Perceptions of Risk: Reflections on the Psychometric Paradigm

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HISTORY

My interest in psychometrics began during my undergraduate years at Stanford University, where I was fortunate to be exposed to stimulating courses in psychological measurement and personality assessment taught by Quinn McNemar and Lewis Goldberg. My interest in risk occurred "by chance," when I was assigned to be a research assistant to Clyde Coombs during my first year as a graduate student in psychology at the University of Michigan. I was fascinated by a study Coombs was doing in which he examined people's preferences among gambles. I replicated and extended this study as a first year project. The following year I began to work with Ward Edwards, who was doing experimental studies of risk-taking and decision making. In Edward's laboratory I met Sarah Lichtenstein and Amos Tversky, who were also students of Edwards. Lichtenstein, Edwards, and I teamed up in a study of boredom induced changes in preference among bets (Slovic, Lichtenstein, & Edwards, 1965). Lichtenstein and I went our separate ways but were reunited in Eugene, Oregon in 1966, and have worked together since then.

In about 1975, Lichtenstein, Baruch Fischhoff, and I began a research program designed to study what we referred to as "cognitive processes and societal risk taking" (Slovic, Fischhoff, & Lichtenstein, 1976). This initiative was a natural evolution of the laboratory studies on decision making under risk that Lichtenstein and I had been doing since 1960. In 1970, we were introduced to Gilbert White, who asked if our research could provide insight into some of the puzzling behaviors he had observed in the domain of human response to natural hazards. Much to our embarrassment, we realized that our laboratory studies had been too narrowly focused on choices among simple gambles to tell us much about risk-taking behavior outside the laboratory.

White's questions were intriguing and, with Howard Kunreuther, we turned our attention to natural hazards, attempting to relate behavior on flood plains and earthquake faults to principles that had been emerging from psychological studies of probabilistic judgments and risky choice (Slovic, Kunreuther, & White, 1974). We found the work that Amos Tversky and Danny Kahneman had been doing on heuristics and biases in probabilistic thinking (Tversky & Kahneman, 1974) to be particularly valuable in explaining people's responses to the threats posed by natural hazards. The mid-1970s were a time in which concerns about pesticides and nuclear power were rapidly increasing and we soon found our attention drawn to technological hazards. Discovery of Chauncey Starr's stimulating article on "Social Benefit and Technological Risk" (Starr, 1969) set us on a course that my colleagues and I continue to explore today.

The Psychometric Paradigm and its Origins

Starr's paper sought to develop a method for weighing technological risks against benefits to answer the fundamental question "How safe is safe enough?" His *revealed preference* approach assumed that, by trial and error, society arrives at an essentially optimum balance between the risks and benefits associated with any activity. Under this assumption, one may use historical or current risk and benefit data to reveal patterns of "acceptable" risk/benefit tradeoffs. Examining such data for eight industries and activities, Starr concluded that (a) acceptability of risk from an activity is roughly proportional to the third power of the benefits from that activity; (b) the public will accept risks from voluntary activities (such as skiing) that are roughly 1000 times as great as it would tolerate from involuntary activities (such as food preservatives) that provide the same level of benefits; and (c) the acceptable level of risk is inversely related to the number of persons exposed to the risk.

The merits and deficiencies of Starr's revealed preference approach have been debated at length (see, e.g., Fischhoff, Slovic, & Lichtenstein, 1979; Otway & Cohen, 1975). We were particularly concerned about its assumptions. It is politically conservative in that it enshrines current economic and social arrangements, assuming that *accepted risks* are *acceptable risks*. It ignores distributional questions (who assumes what risks and who gets what benefits). It makes strong assumptions about the rationality of people's decision making in the marketplace and about the freedom of choice that the marketplace provides. It assumes not only that people have full information but also that they can use that information optimally. Finally, from a technical standpoint, it is no simple matter to develop the measures of risks and benefits needed for the implementation of this approach.

Concerns about these assumptions and the difficulties of data collection motivated us to conduct an analogous study using questionnaires to ask people directly about their perceptions[1] of risks and benefits and their *expressed preferences* for various kinds of

[1] The word *perception* is used here and in the literature to refer to various kinds of attitudes and judgments.

risk/benefit tradeoffs. This approach appealed to us for several reasons: it elicits current preferences; it allows consideration of many aspects of risks and benefit besides dollars and body counts; and it permits data to be gathered for large numbers of activities and technologies, allowing the use of statistical methods to disentangle multiple influences on the results. Over the years, many studies of risk perception have been carried out using this approach (Slovic, 1987).

In our replication of Starr's study, and in much of our subsequent work, we went beyond merely asking about risk and benefit. Borrowing from personality theory, we also asked people to characterize the "personality of hazards" by rating them on various qualities or characteristics (e.g., voluntariness, catastrophic potential, controllability, dread) that had been hypothesized to influence risk perception and acceptance (Starr, 1969; Lowrance, 1976).

Another distinguishing feature of our studies has been the use of a variety of psychometric scaling methods to produce *quantitative* measures of perceived risk, perceived benefit, and other aspects of perceptions (e.g., estimated fatalities resulting from an activity). First we used magnitude estimation techniques (Stevens, 1958) to assess risks and benefits and perceived frequencies of fatal events (Fischhoff et al., 1978; Lichtenstein et al., 1978). Later we moved to numerical rating scales. In subsequent studies, we have supplemented these measures with traditional attitude questions and non-traditional word association and scenario generation methods. We have referred to this general approach and the theoretical framework in which it is embedded as the *psychometric paradigm*.

Of course, the psychometric paradigm, with its elicitation of perceptions and expressed preferences has its own assumptions and limitations. It assumes people can provide meaningful answers to difficult, if not impossible questions ("What is the risk of death in the United States from nuclear power?"). The results are dependent upon the set of hazards studied, the questions asked about these hazards, the types of persons questioned, and the data analysis methods. The questions typically assess cognitions--not actual behavior. Despite these and other limitations, the studies using this approach have invariably produced coherent and interesting results that have motivated further use of the paradigm.

One of the most important assumptions in our approach is that risk is inherently subjective. Risk does not exist "out there," independent of our minds and cultures, waiting to be measured. Human beings have invented the concept *risk* to help them understand and cope with the dangers and uncertainties of life. There is no such thing as "real risk" or "objective risk." The nuclear engineer's probabilistic risk estimate for a reactor accident or the toxicologist's quantitative estimate of a chemical's carcinogenic risk are both based on theoretical models, whose structure is subjective and assumption laden, and whose inputs are dependent upon judgment. Non-scientists have their own models, assumptions, and subjective assessment techniques (intuitive risk assessments), which are sometimes very different from the scientist's methods. It was no accident that our studies asking people (and experts) to judge risk left risk undefined. This was done to allow the inherent subjectivity of risk to be expressed.

