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Perspectives

Risk Analysis and Risk Management in an Uncertain World[1]

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The tragic attacks of September 11 and the bioterrorist threats with respect to anthrax that followed have raised a set of issues regarding how we deal with events where there is considerable ambiguity and uncertainty about the likelihood of their occurrence and their potential consequences. This paper discusses how one can link the tools of risk assessment and our knowledge of risk perception to develop risk management options for dealing with extreme events. In particular, it suggests ways that the members of the Society for Risk Analysis can apply their expertise and talent to the risks associated with terrorism and discusses the changing roles of the public and private sectors in dealing with extreme events.

1. INTRODUCTION

I am honored to receive the Distinguished Achievement Award from the Society for Risk Analysis (SRA). SRA is a unique organization because its membership is drawn from the physical and biological sciences, engineering, and the social sciences. This blend of researchers and practitioners provides an opportunity for creative dialog with respect to a wide variety of problems involving risk analysis and risk management in an uncertain world.

The tragic attacks of September 11 and the ensuing bioterrorist threats associated with anthrax have raised a set of issues regarding how we deal with events where there is considerable ambiguity and uncertainty about the likelihood of their occurrence and their potential consequences. The following questions should be addressed in order to develop meaningful strategies for dealing with these extreme events:

- How can we link the tools of risk assessment and our knowledge of risk perception to develop risk management options that are likely to be successfully implemented?
- What are the changing roles of the public and private sectors in dealing with these risks?
- How can we utilize lessons from dealing with past extreme events in helping to plan for the future?

I believe SRA can help develop strategies for coping with the fallout from these unprecedented events. This paper will address the challenges and opportunities for SRA in playing this leadership role. Rather than referencing the wide range of relevant papers that have appeared in *Risk Analysis* and other journals on the topics discussed here, I have listed a selected set of recent books and papers, many of which provide a comprehensive list of references relevant to the topics discussed in this paper.

2. RISK ASSESSMENT[2]

One of the cornerstones of SRA's success has been the many contributions that the membership has made to the area of risk assessment, ranging from

1 This article is the text from a speech given by Dr. Kunreuther on December 3, 2002, at the annual meeting of the Society for Risk Analysis (SRA) held in Seattle, Washington. The speech was given following Dr. Kunreuther's acceptance of the SRA Distinguished Achievement Award (co-recipient with Dr. Suresh Moolgavkar).

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2 See Haimes (1998) for a comprehensive summary of recent work in risk assessment.

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early studies of fault and event trees for nuclear power to National Academy studies on understanding risk (National Research Council, 1996).

2.1. Nature of the Field

The field of risk assessment encompasses studies that estimate the chances of a specific set of events occurring and/or their potential consequences. For those like myself who are users rather than creators of risk assessments and vulnerability studies, we need to appreciate that most of these published papers represent the tips of icebergs—a 10-page article in *Risk Analysis* characterizing the likelihood of a nuclear power accident often represents the culmination of person-months or years of collecting and analyzing volumes of data.

Scientists and engineers need to provide the users of these data with a picture of what is known regarding the nature of a particular risk and the degree of uncertainty surrounding these estimates, while at the same time being sensitive to their role as assessors of these estimates. Experts in the field need to take special care not to provide these estimates through the filter of their values.

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 he or she 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.

2.2. Use of Exceedance Probability (EP) Curves

One way to capture 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.

To illustrate with a specific example, suppose one was interested in constructing an EP curve for dollar losses to homes in Seattle from an earthquake. Using probabilistic risk assessment, one combines the set of events that could produce a given dollar loss and then determines the resulting probabilities of exceeding losses of different magnitudes. Based on these estimates, one can construct the mean EP depicted in Fig. 1. By its nature, the EP curve inherently 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 the figure.

