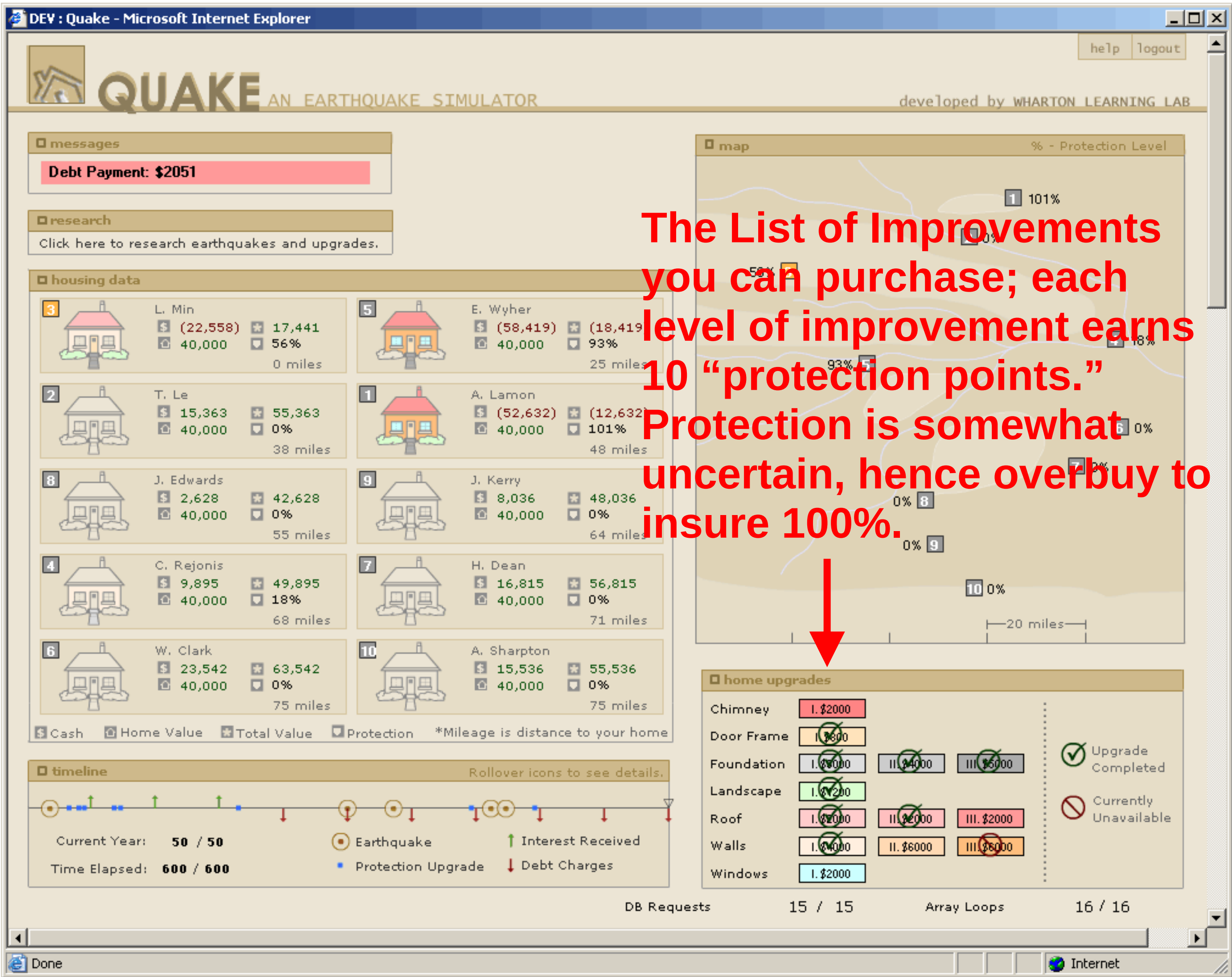
Another policy issue is how much and what kind of information about others' actions leads to the best outcomes. The experiment we reported on provided quite a bit of information about both others' actions (the level of protection for each of several kinds of protective measures) and outcomes (the level of damage to several parts of the house). It is possible that providing such highly detailed information about not only oneself but also others leads to “information overload.” When provided with too much information, decision makers may be less inclined to look at others’ actions or may be less able to draw the right inferences from others’ actions when they do look at them. Providing less information may be better than providing more. On the other hand, economic theory has shown that providing information about others’ behavior but not their outcomes can lead to socially inefficient imitation cascades (e.g., Banerjee (1992); Bikhchandani, Hirshleifer, and Welch (1992)). In short, there is a need for future research to address how much and what kind of information should be provided to decision makers to improve the level of investment in risk mitigation measures.

