Technology, Risk, and Society

An International Series in Risk Analysis

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Decision Science and Social Risk Management

A Comparative Evaluation of Cost-Benefit Analysis, Decision Analysis, and Other Formal Decision-Aiding Approaches

D. Reidel Publishing Company

A MEMBER OF THE KLUWER ACADEMIC PUBLISHERS GROUP

Dordrecht / Boston / Lancaster / Tokyo

Chapter 1

Social Risk Management

The risk problems facing society today have many characteristics that limit and otherwise complicate the application of formal analysis. Since not all problems possess these complicating qualities to the same degree, some problems may be addressed more effectively by certain decision-aiding approaches than by others. To identify the most useful approach, the analyst must clearly understand the decision problem being addressed. A comparative evaluation of approaches must therefore begin with a characterization of social risk management decisions.

The purpose of this chapter is to describe the nature of social risk management and to identify some of the important dimensions along which risk decisions differ. Discussed first is the nature of the risks that create public concern and pressures for government action. This is followed by a discussion of possible government roles in risk management and an exploration of the factors that make government risk decisions difficult. Next, the institutions and mechanisms that have evolved for social risk management are summarized, and finally, a preliminary taxonomy is provided for distinguishing among risk problems. The taxonomy, which is synthesized from the discussion throughout this chapter, provides one of the elements necessary for the development of a conceptual framework for comparing decision-aiding approaches.

Nature of Risk

What is risk? What causes risk? How much risk are we currently facing? These questions are more difficult to answer than one might expect. To begin with, risk is not an easy word to define.

Meaning of Risk

People speak of business risk, social risk, economic risk, safety risk, investment risk, military risk, political risk, and so on. Depending on context, risk can mean different things. A dictionary lists several definitions, including "the possibility of suffering harm," "the amount an insurance company stands to lose," and "the possibility and degree of loss or injury." Our perspective in defining risk is consistent with the broadest and most general of the definitions presented by risk analysts: risk is defined as an uncertain situation in which a number of possible outcomes might occur, one or more of which is undesirable. With this definition, uncertainty is clearly fundamental to the concept of risk. If you know for certain that you will bear the burden of some specific undesired outcome, we might feel sorry for you, but we would not say that you are experiencing risk.

If the focus is decision making, estimating the magnitude of risk so as to permit a comparison of the risks associated with alternative actions is the major concern. In the case of a risk associated with an event, experiments show that people's perceptions of the magnitude of the risk depend on how likely they think the event is and how serious they consider the effect to be. Following this line of reasoning, risk analysts argue that the level of risk should be measured in terms of the probability (relative likelihood) of the possible outcomes (in a given time period) and measures of the magnitude (seriousness) of the consequences of those outcomes. Fundamentally, then, risk may be represented as a probability distribution over adverse consequences.[1]

Figure 1 illustrates several of the most common ways to display a risk that has been quantified as a probability distribution. Figure 1(a) applies to a case in which there are only two possible outcomes to a risk, for example, death or no death. In this case the probability of the bad

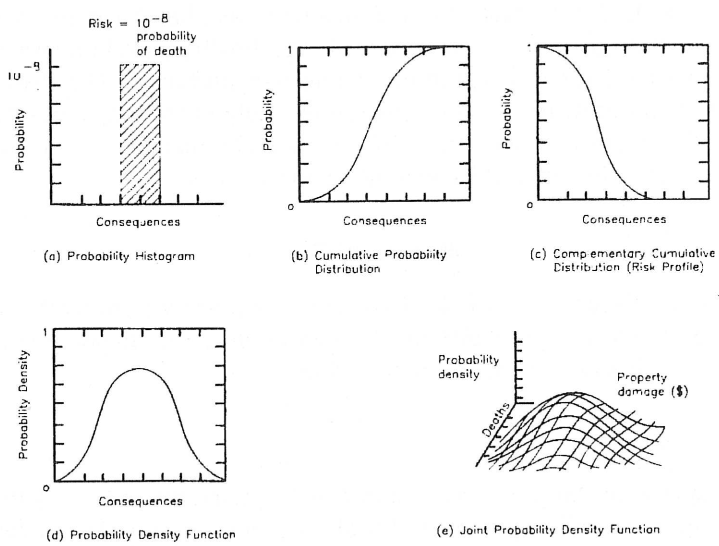

Fig. 1. Common ways to display quantified risks.

outcome, probability of death, is sufficient to describe the probability distribution. Figure 1(b) shows a probability display applicable to the case where the risk involves a range of possible consequence levels. The curve is called a cumulative probability distribution and its height at any consequence level shows the probability that actual consequences will be less than or equal to that level. Figure 1(c) is the reverse of the cumulative probability distribution. Its height at any consequence level indicates the probability that actual consequences will be greater than or equal to that level, and it is called a complementary cumulative probability distribution. It is also sometimes called a risk profile. Figure 1(d) is an intuitive but less easy to use display called a probability density function. The height of the curve at any given consequence level is proportional to the relative likelihood of that level of consequence occurring. The probability of consequence levels between any two values may be obtained as the area under the curve between those values. Figure 1(e) illustrates the sort of display that may be needed to describe risks that produce more than one type of consequence, for example, multiple deaths and property damage. The figure shows a joint probability density function. The curve defines a surface whose height at any point is proportional to the relative likelihood of simultaneously obtaining the combination of consequences associated with that point.

The consequences represented in probability distributions that quantify risks might be adverse effects to human health, plants, animals, materials, or other items of value, and might be measured in terms of fatalities, injuries, days of disability, man-hours of labor lost, incidence of cancer, property lost, or fish killed. Just how probability distributions for these sorts of consequences might be computed or estimated as part of a decision-aiding approach is described in Chapter 2 and the Appendices. The purpose of introducing such technical issues at this point is to clarify the concept of risk that is adopted throughout the discussion.

Notice that conceptualizing risk as a probability distribution allows risks to be altered either by a change in probabilities or by a change in possible consequences. This two-dimensional characteristic makes it impossible to find a completely satisfactory single number for measuring the level of risk. Common single-number summary statistics, such as the probability of loss, the maximum credible consequence level, the expected number of fatalities per year, the probability of fatality per exposed person per year, and so forth, fail to distinguish adequately among the different forms that risk can take. For example, the most commonly used summary measure is expected value of risk — the sum (or integral) of the products of probabilities and consequences. This measure fails to distinguish risks that involve a large probability of minor consequences from those that imply a small probability of a major catastrophe.