A key question that needs to be addressed in constructing an EP curve for extreme events is the degree of uncertainty regarding both probability and outcomes. It is a lot easier to construct an EP curve for natural disasters and chemical accidents than it is for terrorist activities. But even for these more predictable accidents or disasters, 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 Fig. 1

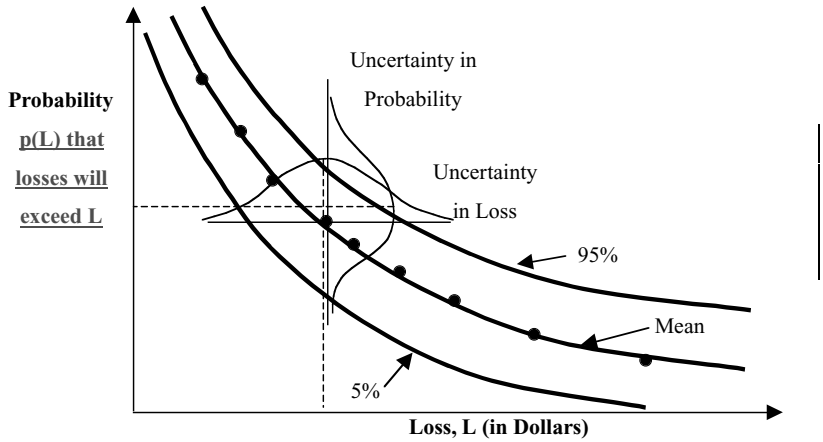

Fig. 1. Example of exceedance probability (EP) curves.

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 state 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 Fig. 1, 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 about others.

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

- What are the chances that Seattle 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 is the probability that an airplane will crash into the Sears Tower in the next year and how serious would the consequences be?
- 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 Seattle. The experts normally require more precise information for defining the event. They are likely to ask: "What is the geographic area that defines Seattle?" "What do you mean by next year (i.e., starting today or January 1, 2003)?" "What is an indirect loss?"[3] 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 of the analysis know what they have received.[4]

3. RISK PERCEPTION AND CHOICE UNDER UNCERTAINTY[5]

Traditional risk assessment focuses on losses that are often measured in monetary units. Risk perception is concerned with the psychological and emotional factors that have been shown to have an enormous impact on behavior. In a set of path-breaking studies begun in the 1970s, Paul Slovic, Baruch Fischhoff, and other psychologists began measuring laypersons' concerns about different types of risks.

These studies showed that those hazards for which the person had little knowledge and most dreaded were perceived as being the most risky. For some technologies, such as nuclear power, and activities such as storing radioactive waste, there was a wide disparity between the views of the general citizenry and those of experts. The general finding that laypersons see the world differently from the scientific community also raised a set of questions as to the nature of the decision-making process for dealing with risks. The sections that follow explore how recent research on risk perception has broadened the nature of the risk assessment process and has increased our understanding of choice under uncertainty.

3.1. Impact of Stigma and Social Amplification of Risk

For a long time, members of the scientific community felt it was appropriate to ignore the public's perception of the risk if it differed significantly from their own estimates. For its part, the public did not believe the experts' figures because they were not communicated very well, the assumptions on which they were based were not well stated, and there was little understanding as to why experts disagreed with each other.

The situation has changed in recent years because there has been increased sympathy for including these psychological and emotional factors as part of the risk assessment process. Recent studies have confirmed this view by showing that the public will assiduously

[3] My 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] See Slovic (2000) for a comprehensive summary of recent work in risk perception.

avoid certain activities if such activities are perceived to be unduly dangerous. More specifically, there is a *stigma* associated with technologies, places, and products when the public perceives them to be hazardous.[6] However, in many of these situations the scientific evidence suggests that there is no reason to be concerned about these risks.[7]

A salient example of stigma is the reaction to products that are deemed to be carcinogenic even though there is limited, if any, scientific evidence to support this position. Take yourself back to 1989 when the public was panicked about eating apples that contained the chemical Alar. The assertion that Alar was carcinogenic was based on animal studies, which were considered suspect by toxicologists because the doses used were unrealistically large. Moreover, there was no evidence from epidemiological studies that showed Alar to be a human carcinogen. Yet these scientific findings were *not* communicated to the public, who therefore became alarmed at the prospect of being exposed to Alar.

The public's strong reaction to Alar illustrates another phenomenon that is well documented in the literature—the social amplification of risk and its relationship to stigma (Kasperson, Jhaveri, & Kasperson, 2001). Stimulated by media reporting, the public's perception of the risk is often amplified in ways that would be difficult to explain if one were focusing on the standard elements of any technical risk assessment—probability times direct losses.

In the case of Alar, the media amplified the risk and effectively stigmatized the product. Millions of consumers stopped buying apples and apple products after CBS ran a news story on "60 Minutes" stating that the chemical Alar could cause cancer. The losses to apple growers from this media blitz were enormous and undoubtedly would have been even greater had they not stopped using Alar on apples soon after the CBS program was aired.