Finally, lack of interest in investing in protective measures is a concern when risks or outcomes are interdependent. However, there is considerable empirical evidence that when there are externalities, people often do not behave according to the tenets of economic theory and mute self-interest seeking (Camerer, Loewenstein, and Rabin (2004)). Future research may want to investigate the extent to which norms of fairness facilitate the emergence of mutually beneficial outcomes in situations of interdependent security and interdependent risk.

Appendix 1 Screen Shots of the Earthquake Simulation




DEV : Quake - Microsoft Internet Explorer
QUAKE AN EARTHQUAKE SIMULATOR
developed by WHARTON LEARNING LAB
messages
Debt Payment: $2051
research
Click here to research earthquakes and upgrades.
housing data
map
% - Protection Level
This box will change whenever a wealth change occurs. There will be 10 interest payments at 10%.
home upgrades
Chimney
Door Frame
Foundation
Landscape
Roof
Walls
Windows
Upgrade Completed
Currently Unavailable
timeline
Rollover icons to see details.
Current Year: 50 / 50
Time Elapsed: 600 / 600
Earthquake
Interest Received
Protection Upgrade
Debt Charges
DB Requests 15 / 15
Array Loops 16 / 16
Done
Internet


DEV : Quake - Microsoft Internet Explorer
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QUAKE AN EARTHQUAKE SIMULATOR
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messages
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research
Click here to research earthquakes and upgrades.
housing data
L. Min
(22,558)
17,441
40,000
56%
0 miles
E. Wyher
(58,419)
40,000
93%
25 miles
T. Le
15,363
55,363
40,000
0%
38 miles
A. Lamon
(52,632)
40,000
101%
48 miles
J. Edwards
2,628
42,628
40,000
0%
55 miles
J. Kerry
8,036
48,036
40,000
0%
C. Rejonis
9,895