In sum, the psychometric paradigm encompasses a theoretical framework that assumes risk is subjectively defined by individuals who may be influenced by a wide array of psychological, social, institutional, and cultural factors. The paradigm assumes that, with appropriate design of survey instruments, many of these factors and their interrelationships can be quantified and modeled in order to illuminate the responses of individuals and their societies to the hazards that confront them.

EARLY RESULTS

The early results from psychometric studies of perceived risk have been reviewed by Slovic (1987) and will be referred to only briefly in this section.

One of the most exciting findings, to those of us who drafted the first questionnaires (and who realized their difficulty), was that people could, and would, answer them, making hundreds of judgments per person in sessions lasting up to several hours. Equally surprising to us was that the results seemed to make sense and provide insight into many of the puzzling phenomenon evident in societal risk management and its controversies. Perceived and acceptable risk appeared systematic and predictable. Psychometric techniques seemed well-suited for identifying similarities and differences among groups with regard to risk perceptions and attitudes. Our results also showed that the concept "risk" meant different things to different people. When experts judged risk, their responses correlated highly with technical estimates of annual fatalities. Lay people could assess annual fatalities if they were asked to (and they produced estimates somewhat like the technical estimates). However, their judgments of "risk" were sensitive to other factors as well (e.g., catastrophic potential, controllability, threat to future generations) and, as a result, differed considerably from their own (and experts') estimates of annual fatalities.

Another consistent result from psychometric studies of expressed preferences was that people tended to view current risk levels as unacceptably high for most activities. The gap between perceived and desired risk levels suggested that, contrary to the assumptions of the revealed preference approach, our respondents were not satisfied with the way that market and other regulatory mechanisms had balanced risks and benefits. Across the domain of hazards, there seemed to be little systematic relationship between perceptions of current risks and benefits. However, studies of expressed preferences did seem to support Starr's conclusion that people are willing to tolerate higher risks from activities seen as highly beneficial. But, whereas Starr concluded that voluntariness of exposure was the key mediator of risk acceptance, studies of expressed preference have shown that other characteristics, such as familiarity, control, catastrophic potential, equity, and level of knowledge, also seem to influence the relationship between perceived risk, perceived benefit, and risk acceptance.

Various models have been advanced to represent the relationships between perceptions, behavior, and these qualitative characteristics of hazards. As we shall see, the picture that emerges from this work is both orderly and complex.

Factor-Analytic Representations

The "personality profiles" that emerged from psychometric studies showed that every hazard had a unique pattern of qualities that appeared to be related to its perceived risk.

Figure 1 shows the mean profiles that emerged for nuclear power and medical x-rays in one of our early studies (Fischhoff et al., 1978). Nuclear power was judged to have much higher risk than x-rays and to need much greater reduction in risk before it would become "safe enough." As the figure illustrates, nuclear power also had a much more negative profile across the various risk characteristics.

Insert Figure 1 about here

We observed that many of the qualitative risk characteristics that made up a hazard's profile were highly correlated with each other, across a wide range of hazards. For example, hazards rated as "voluntary" tended also to be rated as "controllable" and "well-known"; hazards that appeared to threaten future generations tended also to be seen as having catastrophic potential, and so on. Investigation of these interrelationships by means of factor analysis indicated that the broader domain of characteristics could be condensed to a small set of higher-order characteristics or factors. Figure 2 presents a spatial representation of hazards within a factor space derived from more than 40,000 individual ratings (34 respondents x 81 hazards x 15 characteristics per hazard).

Insert Figure 2 about here

The factor space presented in Figure 2 has been replicated across numerous groups of laypeople and experts judging large and diverse sets of hazards.[2] The factors in this space reflect the degree to which a risk is understood and the degree to which it evokes a feeling of dread.

Research has shown that laypeople's risk perceptions and attitudes are closely related to the position of a hazard within the factor space. Most important is the factor "Dread Risk." The higher a hazard's score on this factor (i.e., the further to the right it appears in the space), the higher its perceived risk, the more people want to see its current risks reduced, and the more they want to see strict regulation employed to achieve the desired reduction in risk. In contrast, experts' perceptions of risk are not closely related to any of the various risk characteristics or factors derived from these characteristics. Instead, experts appear to see riskiness as synonymous with expected annual mortality (Slovic, Fischhoff, & Lichtenstein, 1979). As a result, many conflicts about "risk" may result from experts and laypeople having different definitions of the concept. In such cases, expert recitations of "risk statistics" will do little to change people's attitudes and perceptions.

Perceptions have Impacts

Another direction taken by early work within the psychometric paradigm was to examine the role of perceptions in determining the degree of impact resulting from the

[2] As we shall see, later, smaller, and more homogeneous hazard sets can produce different spaces

occurrence of an "unfortunate event" (e.g., an accident, a discovery of pollution, sabotage, product tampering, etc.).

Risk analyses typically model the impacts of such events in terms of direct harm to victims--deaths, injuries, and damages. The impacts of an unfortunate event, however, sometimes extend far beyond these direct harmful effects, and may include indirect costs to the responsible government agency or private company that far exceed direct costs. In some cases, all companies in an industry are affected, regardless of which company was responsible for the mishap. In extreme cases, the indirect costs of a mishap may even extend past industry boundaries, affecting companies, industries, and agencies whose business is minimally related to the initial event. Thus, an unfortunate event can be thought of as a stone dropped in a pond. The ripples spread outward, encompassing first the directly affected victims, then the responsible company or agency, and, in the extreme, reaching other companies, agencies, and industries.

Some events make only small ripples; others make big ones. Early theories equated the magnitude of impact to the number of people killed or injured, or to the amount of property damaged. However, the accident at the Three Mile Island (TMI) nuclear reactor in 1979 provided a dramatic demonstration that factors besides injury, death, and property damage can impose serious costs. Despite the fact that not a single person died at TMI, and few if any latent cancer fatalities are expected, no other accident in our history has produced such costly societal impacts. In addition to its impact on the utility that owned and operated the plant, this accident also imposed enormous costs on the nuclear industry and on society.

These came from stricter regulation, reduced operation of reactors worldwide, greater public opposition to nuclear power, reliance on more expensive energy sources, and increased costs of reactor construction and operation. The point is that traditional economic and risk analyses tend to neglect these higher-order impacts, hence they greatly underestimate the costs associated with certain kinds of mishaps.

A conceptual framework aimed at describing how psychological, social, cultural, and political factors interact to "amplify risk" and produce ripple effects has been presented by Kasperson, Renn, Slovic et al. (1988). An important element of this framework is the assumption that the perceived seriousness of an accident or other unfortunate event, the media coverage it gets, and the long-range costs and other higher-order impacts on the responsible company, industry, or agency are determined, in part, by what that event signals or portends. *Signal value* reflects the perception that the event provides new information about the likelihood of similar or more destructive future mishaps (Slovic, Lichtenstein, & Fischhoff, 1984).