On a personal note, my wife, Gail, who works with children from birth to age three felt it was important to pay twice as much for "uncontaminated" apple juice despite my assurances to her that there was no scientific evidence that Alar was dangerous. Gail's concern was what the parents of these tiny tots would say if they knew that she had given them apple juice that contained Alar.[8]

3.2. Difficulties in Estimating Low Probabilities

The problems associated with risk perception are compounded by the difficulty individuals have in interpreting low probabilities when making decisions (Kunreuther, Novemsky, & Kahneman, 2001). In fact, there is evidence that people may not even want data on the likelihood of an event occurring. A recent study of several hypothetical risky managerial decisions shows that when individuals are required to search out their own information, they rarely ask for any data on probabilities. One group was given a minimal description and the opportunity to ask questions. Only 22% of these respondents asked for probability information. Not one of these respondents asked for precise probabilities. Another group of respondents was given precise probability information, and less than 20% of these respondents mentioned the word "probability" or "likelihood" in their verbal protocols (Huber, Wider, & Huber, 1997).

If people do not think probabilistically, how do they make their choices? There is now a large body of evidence showing that individuals' risk perceptions are affected by judgmental biases.[9] The *availability heuristic* is one of the most relevant ones for dealing with extreme events. Under this heuristic, people estimate the likelihood of an event by the ease with which they can imagine or recall past instances of the event. In cases where the information on an event is salient so that individuals fail to take into account the base rate, many people will tend to overestimate the probability of the event occurring. Following the terrorist activities of September 11 many people refused to fly because they perceived the chances of being on a hijacked plane to be extraordinarily high even though it could be argued that the likelihood of such events occurring in the future was extremely low given increased vigilance and added protection by the federal government.

More generally, in the case of low-probability events there are often two extreme reactions to risks: either "it will happen to me" or "it won't happen to me." These responses are influenced unduly by

6 The ancient Greeks used the word *stigma* to refer to a mark placed on an individual to signify infamy or disgrace, thus suggesting that the person posed a risk to society.

7 See Flynn, Slovic, and Kunreuther (2001) for recent studies on the impact of stigma on risk perception.

8 It is not clear to me how much Gail would have been willing to pay for "uncontaminated" apple juice to avoid the regret that would have occurred if one of the parents asked whether the juice contained Alar.

9 For the classic types of biases individuals utilize in making judgments, see Kahneman, Slovic, and Tversky (1982).

personal experience or media events. Here are a few examples:

- I bought my first set of battery cables only after my car wouldn't start and had to be towed. The towing charge was twice as much as the cost of the battery cables.
- Most homeowners in California purchase earthquake insurance only after experiencing a quake. When asked whether the probability of a future event is *more likely, the same, or less likely than before the disaster*, most people responded by saying "*less likely*."
- Until seat-belt laws were instituted in the United States, most drivers refused to wear them. When asked why, many responded, "I won't have an accident." This response is consistent with the well-documented finding that the great majority of individuals feel they are better at driving than the average driver (Svenson, 1981).

3.3. Role of Affect in Decision Making

These examples illustrate that other factors besides probability and consequences influence choices under risk and uncertainty. There is a growing body of evidence that affect and emotions play an important role in people's decision processes (Slovic *et al.*, 2002; Loewenstein *et al.*, 2001). These factors play a particularly important role when individuals face a decision that involves a difficult tradeoff between attributes or where there is ambiguity concerning what constitutes a "right" answer. In these cases, people often appear to resolve tasks by focusing on those cues that send the strongest affective signals.

In other words, rather than basing one's choices simply on the likelihood and consequences of different events, as normative models of decision making suggest one do, individuals are also influenced in their choices by emotional factors such as fear, worry, and love. To illustrate, consider the following experimental study (Hsee & Kunreuther, 2000), which examines how special feelings for an object influence the price one is willing to pay for insurance:

> You are in Europe and bought a vase there for $200. It is too heavy for you to carry home. You ask a local shipping company to ship the vase to your home in the U.S. There is some chance that the vase will get damaged during shipment. You can buy shipping insurance from an independent insurance company. Buying the insurance will not change the chances that the vase will get damaged. But if you buy the insurance and if the vase gets damaged, you will be compensated by the insurance company for what you paid for the vase, namely, you will receive a $200 check. If you don't buy the insurance and if the vase gets damaged, you will not receive any compensation.