Psychologists would argue that even the two-dimensional technical definition of risk fails to capture all of the considerations that are important from a social perspective. Studies have found that in addition to probabilities and magnitude of possible consequences, other considerations influence how people "feel" about risk (e.g., Milburn and Billings 1976; Rowe, 1977b). For instance, attitudes tend to be influenced by the extent to which the potential consequences are concentrated in space and time (e.g., 200 people dying in a commercial airline crash compared with 200 unrelated deaths from automobile accidents), the degree of personal control over those risks (e.g., the risk of injury from skiing compared with that from nuclear war), and whether the individuals exposed to the risk share in the perceived advantages associated with the source of the risk (e.g., smoking risks compared with the health risks of air pollution).[2]

Keeney *et al.* (1979) suggest that, at a minimum, the analyst would have to compute the following measures to characterize mortality risk in a way that is sensitive to social concerns:

(1) Total expected fatalities per year (to measure aggregate societal risk);
(2) Probabilities of fatality for each exposed individual (to permit comparing that risk with others, such as the risk from smoking, or driving a car);
(3) Probabilities of fatality for individuals grouped by occupation, geographic location, etc. (to allow equity comparisons to be made); and
(4) Probabilities of exceeding specific numbers of fatalities per year (to allow for sensitivity to catastrophe).

Even the multitude of numbers that would be produced by such an analysis would fail to account for all the characteristics that influence risk perception. Furthermore, these measures fail to address the risk of injury and property damage. Completely measuring risk is thus a difficult, if not impossible, task. As will be described later, the social acceptability of a decision-aiding approach may be diminished to the extent that it fails to reflect important social as well as technical aspects in its representation of risk.

Character of Existing Risks

How risky is life today? According to one important statistic — the death rate — the American public has never been safer. Mortality rates have declined significantly since 1930, with the largest gains in the youngest age groups (Bailey 1980). The overall accident death rate has decreased 20 percent in the past ten years and 40 percent since 1912. Except for deaths from motor vehicle accidents, which rose prior to 1970 because of increased driving, deaths from other accidents have dropped sharply as a

result of improved medical care, job safety, and a reduction in the work force engaged in dangerous occupations (such a farming). Mining accidents occur far less frequently, many industrial accidents have been reduced, and automobile fatalities show signs of decreasing. Life expectancy in the United States is now more than twenty years greater than it was in 1920 (Dodge and Civiak 1981).

Furthermore, major accidents and disasters are occurring less frequently. In the past one hundred years, eight events have occurred in the U.S. in which one thousand or more persons were killed (excluding wars and epidemics), but none has occurred since 1928 (National Safety Council 1979). Prior to 1928 an accident of this size happened roughly every eight years. Similarly, the frequency of accidents causing a hundred or more fatalities has dropped sharply since the 1940s. Historical frequency versus magnitude data show that frequency falls rapidly with magnitude for all U.S. accidents and natural disasters.[3]

Despite increased longevity and the reduction in the frequency of disasters, public concern about risk is increasing. According to a Harris poll (Harris and Associates 1980) most Americans believe life is getting riskier: 78 percent of the public surveyed agreed that "people are subject to more risk today than they were 20 years ago," and 55 percent indicated that "risks to society stemming from various scientific and technological advances will be somewhat greater 20 years from now than they are today."

Is increasing public concern in the face of a statistical decline in death rates a contradiction? Not necessarily. As noted above, risk is a multidimensional concept having more attributes than simply the age-specific average rate of death. Modern risks are perceived by the public as possessing characteristics that psychological studies show are of special concern — the possibility of catastrophe, inequities because those at risk do not directly benefit from the processes that generate the risk, lack of control by the individuals exposed, and possible long-term, irreversible consequences. Crime, an especially inequitable form of risk, is a source of considerable worry to many Americans, particularly those living within the inner cities. The risk of nuclear war is a major concern because of its catastrophic consequences. Yet, this risk is not at all reflected by increased life expectancy. Environmental risk, which is perceived as being inequitable and having potential long-term consequences, is another category that polling data indicate is of increasing concern to Americans (Harris and Associates 1980). Examples of environmental risks with possible long-term consequences include the risk of ozone depletion due to emissions of fluorocarbons, risk of radioactive leakage from nuclear accidents or from the disposal of nuclear wastes, and the risk that experiments with recombinant DNA will create new diseases for which there are no known cures or vaccinations.

There are a number of other differences between today's risks and those of the past. Risks of the distant past were primarily caused by natural events, while more recent risks, beginning with the industrial revolution, are largely the result of man-made technological developments. Along with the greater degree of enfranchisement of today's electorate has come the belief that individuals have a right to shape their environment. Because technological risks are to an extent self-imposed at the societal level, the debate over which risks are acceptable and which are not has become much more relevant. The recent increase in the federal government's role in technology regulation and its acceptance of responsibility for identifying and controlling health and safety contributes to increased public awareness and concern over risk. Finally, technology not only creates new risks but also produces greater awareness of those risks by introducing improved measurement techniques that enable even low-level risks to be identified.

Components of the Risk-Generation Process

The concept of risk may be clarified by exploring its essential components. For many risks, including those affecting humans, plants, animals, materials, and the environment, three conditions must be met (or thought to exist) before a risk can occur. First, there must be a source of risk; that is, a hazard. The hazard might be a nuclear power plant that may release radioactive material, a dam that might break, the sharp blades of a power lawn mower, the poorly understood chemical in a new drug, or the burning rays of a hot summer sun. Second, there must be an exposure process by which people, animals, plants, or materials of value may be brought into contact with the hazard. The exposure might occur as a result of wind dispersing radioactivity vented from a nuclear power plant, people living below the dam that might break, a homeowner reaching into the spinning blades of a lawn mower, doctors prescribing a new drug to their patients, or a sunbather spending too much time at the beach. Third, there must be a process by which exposure produces adverse effects. This process may consist of increased incidence of cancer resulting from elevated exposure to radioactivity, drowning from the water released in a dam failure, amputated fingers resulting from an accident with a lawn mower, unexpected side effects from a new drug, or sunburn (or skin cancer) from failing to cover up at the beach.

A hazard, an exposure process, and an effects process define a risk in the sense that they determine the level and probability of consequences. People's perceptions of risk involve an additional process that includes an evaluation by individuals or society that the severity, importance, or inequity of the effects is sufficient to be of concern. Figure 2 summarizes these basic components of risk. Together they form the "risk chain." Additional discussion of the first three links of the chain — hazards, exposure, and effects — is provided below. The valuation of risks and other aspects that influence public perception are discussed subsequently.