The informativeness or *signal potential* of an event, and thus its potential social impact, appears to be systematically related to the characteristics of the hazard and the location of the event within the factor space (see Figure 3). An accident that takes many lives may produce relatively little social disturbance (beyond that caused the victims' families and friends) if it occurs as part of a familiar and well-understood system (e.g., a train wreck). However, a small accident in an unfamiliar system (or one perceived as poorly understood), such as a nuclear reactor or a recombinant DNA laboratory, may have immense social consequences if it is perceived as a harbinger of further (and possibly catastrophic) mishaps.

Insert Figure 3 about here

One implication of the signal concept is that effort and expense beyond that indicated by a cost/benefit analysis might be warranted to reduce the possibility of "high-signal accidents." Unfortunate events involving hazards in the upper-right quadrant of Figure 2 appear particularly likely to have the potential to produce particularly large ripples. As a result, risk analyses and risk-management decisions regarding these hazards need to be sensitive to these possible higher-order impacts.

RECENT DEVELOPMENTS

The pace of psychometric research has accelerated in recent years. The early work has been replicated and extended with new and more interesting kinds of respondents and with very different sets of hazards and characteristics. Important concepts from other domains, such as stigma, have been brought to bear upon risk perception and risk-impact analysis.

New Respondents

Our early studies were limited, by financial constraints, to local populations of students and citizen groups (League of Women Voters; business clubs). In recent years, the paradigm has been applied internationally, sometimes with local groups and sometimes with representative national samples. International studies have contrasted perceptions of college students in the United States, Hungary (Englander et al., 1986), Norway (Teigen, Brun, & Slovic, 1988), Hong Kong (Keown, 1989), Japan (Rosa & Kleinhesselink, 1989), Poland (Goszczynska, Tyszka, & Slovic, in press) and the Soviet Union (Mechitov & Rebrik, 1990). Some of the largest discrepancies have been found between American and Hungarian students. The Hungarians perceived much lower risks from 84 of 90 activities. Within each country, the relative ordering of concerns was also much different. Hungarians saw relatively greater risks from hazards in the lower left quadrant of the factor space--railroads, boating, home appliances, and mushroom hunting, whereas the Americans were relatively more concerned with hazards in the upper-right quadrant pertaining to radiation and chemical technologies. Turning to non-student populations, Gould et al. (1988) studied representative samples of 1320 individuals living in New England and the Southwest United States in a replication of our earlier studies. Morgan et al. (1985) surveyed 116 alumni of Carnegie-Mellon University regarding perception of risks from electric and magnetic fields. Kunreuther, Desvousges, and Slovic conducted a national telephone survey in the United States, focusing on perceptions of nuclear power and nuclear waste. We have also conducted two large psychometric surveys of the general public in Sweden (Slovic, Kraus, Lappe, Letzel, & Malmfors, 1989) and Canada (Slovic, Kraus, Lappe, & Major, 1989). Kraus and Slovic (1988) surveyed a large sample of consumers in six different regions of the United States, regarding their perceived risks from household products.

These large-scale studies have produced numerous interesting results, of which I shall mention only a few. One intriguing finding by Morgan et al. (1985) was that perceived risks associated with electric and magnetic fields from power lines and electric blankets were relatively low. However, when the respondents were given a supposedly non-alarming briefing about research on health effects of fields (which said that many studies had been done but no adverse human health effects had yet been reliably demonstrated), their perceptions on subsequent retest shifted towards greater perceived risk. They also saw risks of electric fields from transmission lines and electric blankets as less well known, more dread, more likely to be fatal, less equitable, and less adequately controlled after receiving this information. Today, as research studying health effects of exposure to electric fields remains inconclusive but is discussed frequently in the news, perceptions of risk from these fields is rapidly increasing (Coy, 1989).

A second finding of interest comes from the national surveys we have conducted in Sweden and Canada. Figure 4 shows mean risk/benefit perceptions in Canada for 33 items, more than half of which pertain to medicines and other medical devices and treatments. Careful examination of the figure illustrates some findings that have appeared in a number of surveys. Nuclear power, an industrial radiation technology, has very high perceived risk and low perceived benefit whereas diagnostic x-rays, a medical radiation technology, has the opposite pattern (relatively low perceived risk, very high perceived benefit). A parallel finding occurs with chemicals. Non-medical sources of exposure to chemicals (e.g., pesticides, food additives, alcohol, cigarettes) are seen as very low benefit and high risk;

medical chemicals (e.g., prescription drugs, antibiotics, vaccines, vitamins) are generally seen as high benefit and low risk, despite the fact that they can be very toxic substances and human exposure to them is quite great. The favorable perceptions and acceptance of risks from x-rays and most medicines suggests that acceptance of risk is conditioned by perceptions of direct benefits and by trust in the managers of technology, in this case the medical and pharmaceutical professions. It is also clear that there is no general or universal pattern of perceptions for radiation and chemicals. Further demonstration of this point comes from studies of radon which, like x-rays, is a hazard of little concern to most people (Sandman, Weinstein, & Klotz, 1987). In contrast, food irradiation, like nuclear power, generates enough concern to block the application of that technology. In the domain of radiation and chemical technologies there appears to be little relationship between the magnitude of risk assessed by experts (health physicists, epidemiologists, and toxicologists) and the magnitude of perceived risks. This state of affairs, and the opposition to many technologies that accompanies it, is a source of great frustration and concern to many (see, e.g., Whelan, 1985; Wildavsky, 1979). We shall return to this issue later.

Insert Figure 4 about here

Psychometric surveys provide a wealth of quantitative data that permit one to monitor perceptions over time. In 1987 we replicated a study that we had first conducted in 1979, using the same population (University of Oregon students). Across the eight-year period there was remarkable stability for some items (e.g., non-nuclear electric power, bicycles, tractors, cosmetics, food preservatives). Some items showed sizable increases in perceived benefits (e.g., commercial aviation, satellites, microwave ovens, radiation therapy, heart surgery, lasers) and some showed large decreases in perceived risk (e.g., microwave ovens, lasers, oral contraceptives). By far the greatest change in perception occurred with marijuana, whose perceived benefit decreased from a mean of 53.3 (on a 100-point scale) to 21.2 and whose perceived risk increased from 25.4 to 41.0.

The large national surveys have uncovered numerous strong subgroup differences in perceptions. In Canada, perceptions of risk and benefit were strongly related to region of residence (Quebec, a French culture, stood out), age, sex, education, and degree of political activism. The sex differences were quite interesting. Close to two dozen studies have found that women have higher perceived risk for nuclear power than men (see results from Sweden in Figure 5). In Canada, women's perceptions of risk were equal to or greater than men's for every one of the 33 items studied (see Figure 6), and nuclear power was not exceptional in this regard.