Half the respondents (placed in the high-affection condition) were then asked to imagine:

> You fell in love with the vase at first sight. Even though you bought it for only $200, you feel it is priceless to you, since you have been searching for such a vase for many years.

The other half (placed in the low-affection condition) were asked to imagine:

> You don't have any special feeling for this vase; you find it is OK for its price. You bought it for $200, and think that's about how much it is worth to you.

Both groups of respondents then indicated the maximum amount they would pay for shipping insurance that would compensate them with a $200 check should the vase be broken in transit. The group in the high-affection condition was willing to pay approximately $45 on average for the insurance, whereas the low-affection group was willing to pay less than $25 on average.

Based on a simple benefit-cost analysis one would expect the willingness to pay for insurance to be the same in the two situations since the probability of a loss and the amount of the insurance compensation is identical in both cases. Thus, it appears that there is an additional factor that plays a role in a person's decision about how large a premium he or she is willing to pay for coverage. An insurance claim is viewed by many as a form of consolation should, in the above example, the vase be destroyed. People appear to need more consolation the more affection they have for a product and are thus willing to pay more insurance protection (Hsee & Kunreuther, 2000).

4. RISK MANAGEMENT

In developing risk management strategies for reducing losses and providing protection against extreme events there is a need to incorporate the data from risk assessment studies and the factors that have been shown to influence risk perception. Since a number of studies indicate that people have difficulty processing data regarding low-probability events, this poses challenges for effectively communicating information on the risk to the public.[10]

[10] A comprehensive discussion of how to improve communication of risks to the public can be found in Morgan *et al.* (2002).

One area for future research is determining ways to present information to individuals so that they appreciate the meaning of low and high probabilities. The use of exceedance probability curves, such as those shown in Fig. 1, can indicate the uncertainties surrounding a particular risk. However, as pointed out above, laypersons are not likely to process these data in ways that scientists and engineers would like them to. Risk management approaches must recognize the difficulties that individuals have in collecting and analyzing data from experts. Here are some options that may be helpful in this regard.

4.1. Reframing Probabilities

Most people feel that small numbers can be easily dismissed; large numbers get their attention. By stretching the time frame over which the probability of an extreme event is presented, one may be able to get people to pay attention to an event that they would otherwise ignore. The following two examples illustrate how the same probability, one presented using a long time horizon and the other using a short one, can influence the adoption of protective measures.

- *Seat Belt Usage*. People are more willing to wear seatbelts if they are told they have a 0.33 chance of an accident over a 50-year lifetime of driving rather than a 0.00001 chance each trip (Slovic, Fischhoffj, & Lichtenstein, 1978).
- *Earthquake Protection*. If a company 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 at least one earthquake during the entire period is 1 in 5 rather than learning that it is 1 in 100 in any given year (Weinstein, Kolb, & Goldstein, 1996).

People also are willing to pay considerably more to reduce the risk of some adverse event if the likelihood is depicted in ratios rather than in very tiny probabilities (Stone, Yates, & Parker, 1994). For example, suppose one hears that the risk of an event occurring when one is protected is half of what it is when one is not protected. Framing the probability reduction in this way elicits a far stronger reaction than saying the risk is reduced from 0.000006 without protection to 0.000003 with protection. Studies have shown that even just multiplying the numerator and denominator of a probability estimate by a constant so the numerator is large—presenting it as 10 in 1,000 or 100 in 10,000 instead of 1 in 100—makes it more likely that people will pay attention to the event (Slovic, Monahan, & MacGregor, 2000).

4.2. Using Economic Incentives

One can utilize both positive and negative economic incentives to encourage individuals to take protective measures. Here, again, the way people process information on the costs and benefits of reducing the risk plays an important role in their decision on whether to take protective action. Suppose that one provides premium reductions on insurance policies for those who undertake loss-reduction measures (e.g., strengthening their house against natural disasters; installing dead-bolt locks to ward off criminals). If people think only about the impact of these protective measures on the reduction in risk for the next year or two, then they will *not* view these measures as financially attractive if there is a large up-front cost associated with the protective measure.