Hazards

Hazards are present across virtually the entire range of modern human activity. Technological health and safety hazards include substances used in growing, processing, and distributing food; drugs and medical procedures; pollutants discharged into the air or water from homes and commercial or industrial enterprises; occupational dangers, such as accidents from heavy machinery; contagious diseases; potentially harmful materials used in clothing and the construction of homes; products consumed for recreational purposes, such as tobacco and alcoholic beverages; and so on, *ad infinitum*. These and other hazards not only

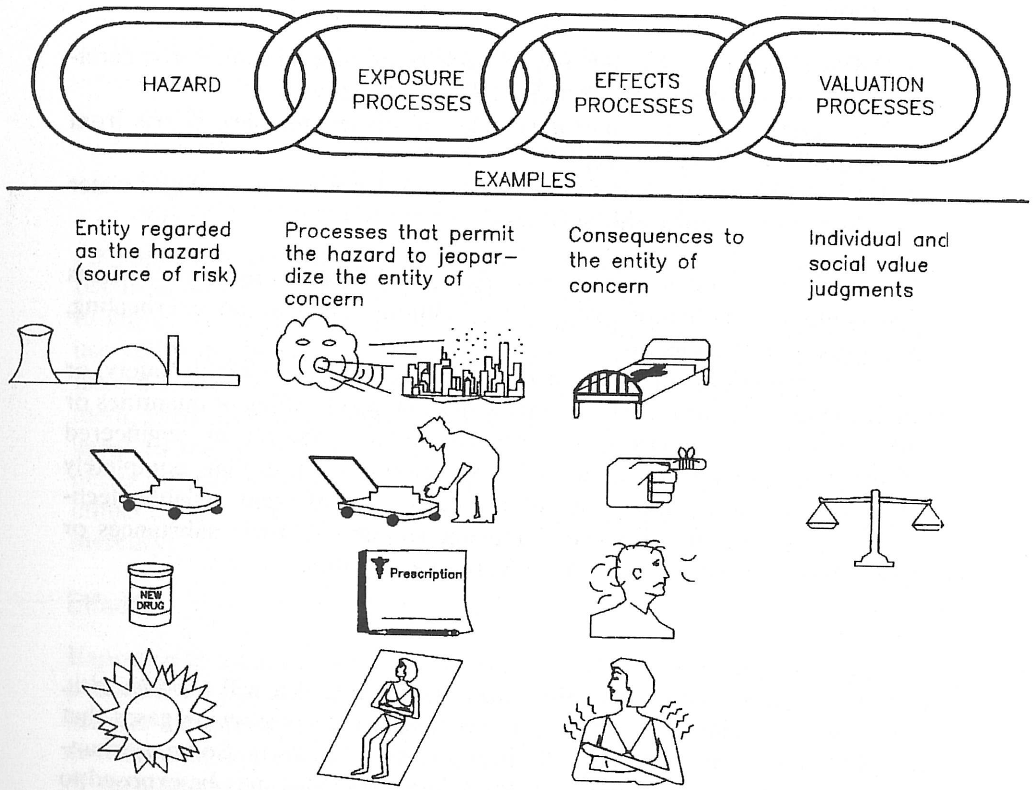

Fig. 2. The risk chain and examples.

create the potential for adverse effects to human health, they may also threaten plant and animal life and create property loss and material damage.

Several risk analysts have attempted to arrange the vast array of hazards into organizing categories. Because systems or processes may be hazardous if one or more of their parts are hazardous, one approach is to consider the most fundamental sources of risk, what some authors have referred to as risk agents. Sagan (1984), notes that fundamental agents for health, safety, and enviornmental risks are

1. Chemical (e.g., atmospheric pollutants, potentially toxic ingredients of food, drugs, and cosmetics)
2. Biological (e.g., viruses, bacteria)
3. Physical (e.g., mechanical force, acoustic energy, ionizing and non-ionizing radiation, heat, pressure)

Rowe and Broder (1979) group fundamental sources of risk into three categories:

1. Toxic materials (e.g., chemicals such as cyanide and mercury, carcinogens, radioisotopes, pesticides, DNA derivatives)
2. Kinetic energy (e.g., motor vehicles, airplanes, missiles, debris from satellites and spacecraft)
3. Stored potential energy (e.g., stored petroleum and natural gas, water in dams and tanks, combustibles)

The most significant sources of risk, Rowe and Broder argue, are systems that contain combinations of these conditions (such as an overheating, fully pressurized nuclear reactor).

For a technology, product, process, or system to be a health, safety, or environmental hazard, it must contain risk agents in sufficient quantities or intensities to be of concern. Furthermore, any natural or engineered systems that contain or limit the dangers must be less than completely effective. Because safety systems are rarely 100 percent reliable, technological systems that involve significant amounts of toxic substances or high levels of energy are generally regarded as hazards.

Exposures

The fact that a hazard exists does not guarantee that it will produce risk. For example, solar prominences — the great arches of glowing gases that erupt from the sun — create little if any risk on the earth. Some mechanism must exist by which people or the things they value may be exposed to the hazard or its risk agents. Seven mechanisms have been identified by which exposures may occur (National Research Council 1982):

1. *Self-hazardous behavior*: Situations in which individuals voluntarily expose themselves to a hazard (e.g., smoking, alcohol abuse, not wearing seatbelts, hang gliding)
2. *Hazardous behavior*: actions by individuals that expose other individuals to hazards (e.g., crime, speeding, drunken driving, child abuse, smoking in public places)
3. *Cogeneration*: Cases where the combined voluntary actions of two or more parties expose one of them to a hazard (so that an incentive exists for the nonrisk-bearing party not to fully disclose information to the risk-bearing party; e.g., risks imposed on workers by employers and risks imposed on consumers through their purchase of products supplied by producers)
4. *Production externalities:* Exposures to hazards produced or released to the environment as unwanted by-products of the production or consumption of goods (e.g., air pollution, water pollution, nuclear accidents, hazardous wastes)
5. *Natural processes:* Exposures to hazards produced by nature (e.g., earthquakes, droughts, floods, diseases, genetic mutations)
6. *Economic processes:* Exposures incurred as a result of economic conditions (e.g., poverty-induced disease and unemployment-induced stress)
7. *Government policies:* Exposures resulting from the actions of government (e.g., nuclear war, contamination of the earth from collecting and returning soil samples from other planets)

As implied by several of the mechanisms identified above, exposures often occur as an unavoidable consequence of the existence of a hazard. If, for example, the hazard is a product or a technology, then its distribution and use will bring people and the things they value into contact with it. If the hazard is a process or a system that releases risk agents into the environment, then several natural pathways will exist that may transport the risk agent to the physical proximity of humans. For example, exposures may occur through air and water transport (as is the case with many industrial effluents) or transport through the food chain (such as occurs with mercury).

Effects

Exposure to a hazard will produce risk provided that the exposure has the potential of producing adverse consequences. These consequences can include early fatalities and injuries, latent cancer fatalities, genetic effects, environment degradation, and economic losses. The magnitude or severity of such effects depends on the conditions of exposure and characteristics of the people and items exposed. In some cases, exposures to significant hazards may result in no adverse effects. Safety equipment, protective clothing, antibiotics, or vaccines may be quite effective in limiting or mitigating the effects of exposures to hazardous substances or situations. In the case of toxic chemicals, the health status of the exposed individuals can have a significant impact on the effects produced. Particularly sensitive groups might include pregnant women, very young and very old people, and persons with impaired health. Some differences in health effects can be attributed to differences in "effective" rather than "administered" dosages. If dose is interpreted as what is adsorbed or absorbed at a target organ, then different individuals might experience different doses from the same exposure, as a result of differences in physiology, personal habits, and so forth. This is of particular importance, for example, in determining the health effects of cumulative toxicants (such as lead) for which several exposure pathways may exist (e.g., breathing air, eating food, and drinking water).