Insert Figures 5 and 6 about here

New Hazard Domains

The earliest psychometric studies were distinguished by their comparisons of large hazard sets containing items as diverse as bicycles and nuclear power plants. Factor analysis of relationships among these items produced what might be called a "global space" as shown in Figure 2. A question, of both theoretical and practical significance, is whether the global structure would also pertain to a "local" set of hazards, all falling within the same general category. For example, one point in Figure 2 represents the technology "railroads." But all railroad hazards may not be the same. Would a taxonomy consisting solely of railroad hazards have the same factor structure as Figure 2?[3]

To answer this question, Kraus and Slovic (1988) put the railroad point "under a microscope" to examine its structure. We constructed 49 railroad accident scenarios based on combinations of the following components:

- Type of train: traditional, high speed, rapid transit
- Type of cargo: passengers, benign cargo (e.g., grain), chemicals
- Type of accident: two-train collision, train-car collision, derailment
- Location of accident: tunnel, open ground, bridge, grade crossing, mountain pass
- Cause of accident: human error, sabotage, earthquake, mechanical failure.

Each railroad scenario was rated by 50 subjects on perceived riskiness as well as on 10 additional characteristics prominent in previous taxonomies of perceived risk. Several

[3] The answer is not intuitively obvious. Local and global representations have the same dimensions for some objects (e.g., rectangles are always defined by height and width no matter how similar or dissimilar they are), whereas the dimensions needed to represent diverse emotions such as love, pride, worry, or anger differ from the local dimensions needed to characterize the various aspects of a single emotion such as love--puppy love, maternal love, and so on (Gerrig, Maloney, & Tversky, 1985).

other hazards, such as nuclear reactors, fire fighting, bicycles, and DNA research were also rated to help calibrate the railroad data.

Psychometric analysis of these data showed considerable similarity between the railroad space and previous representations based on diverse hazards. The railroad space was well represented by two factors in which knowledge and catastrophic potential played defining roles. The results also demonstrated that not all rail hazards are well represented by the point labeled "railroads" in Figure 2. A train carrying explosive chemicals near a city was perceived to be more like a nuclear reactor than like other rail hazards. A train carrying non-toxic freight evoked little concern. The heterogeneity of railroad hazards has important practical implications linked with our discussion earlier of signal value and impact. It may be important for policy makers and system designers to know that there are substantial differences between the degree of concern people show for an ordinary freight train derailment and the enhanced concern (and social disruption) likely to be associated with the derailment of a train carrying toxic chemicals. Thus representing railroads as a single, homogeneous category, may be quite misleading as a predictor of societal response to specific railroad hazards and accidents.

This latter point was made again in a follow-up study by Slovic, MacGregor, and Kraus (1987), which examined perceptions of risk and signal value for 40 structural defects in automobiles of the kind that compel manufacturers to initiate a recall campaign. The defects were diverse, ranging from faulty defrosters to gasoline fumes that enter the passenger compartment and problems that reduce the effectiveness of steering or braking systems. Each defect was rated on a set of risk-characteristic scales that included overall vehicle riskiness, manufacturer's ability to anticipate the defect, severity of possible consequences, observability, and likelihood that the rater would comply with the recall notice (bring the car in for repair) if the defect occurred in the rater's automobile. A factor analysis indicated that these judgments could be summarized in terms of two composite factors, one representing the possibility of severe, uncontrollable damage and the other representing the foreseeability of the defect by the manufacturer. Within this two-dimensional representation, the defects were perceived quite differently, as shown in Figure 7. Perceived risk, rated personal compliance with a recall notice, and actual compliance rates for the defects were all highly predictable from location within the factor space (R = .89, .81, and .55, respectively). One defect stood out much as nuclear hazards do in Figure 2. It was a fuel-tank rupture upon impact (labeled FUELRPTR), creating the possibility of fire and burn injuries. This, of course, is similar to the notorious design problem that plagued the Ford Pinto and that Ford allegedly declined to correct because a cost-benefit analysis indicated that the correction costs greatly exceeded the expected benefits from increased safety (*Grimshaw v. Ford Motor Company*, 1978). Had Ford done a psychometric study, the analysis might have highlighted this particular defect as one whose seriousness and higher-order costs (lawsuits, damaged company reputation) were likely to be greatly underestimated by their cost-benefit analysis.

Insert Figure 7 about here

MacGregor and Slovic (1989) subsequently applied a similar analysis to 30 automobile subsystems, including braking, steering, suspension, engine, signaling, electrical, and fuel systems. Comparisons between perceptions of risk and data on accident causes showed that drivers appropriately recognized the importance of brakes but underestimated the risks posed by faulty communication and signaling systems such as headlights, brake lights, marker lights, turn signals, and horn.

Several additional studies have focused on specific classes of hazards. Representative samples of the general public in Sweden and Canada rated a hazard set that primarily consisted of medicines. The two-factor representation resulting from the study in Sweden is shown in Figure 8. Factor I, which was labeled "Risk," consisted of three scales: perceived risk, the likelihood of harm, and the seriousness of harm given a mishap. Factor II, which was called "Warning," consisted of scales measuring newness, knowledge of risk, and degree of warning signal, given a mishap. As one goes from left to right in the space, perceived risk increases. As one goes from the bottom to the top, the items are judged to have risks that are judged to be newer and less precisely known and a mishap is judged as providing a stronger warning about the possibility that the risk is greater than was previously believed. Two features of this space stand out. First, all medicines are not alike, perceptually. Vaccines, antibiotics, and antiarthritic drugs, each of which can have significant risks, are perceived as rather benign (close to aspirin and laxatives). Anti-depressant drugs and sleeping pills stand out as the pharmaceutical drugs of greatest concern, a fact that we have traced to concerns about addiction, abuse, and overdosing. Second, all of the medicines cluster near the midpoint of the warning dimension, suggesting a moderate but not extremely high potential for ripple effects in the event of adverse reactions or other problems. Of course, under certain conditions, it is clear that medicine failures can have immense repercussions, as happened with Thalidomide.

Insert Figure 8 about here

Another special domain that we have studied only with college student subjects (Slovic et al., 1987) consisted of 37 LULUS (locally unwanted land uses) and other noxious environmental features such as smog, crime, air pollution, prisons, earthquake proneness, chemical and nuclear waste storage facilities, and so on (see Table 1). A large sample of students rated each of these items on each of seven risk-characteristic scales, resulting in the factor space shown in Figure 9. It is significant that a nuclear-waste repository (said to be located 100 miles away) was perceived more negatively across the scales than a nuclear power plant, a high crime rate, an industrial waste disposal problem, and most other noxious features. Perceived personal risk was highly correlated with Factor 1 ($r = .72$) and was not significantly related to Factor 2.