There is considerable empirical evidence from field surveys and controlled laboratory experiments that people are often myopic and hence look for a quick return on an investment that in actuality yields benefits over the life of the property (Elster & Loewenstein, 1992; Kunreuther, Onculer, & Slovic, 1998). In such cases, next year's reduced insurance premium is small change relative to the high up-front investment expenditure.

Fines coupled with specific regulations or standards can be used to encourage protective measures but there has to be a sufficiently high probability that the negligent individual or firm will get caught. Otherwise, the person or manager is likely to play a different game than intended—ignoring the regulation. If the probability is sufficiently low and/or the fine is not very large, then it may pay in the long run not to take protective action. The behavior in such cases is not all that different from the decision not to put a quarter in the parking meter because one feels that there is a small chance of getting a ticket and, if one does, the amount one has to pay is not that high.

4.3. Need for Private-Public Partnerships

There is a need to bring together interested parties from the private sector, representatives from public-interest and citizen groups, and leaders from governmental organizations to deal with risk management strategies. This type of private-public partnership is likely to be more successful than if these groups work independently.

To illustrate how such a partnership would work, consider the challenges associated with getting individuals or firms to adopt cost-effective measures to reduce losses from hazardous events. Suppose an industrial firm can spend $15,000 to make its plant more earthquake resistant, which will save it $200,000 in property damage from a severe quake that has an annual probability of 1 in 100. The firm might have trouble justifying the decision in the short run even if it received a premium reduction from its insurer. In this case the expected reduction in annual damage from the investment is $2,000 (i.e., 1/100 * $200,000), so that an insurer could reduce its premium to the firm by approximately this amount. The $15,000 investment wouldn't pay for itself in a two- to five-year payback period, which is often required by a firm's management.

How could one encourage the managers of the firm to make this investment? Insurers and banks can work together to offer incentives in the form of disaster mitigation loans. By offering a 20-year loan with an interest rate of 10% the firm would now face an annual loan payment of $1,700. Combining this payment with an annual $2,000 reduction in its insurance premium, the firm comes out ahead by $300 per year. The bank earns a reasonable interest rate and the insurers have a reduced chance of experiencing large claims from disasters by encouraging their policyholders to adopt loss-reduction measures. Everyone is a winner!

Even with these financial incentives, there may be a need for government regulations and standards. When a building collapses it may break a pipeline and cause a major fire that could damage other property not affected by the earthquake. Losses from these and other *externalities*[11] would not be covered by the firm's insurance policy. A well-enforced building code that requires cost-effective mitigation measures would help reduce these risks and obviate the need for financial assistance to those who would otherwise suffer uninsured losses.

If the private sector feels that it cannot provide insurance protection against losses from catastrophic events, then one may need some type of government pooling arrangement to cover these losses. The Florida Hurricane Catastrophe Fund was established by Florida following Hurricane Andrew when a number of insurers claimed that they could not in the future include windstorm coverage as part of the standard homeowner coverage (Lecomte & Gahagan, 1998). After the 1994 California Northridge earthquake, insurers had a similar reaction to providing earthquake coverage in California. In 1996, the state formed the California Earthquake Authority, which offers homeowners earthquake coverage as a separate policy (Roth, 1998).

At the national level, a successful example of the use of an insurance pool is the one that provides coverage against catastrophic losses from nuclear power plant accidents in the United States. Under the Price-Anderson Act, a group of private insurers agreed to provide coverage to utility companies for losses that can total up to $8.2 billion (U.S. Congress, 1995).

5. APPLICATION TO TERRORISM

How can SRA members apply their talents and expertise to the risks associated with terrorism? The discussion above illustrates that in the development of risk management strategies there is a critical need to combine our knowledge of the nature of the risks with the public's reaction to them.

5.1. Risk Assessment and Vulnerability Analyses

A particularly startling feature of the September 11 attacks was the dramatic disruption of the activities of the world's most powerful nation by a handful of determined individuals. This suggests that risk assessment needs to be supplemented by *vulnerability analyses* that characterize the forms of physical, social, political, economic, cultural, and psychological harms to which individuals and modern societies are susceptible. Many millions of dollars have already been spent on a variety of actions that are designed to reduce our vulnerability.