49,895
40,000
18%
68 miles
H. Dean
16,815
56,815
40,000
0%
71 miles
W. Clark
23,542
63,542
40,000
0%
75 miles
A. Sharpton
15,536
55,536
40,000
0%
75 miles
Cash
Home Value
Total Value
Protection
*Mileage is distance to your home
timeline
Rollover icons to see details.
Current Year: 50 / 50
Time Elapsed: 600 / 600
Earthquake
Protection Upgrade
Interest Received
Debt Charges
map
% - Protection Level
101%
20 miles
The List of Improvements you can purchase; each level of improvement earns 10 “protection points.” Protection is somewhat uncertain, hence overbuy to insure 100%.
home upgrades
Chimney
Door Frame
Foundation
Landscape
Roof
Walls
Windows
I. $2000
II. $6000
III. $2000
I. $2000
Upgrade Completed
Currently Unavailable
DB Requests
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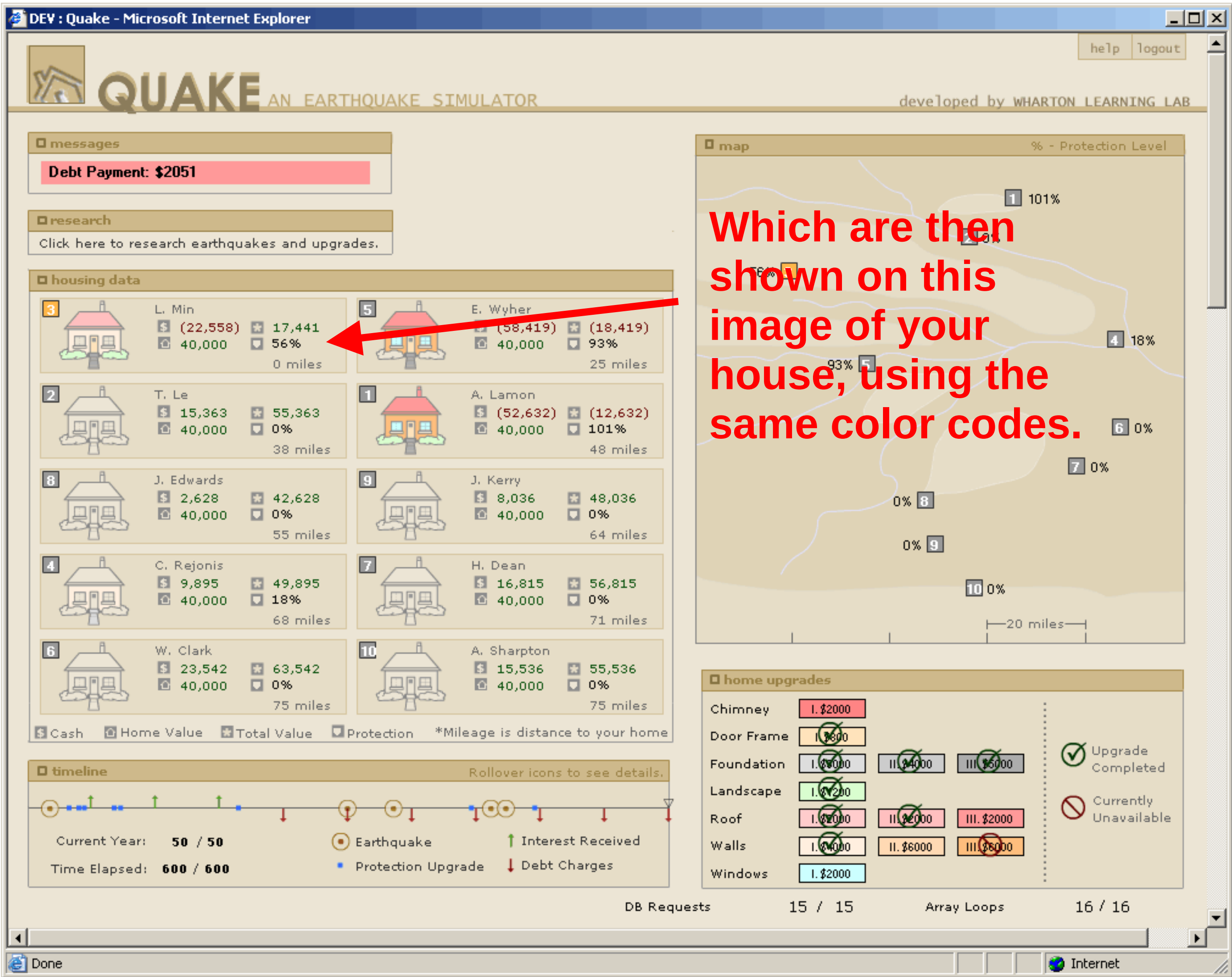
Array Loops
16 / 16
Done
Internet



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developed by WHARTON LEARNING LAB
messages
Debt Payment: $2051
research
Click here to research earthquakes and upgrades.
housing data
L. Min (22,558) 17,441 40,000 56% 0 miles
E. Wyher (58,419) (18,419) 40,000 93% 25 miles
T. Le 15,363 55,363 40,000 0% 38 miles
A. Lamon (52,632) (12,632) 40,000 101% 48 miles
J. Edwards 2,628 42,628 40,000 0% 55 miles
J. Kerry 8,036 48,036 40,000 0% 64 miles
C. Rejonis 9,895 49,895 40,000 18% 68 miles
H. Dean 16,815 56,815 40,000 0% 71 miles
W. Clark 23,542 63,542 40,000 0% 75 miles
A. Sharpton 15,536 55,536 40,000 0% 75 miles
Cash Home Value Total Value Protection *Mileage is distance to your home
timeline
Rollover icons to see details.
Current Year: 50 / 50
Time Elapsed: 600 / 600
Earthquake
Interest Received
Protection Upgrade
Debt Charges
map
% - Protection Level
Which are then shown on this image of your house, using the same color codes.