Similarly, the specifics of the effects processes are critical to determining the risks to materials, plants, and animals resulting from exposure. For example, coatings such as paint often dramatically reduce the damage to materials caused by environmental contaminants. The environmental damage caused by acid rain depends on the existing *p*H of lakes and soil. Whether domestic livestock will succumb to a contagious disease may depend on the general health of the animals and whether their feed contains antibiotics to improve their resistance to the disease.

The Role of Government in Risk Management

The responsibilities and limits of government are important considerations for placing risk regulation into perspective. Discussed below are the basic economic and social arguments for government intervention to control risk and roles that government might adopt in risk regulation.

Arguments for Regulation

Economists who argue for regulation tend to focus on externalities — situations in which free markets do not produce a desired level of health and safety because the prices consumers face do not reflect true social values. According to economic theory, an individual whose initial desire for a commodity exceeds its price will continue to purchase the commodity until the benefit derived from the last amount purchased equals the price paid for that amount. An externality exists if either the production or consumption of the product produces costs or benefits to others that are not reflected in the prices consumers face.

Lave (1972) identifies several types of externalities involving risks that create problems for a free market. One consists of accidents that injure people other than the person in control. The decisions made by an individual who is driving an automobile, for example, concern all passengers. If the driver ignores the preferences of his passengers (for reaching their destination quickly and safely), he may "purchase" too little (or too much) safety. Another sort of externality revolves around the financial support given a disabled individual or the dependents of someone who is killed. The cost to society of assuming these financial burdens can be extremely large. A third sort of externality is the personal loss faced by family, friends, employer, and community when someone dies.

Lave points out that the market may also produce an insufficient level of safety as a result of imperfections in the marketing of products. For example, because of economics of scale, the cost of mass inoculation for a disease may be only pennies per inoculation. Although almost everyone would agree to mass inoculation, few people may be willing to bear the much larger costs of private inoculations. Major capital purchases can also present a problem for the free market. Once an automobile or house with insufficient safety is purchased, that item is likely to continue to have insufficient safety throughout its life, because the unrepresented preferences of second-hand purchasers may not be well reflected in the market and because the costs to upgrade the safety of such purchases may greatly exceed the costs of building in more safety in the first place. Finally, many safety decisions involve what economists refer to as "public goods." A public good is something that collectively affects individuals. Unlike an ordinary good, which may be appropriated by an individual for his own personal use, one person's satisfaction from a public good is not diminished by the satisfaction gained by others. For example, a dam for flood protection is a public good because it benefits the entire community; no individual can gain the protection on his own without freely extending it to everyone else. Many risk agents are public goods (perhaps "public bads" would be a better descriptor) because they simultaneously affect more than a single individual. Lack of consensus and other difficulties associated with organizing those who might benefit from establishing or eliminating public goods may prevent such actions from being taken through normal market processes.

Externalities and market imperfections, economists argue, often result in a level of production and consumption of goods that improperly balances risks, costs, and benefits. When externalities exist, therefore, the government may be justified in intervening to force a level of safety that is more socially desirable than the inappropriate one reached through the market. Thus failures of the marketplace provide an argument for the need for government regulation.

A more pragmatic answer to the question "When does government have a right to regulate?" is "Whenever public pressures build to make it." According to Lowrance (1976), "The demand for regulation seems to be a crying out at the futility of dealing with the multiplicity of hazards confronting us these days. People call for regulation almost reflexively, as though it were either a panacea or the last resort." Consumers tend to demand government action in situations where individual action is not possible or is very costly and where existing institutions do not appear to be lowering the risk or protecting them against the loss as inexpensively as they believe it can be done. Empirically, risk regulation tends to be associated with trends showing an increase in the incidence and magnitude of adverse effects on particular interests from technological activities or developments, growing public dissatisfaction with industry responses, and loss of confidence in the corrective efforts of the pre-regulatory mechanisms for risk management (Rowe and Broder 1979). In some cases, the impetus for regulatory solutions has come from the industrial sector, as a result of concern about tort liability or other economic consequences, technical uncertainties, lack of insurance at reasonable rates, or the vagaries of state and local laws. Some of the support for increased regulation undoubtedly reflects a general belief that an increasingly wealthy society should trade off more private goods for improved public health and safety.

Paternalism sometimes seems to be a force behind the call for regulation. Hirshleifer *et al.* (1974) note that "some social critics object to . . . the idea that individuals are capable of making their own decisions effectively." Goodin (1980), for example, argues for paternalism over individual risk decisions because, among other things, individuals are incapable of imagining how badly they would feel if the risk became reality. Historically, American society has had a strong preference for individual freedom over paternalism. Nevertheless, a variety of existing laws relating to "victimless" crimes are designed to prevent individuals from voluntarily endangering themselves, especially the young and others who are viewed as not fully capable of weighing the consequences of their actions. Regulation is used to protect those especially vulnerable; for example, stiff fire codes have been established for nursing homes. The government also tends to intervene when appraisal and control of risks require technical expertise that few people possess (Lowrance 1976).

Even though good reasons may exist for considering government intervention, the question of whether or not government should regulate is, as Morgan (1981) observes, ultimately an ethical issue. The difficulty is that regulation generally results in an involuntary incremental cost being imposed on some citizens. If this cost is small compared with perceived benefits of making people a little safer, then most people would probably be in favor of government action. This is essentially a utilitarian philosophy. Other perspectives, however, disagree with this point of view. For example, the libertarian philosophy, which places greater emphasis on individual rights, takes the position that it is wrong for society to take any action that makes some people worse off regardless of whether total social welfare is in some sense advanced. The important point is that the decision to rely on government regulation, as opposed to free market

mechanisms (such as contract liability and insurance), is an ethical decision about which reasonable individuals might well disagree.

Regardless of philosophical debates, government regulation of risk is likely to be with us a while longer. Governmental authority and responsibility to intervene to reduce risk have been firmly institutionalized in the form of a complex system of regulatory agencies and processes which are accepted by the vast majority of the public as legitimate and proper means for promoting a safer and more equitable society. Despite the slow and laborious process by which government risk decisions are made, the inevitable challenges in the courts, the lack of clear evidence that risks are in fact being reduced, and the campaign promises of popularly elected officials to reduce and eliminate regulatory agencies, the regulatory effort continues to grow. The relevant question, therefore, is how to enable government to regulate risk more effectively and efficiently.