As one moves from events where there is considerable historical and scientific data (e.g., earthquakes) to those where there is greater uncertainty and ambiguity (e.g., terrorism), there is a much greater degree of discomfort in undertaking risk assessments. Constructing scenarios that may lead to the occurrence of specific events is a useful first step to take in assessing these risks. The challenge is to characterize the relevant risks and indicate what the probabilities and resulting consequences could be.

A meaningful example of work in this regard is a study undertaken more than 25 years ago by Warner North and his colleagues on estimating the likelihood of microbial contamination of Mars from

11 An externality is a situation in which the action of one person, firm, or governmental unit affects the welfare of another. The action in this example is the design of a house that was not earthquake-resistant.

the first Viking Mission; a landing on the planet was planned for July 4, 1976 (North, 1995). North and his colleagues first constructed a series of scenarios characterizing how microbes could contaminate Martian soil based on the possible location of microbes on the spacecraft and on Martian environmental conditions. They then assigned probabilities of contamination to each of these scenarios and undertook extensive sensitivity analyses to determine how changes in the inputs to the scenarios would lead to changes in the probabilities.

On the basis of these analyses they determined that the probability of contamination was more than one order of magnitude below the predetermined acceptable level of risk of 1 in 10,000. Scientists who had initially expressed concern about the risk of contamination agreed that the mission should proceed without taking further steps to reduce the microbial burden on the Viking Lander. The Viking successfully landed on Mars in the summer of 1976.

5.2. Risk Perception

After a disaster, both those who have experienced the event and those who have followed it in the media often focus on the consequences from another disaster and neglect the probability of its occurrence. A salient example is the anthrax scare in the fall of 2001. Even though there were relatively few fatalities from the disease, these deaths triggered considerable fear that something dreadful could "happen to me."

One reason for this reaction is that the risks were poorly understood and hence it was difficult for experts to estimate what the probability was of receiving an envelope in the mail containing anthrax spores. On the other hand, there was a series of newspaper columns and letters to the editor indicating that the likelihood of contracting anthrax and dying were less than the chances of being hit by a car while crossing the street.

The anthrax scare has similarities to the public's concern with Alar discussed above but there is one big difference between the two situations. With anthrax, there was a great deal more uncertainty as to the perpetrators of this form of bioterrorism, how the spores were disseminated, and how one could avoid contact with them. If one was worried about Alar, one just had to refrain from eating apples or drinking apple juice.

5.3. Risk Management

On a much broader level, the terrorist attacks of September 11 and the anthrax scare have raised the question as to what we should do to mitigate the consequences of future catastrophes and aid the recovery process should another disaster occur. To develop a strategy we need to incorporate our growing knowledge of how individuals process information on extreme events and then make choices.

We know from behavior following natural disasters, such as Hurricane Andrew or the Northridge earthquake, as well as technological accidents, such as the Bhopal chemical explosion or the Chernobyl nuclear power plant meltdown, that individuals and companies are *not* very concerned about these events prior to their occurrence. Only after the event, when it is often too late, do they want to take protective action. Over time this concern dissipates. Thus it is very common for people to cancel their flood or earthquake insurance policies if they have not experienced losses from one of these events for several years.

To mitigate against the consequences of natural disasters one can build safer structures or move out of harm's way. In the case of chemical accidents, one can reduce the inventory level and/or production of specific toxins to lower the risk of another mishap occurring. When it comes to developing a strategy to reduce the risks of future terrorist activities, however, we do not know who the perpetrators are, what their motivations are, the nature of their next attack, or where it will be delivered. Hence it is extraordinarily difficult to know what protective actions to take.

There is an additional challenge associated with allocating resources for dealing with terrorism. Due to our deeply rooted fear, we may not adequately take into account the extraordinarily small likelihood that we will be impacted by a future attack. Hence the government invests huge sums of money in protection to provide reassurance. This may not be the most cost-effective way to utilize our resources. In this sense, Mayor Guiliani's constant reassurances to New Yorkers following the September 11 attacks on the World Trade Center may have done more to reduce the social amplification of risk than millions of dollars of expenditures on pseudo-protective measures such as stationing the National Guard at airports and train stations. In the light of the United States' recent responses to terrorism it is natural to ask the following questions:

- How much should we be willing to pay for small reductions in probabilities that are already extremely low?
- How much should we be willing to pay for actions that are primarily reassuring, but do little to change the actual risk?