Insert Table 1 and Figure 9 about here

A study by Benthin, Slovic, and Severson (1988) examined perceptions of risk and benefit from 30 activities that put young people at risk, including problem behaviors such as excessive drinking, smoking cigarettes, taking drugs, having unprotected sex, and socially approved risk taking such as playing contact sports, skiing, and riding motorcycles. Each of the 30 activities was rated (by high school students--mean age 15.5 years) on 14 characteristics, some taken from our previous risk-perception studies (knowledge of risk, old/new, perceived risk and benefit, control) and some taken from the literature on adolescent behavior (perceived peer influence, admiration).[4] In addition, the respondents (who were anonymous) were asked to indicate whether they had participated in these activities during the past six months. The results indicated that participation in risk activities was related to very distinct cognitive and social perceptions. From a cognitive perspective, young people who engaged in a risky activity reported greater knowledge of its risks, less fear of the risks, less personal risk, more personal control over risk, less ability to avoid the activity, and higher participation in the activity by others. From a social viewpoint, participants in risky activities reported greater peer influence, less desire for regulation of the activity by authorities, and greater benefits relative to risks. Of particular interest was the indication in these data that some highly dangerous activities are also greatly admired. A factor space was derived from these data. However, as we shall see in the next section, this data set

[4] The psychometric paradigm is not restricted to the study of psychological variables as the inclusion of these social variables illustrates.

contains important differences among individuals that can be best analyzed and described by techniques somewhat different than factor analysis.

New Methods of Analysis

The fact that we seem to learn something new about risk perceptions whenever we conduct one of these studies does not indicate, however, that our methodology has been optimal. In a knowledge vacuum, any reasonable empirical study is likely to provide useful insights. Over the years, a number of methodologically sophisticated researchers have criticized this work for (a) providing the characteristics of perceived risk to respondents, rather than letting the respondents provide them (see, e.g., Earle & Lindell, 1984; Perusse, 1980; Vlek & Stallen, 1981); and (b) relying exclusively on principal components factor analysis to examine the dimensionality of the data (Arabie & Maschmeyer, 1988). Vlek and Stallen (1981) used a "vector model" called PRINCALS (de Leeuw & van Rijckevorsal, 1980) to show that individuals differed in their cognitive representations of hazards, thus demonstrating that aggregate representations masked important information. Kraus and Slovic (1988), using a "policy-capturing methodology," also found significant individual differences in subject's models for perceived risk. Johnson and Tversky (1984) collected data on hazards in several different ways, permitting them to apply principal components factor analysis, multidimensional scaling methods, and discrete clustering models to the results. They found that each approach provided different perspectives and insights regarding the representation of perceived risk.

Arabie and Maschmeyer (1988) provided an extensive overview and critique of risk perception methodologies, arguing for greater use of methods permitting individual differences to be represented spatially and greater use of methods based on discrete clustering models. Specifically, they suggest the use of three-dimensional factor analysis (e.g., Kroonenberg, 1983; Tucker, 1964), and multidimensional scaling techniques such as INDSCAL (Carroll & Chang, 1970) to assess individual differences and the use of models such as ADDTREE (Sattath & Tversky, 1977) or ADDCLUS (Shepard & Arabie, 1979) to represent hazards within discrete clusters.

In light of these criticisms, we and others have begun to reanalyze our data sets, using some of these alternative exploratory multivariate techniques. Easterling (1989) has recently applied the INDSCAL method to our data on adolescent risk perception. INDSCAL simultaneously creates a spatial mapping of perceptions and assesses individual differences with reference to the space. Recall that each high school student rated 30 hazards on 14 characteristics, producing a 14 element profile for each hazard. All pairs of profiles (e.g., driving a car vs. rock climbing) are compared and a Euclidian distance measure is computed as a measure of profile similarity for each pair. Analysis of these distance measures by means of INDSCAL produces a group space of hazards and places each individual subject within that space according to the degree to which he or she weights the dimensions of that space (as inferred from the profile similarity matrix for each subject). Figure 10 shows the two major group dimensions that emerged from Easterling's analysis of the adolescent sample. Dimension 1 (horizontal axis) clearly separates the activities, with socially approved activities falling toward the high (right-hand) end of the dimension and socially disapproved activities falling toward the low (left) end. Dimension 2 (vertical axis) appears to reflect aspects of peer influence and admiration, anchored by socially influenced behaviors such as drinking alcoholic beverages, driving a car, listening to loud music, playing sports, and sunbathing at the high end of peer influence and admiration, and by crash dieting, bulimia, diet pills, and drug abuse at the low end.

Insert Figure 10 about here

The INDSCAL analysis produces weights for each dimension for each respondent. The weights given Dimensions 1 and 2 for each of the 30 subjects are plotted in Figure 11. Each single-digit number in the space represents an individual respondent and the number indicates the number of different kinds of destructive risk-taking activities that person had reported engaging in. Each individual is scaled in terms of a vector or arrow emanating from the origin of the space. The number is located at the tip or endpoint of the vector -- the line is not shown. The position of the tip is determined by the angle of the vector which, in turn, reflects the relative weight given each of the dimensions. The distance of the number from the origin reflects the degree to which this model fits the subject's responses. If both dimensions are of equal importance, then the person's point will fall on a straight line bisecting the angle (45 degrees) between the dimensions. Individuals below that line weight Dimension 1 more heavily and those above the line weight Dimension 2 more heavily.

Insert Figure 11 about here

The intriguing result shown in Figure 11 is that adolescents who participated in one or more types of destructive risk taking weighted Dimension 2 more heavily (and Dimension 1 less heavily) than did non-participants in dangerous activities. The line shown in the figure is slightly greater than 45 degrees above the horizontal axis. Prediction based on this line would correctly classify 27 of the 30 young people as either participants or non-participants (zero scorers) in destructive risk taking. These results suggest that adolescents who engage in the dangerous activities located toward the left-hand side of Figure 11 do not perceive a great deal of difference between those activities and the safer activities toward the right-hand side of the space. In other words, some may find these dangerous activities acceptable because they are not perceived to be true risks or outliers within the realm of possible adolescent behaviors. The analysis also indicates that those who engage in destructive risk taking exaggerate the differences between activities on Dimension 2, suggesting that they are relatively more sensitive than non-participants to elements of peer influence.

It is important to add that the analysis depicted in Figures 10 and 11 represents prediction of recent or ongoing behaviors from current perceptions. The challenge for future research is to determine, by means of longitudinal studies, whether individual differences in perceptions develop in advance of engagement in harmful risk taking. If so, this methodology may be able to depict those perceptions in a way that signals or forecasts a change in risk-taking behavior.

This INDSCAL analysis indicates that our previous studies, relying upon factor analysis of group means, may have missed important individual differences in perceptions. Wider use of scaling methods that take individual differences into account seems warranted.

New Theories and Conceptual Frameworks

Confirmatory modeling. Psychometric studies of perceived risk have been relatively theoretical and the methods of data collection and analysis have reflected this orientation. Principal components factor analysis and INDSCAL, which have been illustrated above, along with the other methodologies described by Arabie and Maschmeyer (1988), all fall into the general class of *exploratory* multivariate methods. The data analysis tends to precede conceptual analysis. As useful as these methods may be, they do not allow explicit specification and testing of theory.

We are now at a stage where we can begin to piece together theories and frameworks. Fortunately, there are analytic methods appropriate for this stage. In particular, a variety of techniques known as *confirmatory* multivariate methods have been developed for the express purpose of theory testing. Examples of methods that fall within this class are covariance structure analysis (LISREL) and partial least squares (PLS) analysis (Bentler, 1980; Fornell, 1982).