101%
18%
93%
0%
20 miles
home upgrades
Chimney I. $2000
Door Frame
Foundation
Landscape
Roof III. $2000
Walls II. $6000
Windows I. $2000
Upgrade Completed
Currently Unavailable
DB Requests 15 / 15
Array Loops 16 / 16
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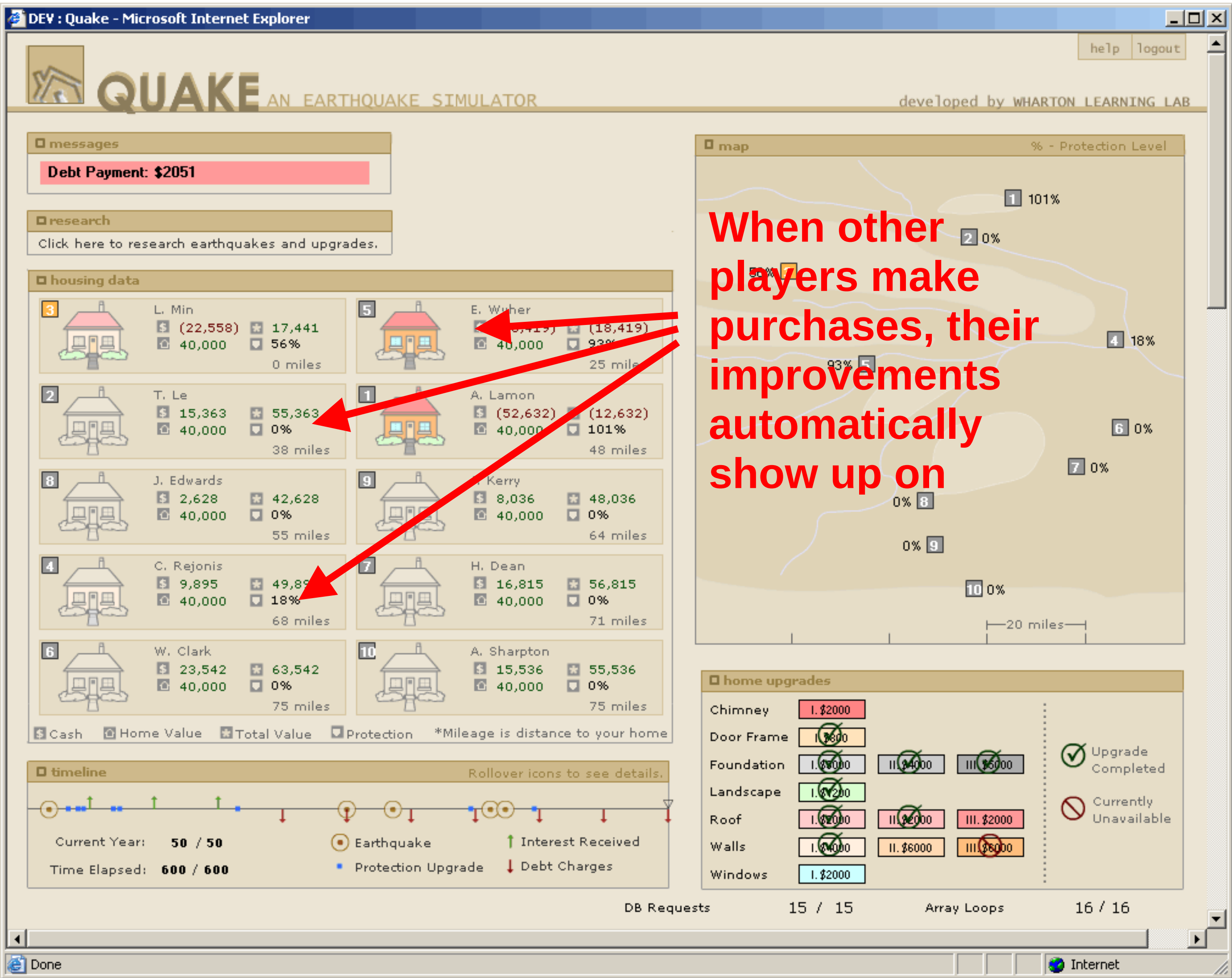
Internet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T. Le
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55,363
40,000
0%
38 miles
A. Lamon
(52,632)
(12,632)
101%
48 miles
J. Edwards
2,628
42,628
40,000
0%
55 miles
Kerry
8,036
48,036
0%
64 miles
C. Rejonis
9,895
40,000
18%
68 miles
H. Dean
16,815
56,815
40,000
0%
71 miles
W. Clark
23,542
63,542
40,000
0%
75 miles
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timeline
Rollover icons to see details.