Government Roles and Alternatives for Risk Regulation

One way to explore the available options for risk regulation is to identify opportunities for altering each element of the risk chain. As noted above, for a risk to exist there must be a hazard, together with a process by which people, animals, plants, or materials may be exposed to the hazard, and a process by which exposure produces adverse effects. Furthermore, if people are concerned about risk they must judge the severity, importance, or inequity of those consequences to be significant. Thus, for example, for the risk of health effects from air pollution to be a concern, a source of air pollutants must exist, humans must have contact with the pollutants, the exposure must produce health consequences, and a value judgment must be made that those consequences are undesirable. Generally speaking, it is possible to reduce a risk by modifying any one of these essential components. In the case of air pollution, the emission may be reduced; the emissions may be prevented from reaching inhabited areas, or people may be prevented from entering the areas where pollution is the highest; people exposed can avoid strenuous activity so as to reduce the adverse effects of exposure; or those exposed can be otherwise compensated to offset the displeasure they feel for having to suffer the health effects.

Another way to explore options for reducing risk is to consider the mechanisms that are available for altering human behavior. Because people are intrinsic to the various components of the risk chain, risks may be modified by using any number of ways of motivating different behavior. Behavior may be modified directly by encouraging individuals to select existing safe alternatives, or indirectly by encouraging the generation of new alternatives that may prove to be safer and more attractive. The Clean Air Act Amendments of 1970 have been cited as an example of a government action designed to produce new technological alternatives. Lave

(1980) notes that some Congressmen who voted for passage of the act remarked that they knew that the emission requirements placed on the automobile were beyond the capability of existing technology. The standards were judged to be of practical value because they would force industry to be innovative in developing new technology.

The most direct way for government to change human behavior is through the implementation of mandatory standards and regulations designed to force individuals to take actions that lessen risk. For example, to reduce injury from automobile accidents, government could pass laws requiring the use of seatbelts. Alternatively, government could require the installation of automatic restraint systems (such as airbags) in all new cars. This illustrates that when risks are cogenerated, government can focus risk-reduction actions on either party to the cogeneration process.[4]

Another approach is to motivate human behavioral changes through incentives. For example, when risks are associated with production externalities, government can attempt to cause producers to bear the social costs of externalities so that the prices consumers pay will reflect such costs. For example, although this is not popular in the United States, Germany has regulated some forms of pollution through the sale of pollution licenses and effluent fees. Other approaches to internalizing the social costs of risks into the prices people pay include legal liability and compulsory insurance. Liability influences the incentives of people and firms to engage in risk-generating activities. Insurance converts uncertain but potentially catastrophic financial losses into relatively small and certain financial payments.

A third approach to modifying behavior is to provide information. The government can provide warnings, such as the label required for cigarette packages reminding the smoker that his behavior is hazardous to his health. It can also provide better data on the risk itself (e.g., possible levels of loss or their probabilities) and ways of protecting oneself (e.g., descriptions of available insurance). If people contribute to or engage in risky behavior because they are not fully aware of their options or of the consequences of what they do, then providing information can have a significant impact.

To illustrate the many options available, Table 1 provides examples of the various possibilities for applying different risk management strategies to different elements of the risk chain. Rows in the table correspond to three distinct processes for generating risks — self-hazardous behavior, cogenerated risks, and externalities — and three different strategies for dealing with each — mandatory requirements, incentives, and information dissemination. The four right-hand columns of the table correspond to the various elements of the risk chain — the source, the exposure process, and the valuation process. The entries in these columns illustrate intervention actions based on the different strategies and directed at different elements

Table 1. Alternative risk-management strategies and examples

		Examples targeted at modifying various links in the risk chain			
Generation process	Risk-management strategy	Modify risk source	Modify exposure process	Modify effects process	Modify consequent utility
Self-hazardous behavior Smoking Alcohol abuse Mountain climbing Skin diving Etc.	Mandatory requirements Legal restrictions Product bans Automatic protection strategies	Ban saccharin	Establish minimum age for consumption of alcohol	Require motorcyclists to wear helmets	Require personal health insurance
	Incentives Insurance premium adjustments Taxing hazardous behavior	Provide public transportation on New Year's Eve (to prevent drunken driving)	Offer reduced-cost health insurance to nonsmokers	Reduce registration fees for cars with passive restraint systems	Offer subsidized insurance for inhabitants of flood plains
	Information dissemination Educational campaigns	Publication of safe operating instructions for hazardous products	Post hazard warnings at national parks	Sponsor advertisements designed to increase seatbelt use	Provide counseling services for the terminally ill
Cogenerated risks Risks to employees from employment Risks to consumers from product purchases	Mandatory requirements occupational safety regulations Product safety standards Regulation of advertising Product bans	Prohibit use of certain pesticides in agriculture	Establish maximum daily radiation dose for workers	Require public restaurants to provide diners with water (in order to reduce dangers of choking)	Enforce product safety liability/compensation laws
	Incentives Wage premiums for risky jobs Liability rules Taxing occupational risks	Provide tax incentives for replacing unsafe equipment	Tax hazardous consumer products to reduce consumption	Provide citrus drinks for government employees working in conditions promoting dehydration	Offer supplementary worker insurance programs
	Information dissemination Product labels Warnings	Provide manufacturers with product safety information	Require safety warnings on consumer products (e.g., step ladders)	Require antidote instructions on poisonous products	Provide information on employment opportunities for the handicapped
Externalities Air, water pollution Radiation Toxic chemicals Noise pollution Nuclear war Auto accidents Etc.	Mandatory requirements Standards Regulations	Establish new source performance standards for emissions of air pollutants	Require nuclear power plant operators to develop community evacuation plans	Require auto makers to install collision-resistant bumpers	Provide emergency relief (e.g., housing) for victims of toxic chemical spills
	Incentives Pollution licenses Effluent fees Insurance Compensation	Tax polluters in proportion to quantity of pollutant emitted	Subsidize mass transit to attract drivers off highways	Offer inexpensive air filtration masks to urban commuters	Offer government-subsidized liability insurance to manufacturers of potentially toxic substances
	Information dissemination Government research Warnings	Government-sponsored R&D on air pollution control technology	Post public warnings at hazardous sites	Report pollution index to warn citizens to reduce activity on high-pollution days	Provide advice and information for horticulture in acid rain areas

of the risk chain. An important observation from Table 1 is that a wide variety of options exists for reducing any particular risk.

Complexity of Social Risk Decision Making

Selecting an appropriate alternative for government risk management is extremely difficult because of the complexity of deriving estimates of risk levels and determining the acceptabilities of these levels. Estimating risk levels is complicated by limited technical and scientific knowledge. Establishing or justifying acceptability is complicated by faulty perceptions and personal value systems (individuals often perfer statistically higher risks) and by the need (in a nonauthoritarian society) to justify decisions with which not all members agree by appeal to some principle of social consent. These three sources of complexity — limited knowledge, disfunctions in human perception of risks, and social consent — are discussed below.