In testing theories, confirmatory approaches are able to analyze multiple criterion and predictor variables, unobservable theoretical variables, and errors in measurement. In contrast, many exploratory procedures can address only one or two of these aspects and none can cope with them all. For example, factor analysis handles unobservable variables but is not confirmatory. Multiple regression allows for tests of significance regarding parameter estimates and the regression equation, and thus in a weak sense is confirmatory. However, such analysis is limited to a single observable criterion variable. In addition, multiple regression assumes that all explanatory variables have the same status and have a direct effect on the criterion variable.

Burns et al. (1990) used confirmatory methods to test the theoretical framework that Kasperson, Renn, Slovic, et al. (1988) developed to explain social impacts of risk events. This theory, labeled "the social amplification of risk," addresses the fact that the adverse effects of a risk event sometimes extend far beyond the direct damages to victims, property, and environment and may result in massive indirect impacts. Models based on analysis of 108 accident events were consistent with the theory in the sense that the social and economic impacts of an adverse event were determined not only by the direct biological and physical consequences of the event, but by elements of perceived risk, media coverage, and signal value. A particularly important signal was the perception that the event was caused by managerial incompetence.

New Forms of Risk Impact -- Stigma

In 1986 we were afforded the opportunity to work with an interdisciplinary team of social scientists in what was the largest social impact assessment project ever attempted. The task was in some sense an impossible one -- to forecast the social and economic impacts on residents and communities in Southern Nevada in the event that the nation's high-level nuclear waste repository was sited, built, and put into operation at Yucca Mountain. As we sought to find some way to approach this daunting task, we came upon the concept of *stigma*. As we examined this concept, it became evident that stigmatization is closely associated with perception of risk.

Goffman (1963) noted that the word stigma was used by the ancient Greeks to refer to bodily marks or brands that were designed to expose infamy or disgrace -- for example, to indicate that the bearer of the mark was a slave or criminal. As it is used today, the word denotes a victim "marked" as deviant, flawed, limited, spoiled, or generally undesirable in the view of some observer. When the stigmatizing characteristic is observed, perception of the victim changes in a negative way. Prime targets for stigmatization are members of minority groups, the aged, persons afflicted with physical or mental disabilities and deformities, and behavioral deviants such as criminals, drug addicts, homosexuals, and alcoholics. Individuals in these categories have attributes that do not accord with prevailing standards of the normal and the good. They are denigrated and avoided.

Jones et al. (1984) attempted to characterize the key dimensions of social stigma. The six dimensions or factors they proposed were as follows:

(1) *Concealability*. Is the condition hidden or obvious? To what extent is its visibility controllable?

(2) *Course*. What pattern of change over time is usually shown by the condition? What is its ultimate outcome?

(3) *Disruptiveness*. Does the condition block or hamper interaction and communication?

(4) *Aesthetic qualities*. To what extent does the mark make the possessor repellent, ugly, or upsetting?

(5) *Origin*. Under what circumstances did the condition originate? Was anyone responsible for it, and what was he or she trying to do?

(6) *Peril*. What kind of danger is posed by the mark and how imminent and serious is it?

Dimension 6, peril, is the key link between stigma and perceived risk, but other dimensions may also come into play in the stigmatization of hazards. It seems evident that stigmatization can be generalized from persons to products, technologies, and environments. For example, nuclear and chemical waste disposal sites may be perceived as repellent, ugly, and upsetting (Dimension 4) to the extent that they become visible (Dimension 1). Such waste sites may also be perceived as disruptive (Dimension 3). They are certainly perceived as dangerous (Dimension 6).

A stigma resulting from pollution by a toxic substance is described by Edelstein (1986), who analyzed a case in which a dairy's cows become contaminated with PCBs for a short period of time. Once this contamination became known (a visible mark) the reputation of the dairy was discredited and its products became undesirable, even though the level of PCBs was never sufficiently high to prohibit sale of those products. Edelstein shows, step by step, how this incident meets the various criteria of stigmatization put forth by Jones et al.

Although Edelstein's case of stigma involved dairy products, only a short leap is required to extend the concept to environments that have been contaminated by toxic substances (Edelstein, 1988). Times Beach, Missouri, and Love Canal, New York come quickly to mind.

We have recently been exploring ways to measure environmental stigma. One method that seems quite promising uses a word-association technique to evoke the imagery, knowledge, attitudes, beliefs, and affective states associated with specific environments. Word associations have a long history in psychology, going back to Galton (1880), Wundt (1883), and Freud (1924). More recently, Szalay and Deese (1978) have employed the *method of continued associations* to assess people's subjective representation systems for a wide range of concepts. This method requires the subject to make repeated associations to the same stimulus, for example,

war: soldier
war: fight
war: killing
war: etc.

Szalay and Deese argue that this technique is an efficient way of determining the contents and representational systems of human minds without requiring those contents to be expressed in the full discursive structure of language. In fact, we may reveal ourselves through associations in ways we might find difficult to do if we were required to spell out the full propositions behind these associations through answers to question.

We conducted a study in which we asked University of Oregon students to produce continued associations to four states: New Jersey, Nevada, Colorado, and California. Subjects answered anonymously and without time pressure, to allow full expression of their thoughts. The results of this study clearly demonstrated environmental stigmatization in the minds of our sample of Oregon students. The image of New Jersey was dominated by pollution including toxic waste, filth, and garbage as members of the most common associative category. New Jersey was also seen as overcrowded, ugly, and associated with crime. Its farms and beaches were very infrequent images. Nevada's imagery was dominated by its desert landscape along with entertainment, gambling, and prostitution. It is also becoming associated with things nuclear (fifth most frequent category). Its scenic beauty, outdoor recreation, and ranches are secondary to these other images. Images of Colorado and California are far more positive than images of New Jersey and Nevada.

Returning to the issue of Yucca Mountain, we conducted a series of studies using the method of continued association to document the relationship between images, risk, preferences, and economically important behaviors (Slovic, Layman, Kraus, et al., 1989). First we demonstrated that cities and states had diverse positive and negative images as noted above. Second, we showed that by rating the degree of positive and negative affective content and summing these ratings across a person's set of images for each stimulus city or stimulus state, we could accurately predict a person's expressed preferences for future vacation sites, places to retire, and places to locate new businesses. Imagery was also predictive of previous visits to a place. Third, we asked people to associate to the concept of an "underground nuclear waste storage facility." The results, shown in Table 2 for a representative sample of residents in Phoenix, Arizona, could not have been more negative, or more representative of a stigmatized environmental facility. Third, we showed that nuclear imagery had already infiltrated the minds of about 10% of our respondents when they associated to the state "Nevada." We traced this nuclear imagery to knowledge of the nuclear weapons test site located near Yucca Mountain. We also found that nuclear imagery, when present, was associated with much lower preference for Nevada as a place to vacation.