Current Year: 50 / 50
Time Elapsed: 600 / 600
Earthquake
Interest Received
Protection Upgrade
Debt Charges
map
% - Protection Level
When other players make purchases, their improvements automatically show up on
101%
18%
0%
20 miles
home upgrades
Chimney
Door Frame
Foundation
Landscape
Roof
Walls
Windows
I. $2000
II. $6000
III. $2000
Upgrade Completed
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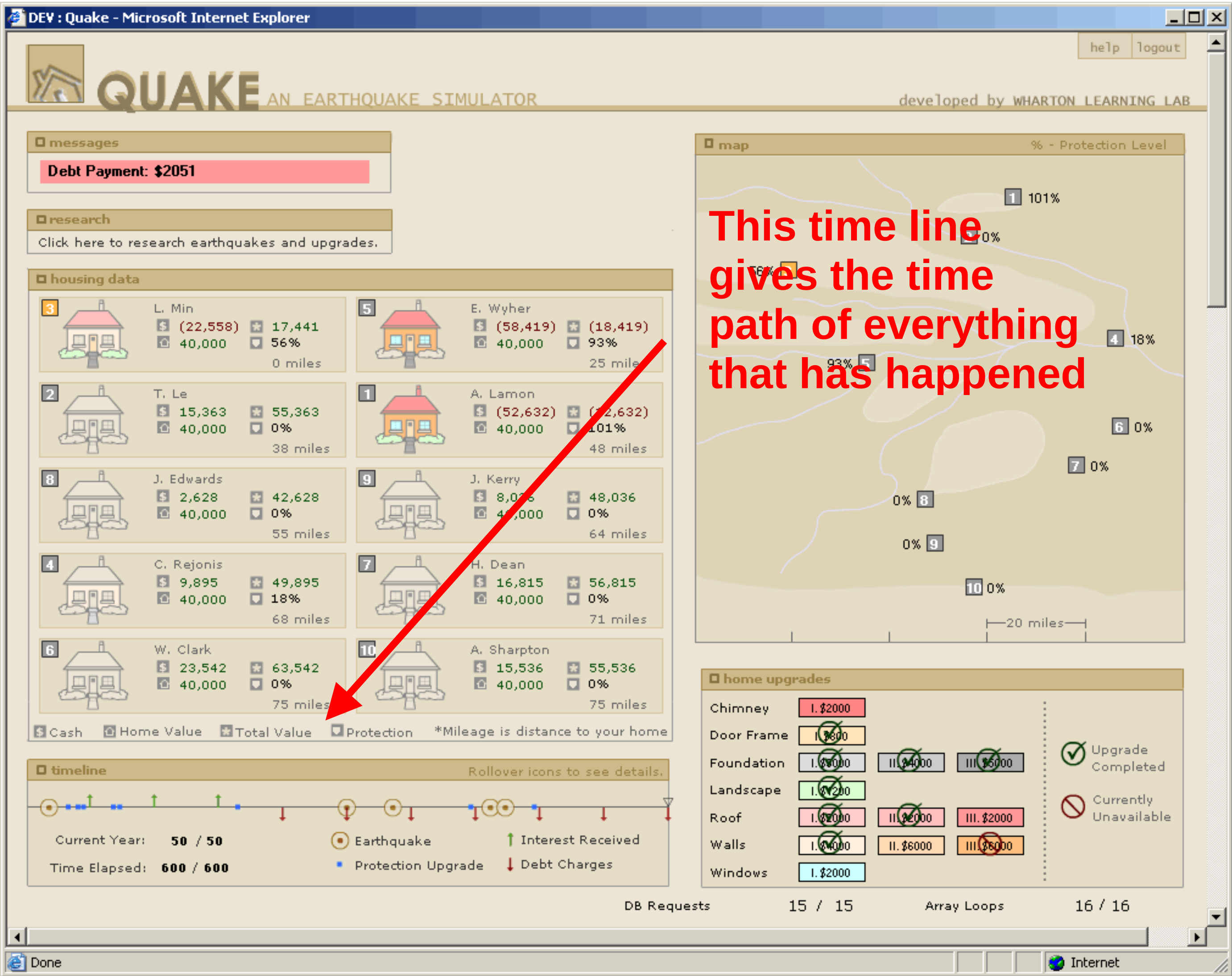
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T. Le 15,363 55,363 40,000 0% 38 miles
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J. Edwards 2,628 42,628 40,000 0% 55 miles
J. Kerry 48,036 0% 64 miles
C. Rejonis 9,895 49,895 40,000 18% 68 miles
H. Dean 16,815 56,815 40,000 0% 71 miles
W. Clark 23,542 63,542 40,000 0% 75 miles
A. Sharpton 15,536 55,536 40,000 0% 75 miles
Cash Home Value Total Value Protection *Mileage is distance to your home
timeline
Rollover icons to see details.