Limited Knowledge

Because of limited knowledge, assessing the risks associated with proposed actions is beset with complications. Each link of the risk chain creates difficulties for decision making: hazards are often hard to identify and characterize, exposures are frequently difficult to estimate, and the damage caused by those exposures is generally difficult to assess. In addition, the impact of proposed actions on any of these links is hard to predict. Finally, as addressed in the next section, a host of problems relating to risk perception creates difficulty for valuing risks.

Hazards

One reason hazards are hard to identify stems from the difficulty of obtaining empirical data which conclusively link adverse effects to products, processes, or technologies. Chance observations of increased disease or injury may lead to a search for causal factors, but an absence of historical exposure data often makes the search difficult. Furthermore, latency (time lag) between initial exposure and appearance of harm means that indications of adverse consequences may not be apparent until the potential harm is great and irreversible. For example, statistically significant increases in lung cancer for asbestos workers were not observed until many years after the workers were first exposed.

Since ethical considerations generally prevent deliberate human experimentation to identify potentially dangerous substances, investigators must rely on epidemiological studies involving uncontrolled human exposures and animal studies. Neither epidemiological studies nor animal bioassays are very powerful, however, unless they are tested hypotheses about

specific effects. Thus, the process often requires hypothesizing one of many possible effects and then hunting for it.

Animal studies are inevitably a controversial means for identifying hazardous substances because of the inherent differences in susceptibility among animal species. Exposures to the same substance may produce a significant adverse effect in one species and no apparent effect in another. For example, a chemical may produce cancer in mice because a metabolite (an intermediate product resulting from the application of the animal's metabolic processes) is a carcinogen, not the administered chemical. Because of differences in metabolic processes, the same effect may or may not show up in man. Although some 1,500 substances have reportedly been shown to be carcinogenic in animal tests, fewer than 30 have been definitely linked with cancer in humans (Tomatis *et al.* 1978).

Epidemiological studies are not only time consuming and expensive, they are also a controversial means of hazard identification. A positive result can be due to a statistical fluke or a failure to control for confounding factors. The population selected for an epidemiological study is likely to be exposed to a range of intervening, potentially causal factors, and it is frequently not possible to isolate the effects of any one of them. For example, the imposition of the 55-mile-per-hour speed limit complicates an assessment of the effectiveness of motor vehicle safety standards implemented during the past decade, and the movement of people from place to place obscures the long-term effects of local air pollution on chronic lung disease. Even in those situations where there is strong evidence that a hazard exists, its characteristics (potency, intensity, probability of releasing toxic substances) may be very difficult to determine. This is especially true for the extreme cases that are often of greatest concern; namely, massive harm resulting from catastrophes and continuous low-level exposures leading to chronic diseases. In the first instance, because there are few or no actual occurrences of the feared catastrophic accident, its probability and consequences cannot be obtained from historical data. In the second, it is virtually impossible to measure directly the magnitude of the effect because the levels are generally masked by higher background levels of ongoing, natural incidences of the effects.

Exposures

Gauging exposure is usually difficult because of the complexity of exposure processes and because information is often incomplete. Only rarely is there adequate information about who is exposed and the degree of their exposure. Large chemical manufacturers may try to keep records on workers exposed to potential hazards, but data on the level of exposure to particular chemicals usually are not precise. The situation with respect to the general population is even worse, because of the lack of effective monitoring mechanisms. Mean contamination levels at specific sites can be monitored; but individuals move from location to location, and contamination levels generally vary dramatically over relatively short distances. Even if accurate exposure data are available, those data have direct applicability only for the assessment of past risks or future risks assuming that exposure levels do not change. Since contemplated actions almost always alter exposure patterns, existing exposure data have only limited applicability for comparative analyses.

Exposure estimation is complicated by the many different "pathways" by which a risk agent might achieve proximity to humans or the things they value. Figure 3, for example, illustrates exposure pathways for a hazardous waste disposal site. If the site fails to contain its toxic chemicals, pollutants may contaminate the air, surface water and sediment, soil, groundwater, and the food chain. Any or all of these pathways may produce significant exposure to humans or the things they value.

If exposure is through the air or water, then the level of risk depends on the fate and transport of risk agents. In many cases, however, the mode of transport, the length of time involved, the distance the substance might travel, and the transformations that it undergoes as it moves are all unknowns. For example, acid precipitation is thought to arise when sulfur and nitrogen oxides emitted during industrial processes and fuel combustion combine with water in the atmosphere. Currently, there is little understanding of how these compounds move through the atmosphere or how they react chemically as they do. Such unknowns can be extremely important in predicting impacts. In the case of air pollution, for example,

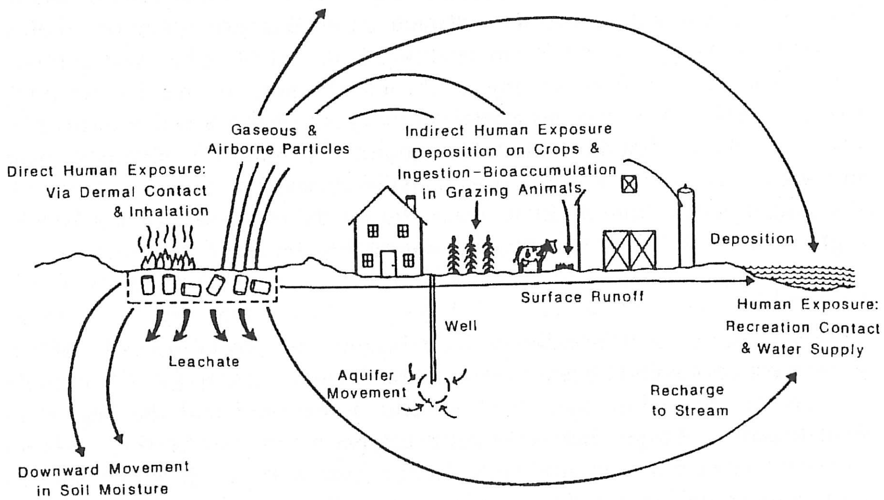

Fig. 3. Environmental pathways from a waste site, from Schweitzer (1982).

order-of-magnitude changes in one-hour average ambient concentrations at a given location are common due to changes in atmospheric conditions.

Even in the simpler cases in which the hazard is associated with consumer products, differences in personal habits make exposure difficult to assess. For example, the amount of a risk agent present in food may be measurable, but differences in food storage practices, food preparation, and dietary habits lead to wide variations in the amount of the agent that individuals ingest. To estimate the risks associated with the use of a pesticide applied to citrus fruit, for example, it would be necessary to know not only how many oranges are consumed by a typical person, but also how many people are fond of eating large numbers of oranges, because the latter group would be at greatest risk. If the risk agent is absorbed when a consumer product is used, patterns of use affect exposure. A solvent whose vapor is potentially toxic, for example, may be used outdoors or in a small, poorly ventilated garage.