We concluded that, were development and operation of the Yucca Mountain site to proceed, any problems associated with the repository would have the potential to link the repository, things nuclear, and many other highly negative images with the state of Nevada and the city of Las Vegas. Increased negativity of imagery, as we had demonstrated, could possibly lead to serious impacts on tourism, migration, and economic development in the Southern Nevada region. Through the mechanisms of social amplification, even minor problems could increase stigmatization, due to heavy media coverage and the attention drawn to these problems by special interest groups. Although precise specification of the probability, magnitude, and duration of such impacts is beyond the state of the art in social science prediction it is clear that such impacts cannot be ignored in decisions about the siting and management of the repository. The State of Nevada has cited the findings from these studies as instrumental in the State's decision to prevent the federal government from performing any further investigation of the Yucca Mountain site (Mckay, 1990).

Insert Table 2 about here

The stigmatization of environments has several important implications for hazardous waste management in general. First, it implies that, whatever the health risks associated with waste products, there are likely to be significant social and economic impacts upon regions perceived as polluted, or as dumps. Second, it also gives additional importance to managing wastes effectively so that stigmatizing incidents (even ones without significant health consequences) will not occur.

Just as environments can become stigmatized by risk problems, so can products (the IUD, the Pinto) and their manufacturers (A. H. Robbins, Ford Motor Company). Union Carbide has undoubtedly become stigmatized because of the Bhopal accident and Exxon as well as because of the oil spill at Valdez.

Technologies become stigmatized by risk, too. The image of most chemical technologies is so negative that when we asked college students and members of the general public to tell us what comes to mind when they hear or read the word "chemicals," by far the most frequent response was "dangerous" or some closely related term (e.g., toxic, hazardous, poison, deadly); beneficial uses of chemicals were rarely mentioned (see Table 3).

Insert Table 3 about here

Toward Deeper Levels of Analysis: Intuitive Toxicology

The power of factor analysis or multidimensional scaling lies in their ability to synthesize tens of thousands of judgments into a few visual displays. This broad descriptive capability carries with it, of necessity, a weakness. The analyses lack depth. They provide only a surface level of description that leaves many questions unanswered. Why do we not dread auto accidents? Why have perceptions of marijuana changed so drastically among college students over the past eight years? Why do adolescents who engage in dangerous activities believe they cannot avoid doing so but, once engaged in them, believe they can control the risks? Why are chemical risks of such great concern?

Answers to these sorts of questions require different methods of analysis -- methods which may afford deeper understanding of specific issues, rather than broad, but shallow, representations.

We have begun to reach for a deeper understanding of perceived risks from chemicals. Given the importance of chemical technologies in our daily lives, the extreme negative perceptions of chemical risks held by so many people is nothing short of astounding. This negativity of perceptions is especially significant in light of the immense scientific and regulatory efforts that have been designed to reduce public exposure to and harm from chemicals. Billions of dollars have been spent on risk-assessment studies by toxicologists and epidemiologists. Massive regulatory bureaucracies have been formed to oversee the use of these risk assessments for standard setting and risk management.

Yet despite this enormous effort, people in the U.S. and many other industrialized nations see themselves as increasingly vulnerable to the risks from chemical technologies and believe that the worst is yet to come. Regulatory agencies have become embroiled in rancorous conflicts, caught between a fearful and dissatisfied public on the one side and frustrated industrialists and technologists on the other. Industry sees an urgent need to communicate with the public but does not know how to do so.

Nancy Kraus, Torbjorn Malmfors, and I have approached this problem from a perspective that we have labeled "Intuitive Toxicology" (Kraus, Malmfors, & Slovic, 1990). Humans have always been intuitive toxicologists, relying on their senses of sight, taste, and smell to detect unsafe food, water, and air. The science of toxicology has been developed to supplement and, in many cases replace, our sensory systems. However, as a report by the National Academy of Sciences has indicated (National Academy of Sciences, 1983), toxicological risk assessment itself is inherently subjective, relying heavily upon assumptions and judgment.

The objective of our current research is to explore the cognitive models, assumptions, and inference methods that comprise laypeople's "intuitive toxicological theories" and to compare these theories with the cognitive models, assumptions, and inference methods of scientific toxicology and risk assessment. We hope that such comparisons will expose the specific similarities and differences within expert communities as well as the similarities and differences between lay perceptions and expert views. We also hope that the knowledge gained from these comparisons will provide a valuable starting point around which to structure discussion, education, and communication about toxicological risk assessment.

We have begun this effort by identifying several fundamental principles and judgmental components within the science of toxicological risk assessment. Questions were developed based on these fundamentals in order to determine the extent to which laypeople and experts share this same knowledge base and conceptual framework. Our questions addressed the following topics:

- conceptions of toxicity
- conceptions of the relationship between chemical dose and exposure and risk to human health
- trust in use of animal and bacterial studies to determine risk to humans
- attitudes towards chemicals and their risks
- interpretation of evidence regarding cause-effect relationships between exposure to chemicals and human health.

Questions on these topics were incorporated into a single questionnaire, designed for both experts and the public. This questionnaire asks a series of questions about chemicals and their risks, using an agree/disagree answer format. The term "chemicals" was defined to include ". . . all chemical elements and compounds, including pesticides, food additives, industrial chemicals, household cleaning agents, prescription and nonprescription drugs, etc." Table 4 presents five of the specific questions used to assess conceptions of toxicity and beliefs about the link between dose and exposure and possible harm.

Insert Table 4 about here

The questions were designed, whenever possible, according to a guiding hypothesis about how experts and "lay toxicologists" might respond. For example, perhaps the most important principle in toxicology is the fact that "the dose makes the poison" (Ottoboni, 1984). Any substance can cause a toxic effect if the dose is great enough. Thus we expected experts to exhibit considerable sensitivity to consideration of exposure and dose when responding to the five items in Table 4. In contrast, the concerns of the public regarding very small exposures or doses of chemicals led us to hypothesize that the public would have more of an "all or none" view of toxicity and would be rather insensitive to concentration, dose, and exposure when responding to the items in Category 1.

The questions in Table 4 comprise a small part of a lengthy survey that we administered to 180 members of the Society of Toxicology and 262 members of the general public. The data showed substantial differences in the attitudes and beliefs of experts and laypeople. Laypeople tended to believe that any exposure to a toxic substance or carcinogen, no matter how small, was likely to prove harmful. Toxicologists had, as expected, a much more differentiated sense of the relationship between dose and degree of exposure and harm. Perhaps most important was the divergence of opinion among toxicologists, themselves, on questions pertaining to the reliability and validity of animal tests for assessing the risks that chemicals pose for humans. This lack of confidence in the science may be a significant cause of the public's anxiety and distrust. We also observed a strong "affiliation bias" indicating that toxicologists working for industry see chemicals as more benign than do their counterparts in academia and government. Industrial toxicologists were somewhat more confident than other experts in the general validity of animal tests -- except when those tests were said to provide evidence for carcinogenicity -- in which case many of the industrial experts changed their opinions that the tests were valid. Similar results have been found by Lynn (1987) and, together, these data clearly show the influence of personal and organizational values on risk assessment.