- How can certain measures, such as strengthening the public health system, which provide much broader protection than terrorism, get the attention they deserve?

More attention needs to be devoted to giving people perspective on the remote likelihood of the terrible consequences they imagine. If we can provide reassurance in this way, we should be able to reduce worry and fear and spend money more wisely than is currently the case.

5.4. Role of Private-Public Partnerships

Finally, let me turn to the question that has been preoccupying the United States since September 11 and is likely to be high on the agenda for the coming months: What are the appropriate roles of the public and private sectors in dealing with terrorism? Prior to the collapse of the World Trade Center towers, there was certainly a concern with terrorism but also a feeling that "it will not happen in my backyard." The private sector was expected to finance protective measures rather than relying on government for any assistance.

Take the airline industry, for example. Before the World Trade Center and Pentagon attacks, if an airline wanted to invest in more secure cockpits or armed guards on flights they would have had to incur these expenses themselves. Each airline decided not to take this action on its own, in part because it may not have felt the risks warranted such action, but also because of competitive pressures. Any airline that invested in these protective measures would have incurred higher costs than the others. Furthermore, there would have been little, if any, appreciation by the flying public as to why these measures were even necessary. Hence, passengers would have been reluctant to pay the higher ticket prices necessary to cover these additional expenses. In short, increased airline protection was a losing proposition for a single company.

The world has changed since September 11. The U.S. government felt it had to bail out the airline industry given that many companies were on the verge of bankruptcy. We now recognize that an airplane can be used to kill many more people than just the passengers and crew, and can create havoc by damaging property and causing large-scale business interruptions. The resulting "fear of flying" by many people has created a demand for safer planes and increased security at airports. In the future, much, if not all, of the cost of these protective measures is likely to be absorbed by the federal government.

On a more general note, the terrorist attacks provide an opportunity to reassess the role of the public and private sectors with respect to providing protection. One needs to recognize that for many situations there may be a need for the public sector to take the leading role with respect to providing protective measures because the private sector may have few economic incentives to take these steps on its own. In a recent paper, Geoffrey Heal and I have addressed this issue by asking the following question: What economic incentives do residents and firms have for undertaking protection if they know that others are not taking these measures and that they could be contaminated by them? (Kunreuther & Heal, 2002a).

To illustrate this point, suppose Airline A is considering whether to institute a system to check its incoming bags on flights to detect the possibility of an explosive that could damage or destroy the plane. It knows that none of the other airlines have instituted such a system. Hence there is some chance that an unchecked bag that is contaminated could be transferred from Airlines B, C, D, or E to one of Airline A's planes. We show that if there is a relatively high probability that such an event could occur, the economic incentive for Airline A to undertake this protective measure under the current liability and insurance systems is somewhat lower than if all the airlines had checked baggage systems.

This result applies to any situation where those who do not take protective measures and are not financially responsible for the damage they cause to others can contaminate a responsible individual or firm. In these cases, one may need government regulations and standards to provide adequate protection against extreme events in ways that provide substantial benefits to the affected individuals and firms.

The same logic applies to the incentive of divisions of firms to invest in protection against a catastrophic accident that could bankrupt the entire organization. The actions of Nick Leeson and the traders he hired at the Barings Futures Singapore office were primarily responsible for bringing down Barings Bank. Arthur Anderson was sent into bankruptcy by the actions of its Houston branch. Both these examples illustrate this type of contamination. If a division knows that other divisions in the firm are not investing in protection, it has less incentive to incur these costs than if the other units were investing in safety measures. There may thus be a need for centralized organizational controls or third-party

inspections from outside the firm to deal with this situation.[12]

5.5. Needed: A Leadership Role for SRA

We have always faced many challenges in dealing with extreme events. The recent terrorist activities have brought these issues to the fore in very graphic ways. There is an opportunity for the membership of the Society for Risk Analysis to reassess the types of risk analyses that need to be undertaken and to play a leadership role in bringing together vulnerability analysis, risk assessment, risk perception, and risk management in ways that will produce substantial benefits to our society.

In my view, it would be useful for SRA to develop a set of recommendations for short-term and long-run strategies for linking science with policy to deal with extreme events such as terrorist activities. This represents both a challenge and an opportunity for our organization and I look forward to working with others on this activity.

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[12] See Kunreuther and Heal (2002b) for more details on this problem.

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