Effects

Assessing the effects of exposure to a risk source is complicated because the analytic relationship between dose and response is inescapably tied to the mechanisms by which exposure causes harm, and these mechanisms are rarely understood. Harm to human health may include injury, illness, death, and genetic effects. Dose-response data are ordinarily available only for relatively high exposure levels. Extrapolation of these data to more frequently occurring low levels generally requires theoretical models. The simplest model would be linear, with the magnitude of the effect depending on the total accumulated exposure. In cases where evidence is available, however, dose-response curves usually show substantial nonlinearities. Sometimes exposure have thresholds below which no effects are observed. In the case of living organisms, for example, this may result because the organisms are able to completely metabolize low levels of some materials, converting them into less harmal materials or excreting them. Furthermore, exposures to a given hazardous substance often produce a response that depends critically on synergistic or antagonistic cofactors. For example, human response to a specific air pollutant is strongly affected by the other air pollutants present, activity level (e.g., exercise rate), the distribution of exposure with respect to time (duration, cumulative exposure, and latency periods), and other environmental conditions (e.g., temperature and humidity).

Extrapolating dose-response relationships from animals to humans is highly uncertain. Differences in size and metabolic rates between man and laboratory animals require that doses used experimentally be converted to infer equivalent human doses. Even under equivalent doses, however, the inherent susceptibility across different species can vary dramatically. For example, the response of different species to equivalent doses of a specific carcinogen may vary by a factor of 100,000 (Gori 1980). Moreover, because the human population is in many respects highly variable, the susceptibility of individuals exposed to harmful substances varies tremendously. Human susceptibility to a carcinogen, for example, may vary by a hundred fold or more among individuals, depending on sex, age, hormonal balance, health, general genetic predisposition, and so forth (Leape 1980).

Estimating the response of ecological systems is often even more difficult than estimating individual human health responses. The state of an ecological system is a delicate balance derived from the interaction of many factors; altering one of them can produce a sequence of changes and an ultimate impact that is much greater than might be expected. Because of the complexity of each ecosystem, estimating its response to a given exposure level is extremely difficult. In the case of acid rain, for example, the rate and extent to which lakes might become acidified or forests damaged through continuation of current rates of acid precipitation is a major source of uncertainty in assessing the significance of this problem.

Impact of regulatory actions

In situations where the relationship between exposure and harm is hard to establish, it will be difficult to project the degree to which a regulatory action might lessen the harm. Furthermore, the effectiveness with which a decision is implemented must be considered. Although analyses generally assume that there will be 100 percent compliance with a regulation, the actual extent may be much less than complete, depending on the nature of the hazard, the cost of compliance, the ease of enforcement, the availability of agency resources, and the degree of cooperation of the regulated parties. Compliance is likely to be a problem in situations where the benefits from an action accrue largely to a single party but the costs are mostly borne by the community at large; for example, disconnecting automobile emission controls for the purpose of improving acceleration. Such situations require an enforcement mechanism to prevent private decisions from countervailing the public interest.

Risk Perception

Critical to determining social response to risk is how individuals perceive the risk of potentially hazardous situations. Psychological research shows that individuals typically over- or underestimate the probabilities associated with certain dangers compared with their statistical frequencies Slovic *et al.* (1983), for example, note that individuals typically believe familiar hazards, such as home appliances and cigarettes, are considerably less dangerous that historical data indicate. Furthermore, people's concern over risks depends on much more than just the perceived likelihood of fatalities.

Risk perception, according to behavioral psychologists, is "an idiosyncratic process of interpretation which involves a subjective probability judgment about the occurrence of an unpleasant event and an interpretation by the individual that reflects how he or she defines and feels about the outcome" (Thomas 1981). The basic research method consists of presenting subjects with lists of hazards. The subjects' task is to scale the hazards in order of severity or to evaluate each hazard according to some set of dimensions. The results point to the importance of external events such as past experiences, as well as internal dynamics such as discussions with others, in determining people's perceptions of risk. As Otway (1980) observes, risk perception "depends upon the information people have been exposed to, what information they have chosen to believe, the social experiences to which they have had access, the dynamics of stakeholder groups, the legitimacy of institutions, the vagaries of the political process, and the historical moment in which it is all happening."

The empirical basis assembled to date is insufficient to support convincingly any firm conclusions about either the specific factors influencing risk perception or the nature of the effects. However, recent research suggests certain plausible relationships. Slovic *et al.* (1981) have found that ratings of risk closely relate to feelings of dread and the likelihood of the mishap being fatal. Other characteristics found to influence risk perception were the degree to which risks are voluntary, controllable, known to science, known to those exposed, familiar, catastrophic, and immediately manifested. They found that judged characteristics generally correlate; for example, risks faced voluntarily were typically judged well known and controllable. Rowe and Broder (1979) explain this effect by suggesting that familiarity through experience (as in the case of relatively frequent events such as storms and earthquakes) leads to the perception of a degree of control over one's survival. For more unfamiliar events (such as the re-entry of Sky-Lab or a nuclear meltdown), there is little experience, and the result is a perception of a lack of control. Similarily, where it is perceived that society is controlling disasters to some degree (e.g., early warning systems for hurricanes coupled with storm shelters and evacuation plans), public anxiety is assuaged. The influence of such characteristics on perception has been found to be much stronger for lay people than for experts, with experts' perceptions lying closer to statistical or theoretical expectations (Fischhoff *et al.* 1981a).

Table 2, based on Otway and von Winterfeldt (1982) and Covello (1985), summarizes the factors that psychological studies suggest have some bearing on risk perception. Although most of the studies on which these findings were based involved small, highly specialized and unrepresentative groups, the results serve to demonstrate that describing risk in terms of a simple probability distribution over adverse consequences may miss many of the factors that people intuitively feel to be relevant.

Table 2. Associations observed in studies of public risk perception

Factor	Conditions associated with increased public concern	Conditions associated with decreased public concern
Severity of consequences	Large numbers of fatalities or injuries per event	Small numbers of fatalities or injuries per event
Probability of occurrence	High probability of adverse consequences	Low probability of adverse consequences
Catastrophic potential	Fatalities or injuries grouped in time or space	Fatalities distributed randomly in time and space
Reversibility	Irreversible consequences	Consequences appear reversible
Delayed effects	Somatic effects that are delayed in time (e.g., cancer)	All effects immediately realized
Impact on future generations	Risk posed to future generations	All risks borne by current generation
Impact on children	Children specifically at risk	Risks threaten adults only
Victim identity	Identifiable victim (e.g., yachtsman lost at sea)	Statistical victims
Familiarity	Unfamiliar risks (e.g., ozone depletion due to emissions of fluorocarbons)	Familiar risks (e.g., household accidents)
Understanding	Lack of personal understanding of mechanisms or processes involved	Mechanisms or processes involved personally understood
Scientific uncertainty	Risks appear to be unclear or uncertain to scientists (e.g., when scientists disagree)	Risks relatively known to science (e.g., actuarial data on automobile accidents)
Dread	Risk evokes fear, terror, or anxiety (e.g., toxic waste dumps)	Risk not dreaded
Voluntariness	Involuntary exposures (e.g., air pollution)	Risks taken at one's own choice (e.g., skiing)
Controllability	Little personal control over risk (e.g., travelling as a passenger in an airplane)	Some personal control perceived (e.g., driving an automobile)
Clarity of benefits	Benefit or need for activity generating risk is questioned (e.g., nuclear power)	Clear benefits
Equity	Those at risk from an activity do not directly gain its benefits	Distribution of risks and benefits appears equitable
Institutional trust	Lack of trust in institutions responsible for risk management (e.g., the Nuclear Regulatory Commission with its perceived ties to industry)	Responsible institutions well trusted (e.g., management of recombinant DNA by universities and the National Institutes of Health)
Personal stake	Individual personally at risk	Individual not personally at risk
Attributability	Risk caused by human failure	Risk caused by nature
Media attention	Much media coverage (e.g., airline crashes)	Little media attention (e.g., on-the-job injuries)