Current Year: 50 / 50
Time Elapsed: 600 / 600
Earthquake
Protection Upgrade
Interest Received
Debt Charges
map
% - Protection Level
This time line gives the time path of everything that has happened
20 miles
home upgrades
Chimney
Door Frame
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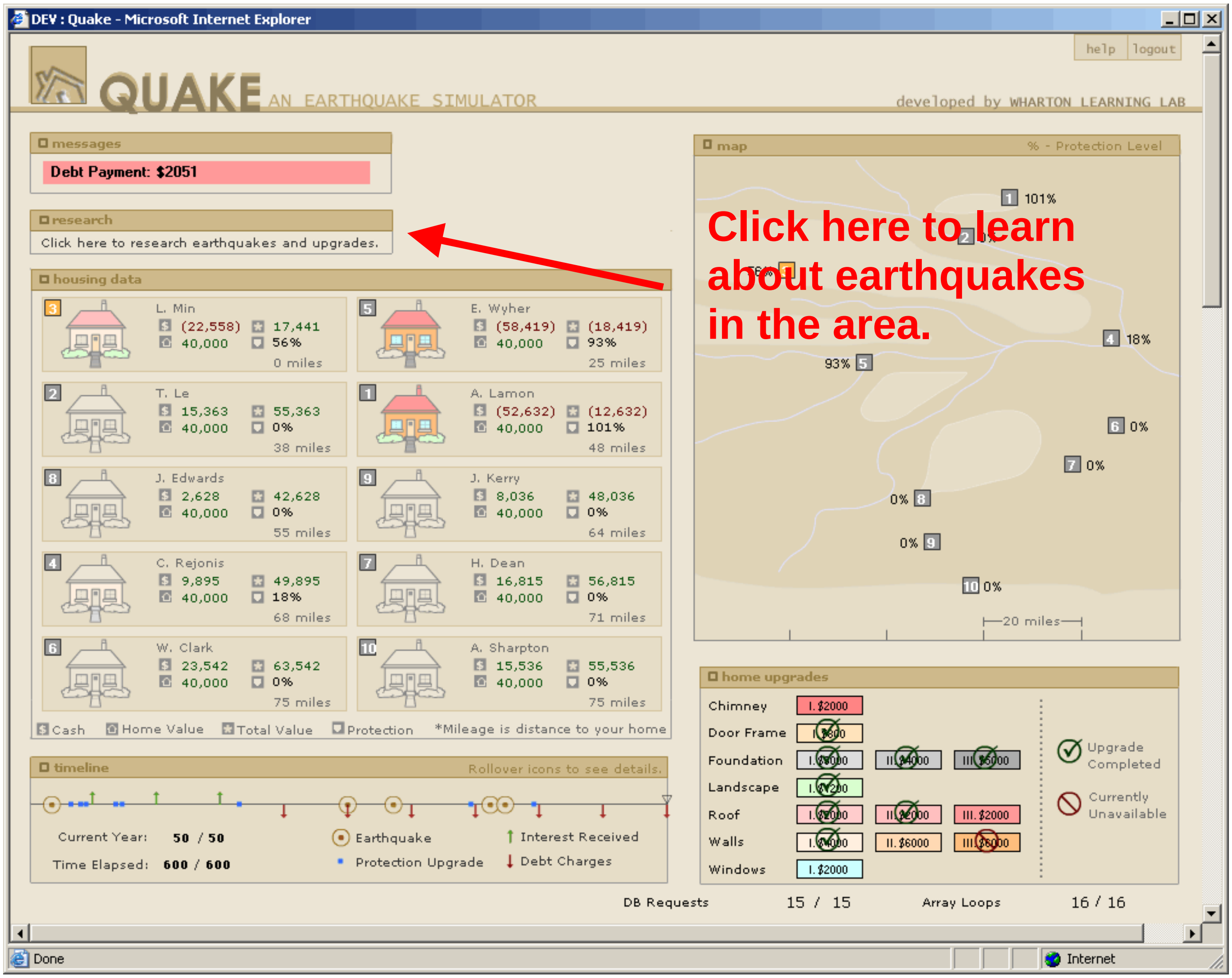
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QUAKE AN EARTHQUAKE SIMULATOR
developed by WHARTON LEARNING LAB
help
logout
messages
Debt Payment: $2051
research
Click here to research earthquakes and upgrades.
Click here to learn about earthquakes in the area.
housing data
map
% - Protection Level
home upgrades
Chimney
Door Frame
Foundation
Landscape
Roof
Walls
Windows
Upgrade Completed
Currently Unavailable
timeline
Rollover icons to see details.
Current Year: 50 / 50
Time Elapsed: 600 / 600
Earthquake
Protection Upgrade
Interest Received
Debt Charges
Cash
Home Value
Total Value
Protection
*Mileage is distance to your home
DB Requests 15 / 15
Array Loops 16 / 16
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