Adapted from Otway and von Winterfeldt (1982) and Covello (1985)

Social Consent

According to the American Declaration of Independence, "... Governments are instituted among Men, deriving their just powers from the consent of the governed." Thus, while individual freedom is a central tenet of our society, freedom is acknowledged to be constrained by an obligation to others, and this social obligation is derived from consent. Individual differences prevent unanimous consent, and few would argue that everyone must agree to every social action. Nevertheless, when government acting as the agent of society attempts to reduce risk by placing constraints on freedom, legitimization demands the availability of ideological arguments that demonstrate that society consents to these constraints.

Douglas and Wildavsky (1982) introduce social consent as a factor contributing to the complexity of social decision making by describing a four-way classification scheme for categorizing risk problems. Both the nature of the risk problem and the appropriate solution depend on whether knowledge is certain or uncertain and on whether consent is contested or complete:

1. In the first case, knowledge is certain and consent complete. This is a situation in which objectives are agreed on and all alternatives and their consequences are well understood. Here the problem is technical, and the solution is one of calculation.
2. In the second case, knowledge may be certain, but consent is contested. Here, the problem is one of disagreement about how to value consequences, and the solution is either more discussion or more coercion.
3. In the third case, where consent is hampered only by uncertain knowledge, the problem is essentially one of insufficient information; hence, the solution is seen as further research.
4. In the last situation knowledge is uncertain and consent is contested. This is not only the most difficult, but also the situation that most commonly is associated with risk. It does not, according to Douglas and Wildavsky, have any obvious solution.

MacLean (1982a) describes three models for justifying social decisions in situations where the explicit consent of those affected cannot be obtained. The first involves justification through an appeal to a concept of implicit consent. This model argues that centralized decisions are allowable as long as the tradeoffs between safety and other benefits imposed by the decisions resemble the tradeoffs that individuals would have made on their own if the situation permitted it. Under these conditions it might then be claimed that individuals implicitly consent to the imposed decisions. An important example would be to select a level of safety for a social decision that is identical to the level that people would select on their own were it not for externalities. Thus, a decision-making mechanism that arrives at social decisions from the preferences for risk and safety revealed by the decisions of individuals in the marketplace might be justified, not so much because market solutions are efficient, but because in a properly functioning market people are assumed to consent to their transactions. MacLean does, however, point out two important difficulties with this model. First, rights and liabilities must be assigned so as to distinguish compensation from blackmail. Second, preferences and values differ: preferences are claimed to reflect what an individual wants, whereas values explain what kind of person one aspires to be. Market prices may not necessarily reflect social values.

MacLean's second model, hypothetical consent, is based on a division of decision making into two stages — establishing agreement on the principles and procedures for making decisions — followed by applications to specific cases. If people consent to the process by which social decisions are reached, then it might be claimed that they accept the decisions that result. For example, a hypothetical consent theorist might argue for principles that ideally rational people would consent to and then deduce further principles for designing "fair" decision-making institutions. In this situation, the consent would be hypothetical because a normative argument would be used for justifying the institutions and principles. The hypothetical consent model provides a comfortable basis for sanctioning fromal decision-aiding approaches based on concepts of rationality or fairness. However, the model requires the legitimization of the acceptable decision-making principles and procedures. In MacLean's view, it seems reasonable to insist that hypothesized consent to procedures be unanimous.

MacLean's last model, nonconsent, is based on the proposition that political and social decisions may be justified by arguments that do not appeal to the consent of the parties affected. This model maintains that some decisions might be legitimitized by a direct appeal to the social values that we seek to secure, even though this might entail endorsing and ranking the values through philosophical arguments. Thus, for example, we may need to interfere with liberty to promote our interest in equality, security, or posterity, because at this particular time we view one value as having more weight or urgency. Support of the nonconsent model requires acknowledging that not all individual preferences need to be given equal weight in the social decision-making process. For example, appeal might be made to arguments of nonconsent to justify locating a hazardous-waste facility in a particular community against the wishes of the local citizens.

As will become clearer in Chapter 2, the decision-aiding approaches appeal for their justification with varying degrees to the different models of consent. The controversy associated with MacLean's three models illustrates that the complexity of social decisions associated with lack of

knowledge and disagreements in risk perception is compounded by the difficulty of establishing social consent.

The Existing Risk-Management System

Consideration of the relevant institutional structure and processes for risk management is important for evaluating and selecting a formal decision-aiding approach. This subsection describes government institutional structure for risk management and the coping strategies that have evolved, including the extent to which quantitative approaches may be used.

Participants

The most important institutional structures for managing risk are tort and common law, particularly those laws related to negligence, liability, nuisance, and trespass; insurance and compensatory plans, including self-insurance pools, true self-insurance, workers' compensation, bonding and escrow, and restoration funds (which might be offered either by private companies, through joint private/government arrangements, or directly by government programs); voluntary standards-setting organizations (e.g., the Underwriters' Laboratory, the National Fire Protection Association, the American National Standards Institute, the American Society for Testing and Materials); and mandatory government standards or regulations. Government can also manage risk to an extent through the dissemination of information and publicity, government procurement, and issuing advanced notice of an intent to regulate. In view of this study's focus on government decision making, a more detailed discussion of the principal participants in the government risk-management system is presented in the following sections.

Congress

Congress enacts the statutory laws for promoting national environmental and health goals and creates the agencies that produce the regulations and standards for achieving these goals. Furthermore, through the laws it passes, Congress permits the courts to regulate conduct by judicial imposition of liability and injunction. Congress also sometimes enacts legislation that directly establishes standards of conduct or prohibits certain activities. It can dictate the factors to be included in and excluded from regulatory decision making (e.g., requiring the banning of any food additive causing cancer in animals), and it can pass special legislation to preempt agency discretion (as it did in acting to prevent the removal of saccharin from the market).[5]

The politics of elective office has a strong influence on congressional decision making. The qualities needed to win an election are not necessarily