Detailed assessments of a person's knowledge, attitudes, beliefs, values, perceptions, and inference mechanisms make up what cognitive psychologists refer to as a "mental model." Our study of intuitive toxicology attempts to describe the mental models of experts and laypersons regarding the effects of chemicals on human health. Mental models of risk from radon and from electric fields are currently being developed at Carnegie-Mellon University. I expect that this paradigm will be increasingly relied upon to describe perceived risk and to facilitate communication about risk.

CONCLUDING REMARKS

The Need for a Multidisciplinary Perspective

Although the psychometric approach has been oriented toward cognitive psychology and behavioral decision theory, I believe that societal response to hazards is multidetermined and thus needs to be studied in a multidisciplinary way.

Occasionally one sees attempts to test "rival disciplinary theories" of risk perception, as though one approach -- social, cultural, psychological, or economic -- could be "the right way" to conceptualize things (see, e.g., Wildavsky & Dake, 1990). This makes little sense to me. It is most certainly the case that information processing (cognition), personality, social factors, economic factors, and cultural factors interact to determine individual and societal response to risk. The mix may be difficult, if not impossible, to separate -- witness the endless debates about nature vs. nurture.

Consider, for example, the quality "dread." Most people in our cultural would judge sudden death from heart disease as less dreaded than death from cancer. I am told that in some eastern cultures the opposite is true -- a lingering death from cancer is preferred because it gives one the opportunity to put one's affairs in order and say goodbye. Thus dread appears to be both psychological and cultural and it does not seem worthwhile to me to attempt to disentangle these various aspects.

Fortunately, the psychometric approach is not inherently psychological, as shown by the inclusion of social variables in the study of adolescent risk taking, the inclusion of institutional and economic variables in the social-amplification study, and the inclusion of political and ideological variables in other studies (Buss, Craik, & Dake, 1986).

Risk Perception and Rationality

Are public perceptions of risk irrational? Many technologists believe that they are. For example, public perceptions of nuclear power risks have evoked harsh reactions from experts. One noted psychiatrist wrote that "the irrational fear of nuclear plants is based on a mistaken assessment of the risks" (Dupont, 1981; p. 8). A nuclear physicist and leading advocate of nuclear power contended that ". . . the public has been driven insane over fear of radiation [from nuclear power]. I use the word 'insane' purposefully since one of its definitions is loss of contact with reality. The public's understanding of radiation dangers has virtually lost all contact with the actual dangers as understood by scientists (Cohen, 1983).

Risk-perception research paints a different picture, demonstrating that people's deep anxieties about nuclear power and its wastes are linked to numerous realities. For example, one reality for the public consists of innumerable news stories about poorly sequestered radioactive wastes from the nation's military reactors contaminating the environment and threatening human health at Hanford, Savannah River, Rocky Flats, Fernald, Ohio and other sites. Another reality for the public is witnessing the Department of Energy declare that it has no confidence in it's two-year, 500 million dollar attempt to evaluate the safety of the proposed waste-repository site at Yucca Mountain, Nevada (Wald, 1989). Well-publicized conflicts among scientists about the ability of animal tests to predict human health effects from chemicals (Associated Press, 1990) form yet another "reality." Thus, although one may legitimately disagree with public perceptions of risk, they are clearly not irrational.

More generally, psychometric research demonstrates that, whereas experts define risk in a narrow, technical way, the public has a richer, more complex view, that incorporates value-laden considerations such as equity, catastrophic potential, and controllability. The issue is not whether these are legitimate, rational considerations, but how to integrate them into risk analyses and policy decisions.

Risk Perception and Risk Analysis

Risk-perception studies indicate that public views about risky technologies need to be taken seriously. The problem is that it is not obvious how to incorporate public perceptions and preferences into risk analysis and decision making. A risk manager who wants to include public perceptions will probably not know how to do so.

Some risk analysts have attempted to provide guidance about how to weigh and combine social and technical considerations. For example, Starr (1969) distinguished between voluntary and involuntary activities in assessing risk-benefit balances and Wilson (1975) and Griesemeyer and Okrent (1981) proposed that large accidents needed to be given proportionally more weight than numerous small accidents totaling the same amount of damage. Rowe (1977) and Litai, Lanning, and Rasmussen (1983) have explored the possibility of adjusting risk estimates to take into account the importance of various risk-perception characteristics; however, their work treats highly interdependent characteristics as though they were independent, thus their analyses are prone to serious "double counting" effects. Fischhoff, Watson, and Hope (1984) have suggested that multi-attribute utility theory be employed to insure that social and psychological factors are incorporated into technical and economic analyses. To my knowledge, none of these various proposals have been developed to the point of application in actual risk analyses.

I know of only one method of risk analysis that has formally integrated technical, economic, and social (perception) factors in a formal way and done so in real applications. This approach has been developed by two Swiss analysts to aid decisions about the safety of ammunition storage depots and transportation systems, including the design of the proposed high-speed railway in Germany (Bohnenblust & Schneider, 1984). The method is essentially a cost-effectiveness approach that allocates more money for risk reduction to hazards that are involuntary, poorly understood, and hard to control. Although this "Swiss model" has been successfully applied in a number of important decision problems, there is a need to align the model more closely with the research that has been done on risk perception and its impacts (e.g., signals, ripples, social amplification). A recent effort in this direction has been initiated by Burns (1990). More generally, there is need for research that determines how the public feels about incorporating risk-perception characteristics as explicit criteria that are traded against cost and more traditional criteria (e.g., lives and health effects).

Risk Perception and Trust

As I contemplate the current problems most in need of research, the issue of trust leaps to the top of the list. The massive discrepancies between expert risk assessments and public perceptions and the acrimonious conflicts over risk-management issues can be seen as reflecting a "crisis in confidence," a profound breakdown of trust in the scientific, governmental, and industrial managers of radiation and chemical technologies. There is a great need to understand the nature of trust in order to develop social and institutional processes for decision making that restore and maintain this vital but fragile quality. Many different methods of analysis can contribute such knowledge but, considering the multidimensional nature of trust (ethics, intentions, competence, . . .) it appears to be a natural candidate for the psychometric paradigm.

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Table 1

Environmental features studied by Slovic et al., 1987

1. Heavy Smog
2. Heavy Traffic
3. High Crime Rate
4. Industrial Waste Disposal Problem
5. Severe Water Problem
6. Nuclear Power Plant
7. Nuclear Waste Storage Site (100 miles away)
8. Earthquake-Prone Area
9. Hurricane/Tornado-Prone Area
10. Acid Rain
11. Strip Mining
12. High Levels of Radon Gas
13. Heavy Use of Pesticides
14. Heavy Use of Herbicides to Control Weed and Grass Growth
15. Asbestos-Insulated Buildings
16. Plutonium Plant
17. A Main Route for Transporting High-Level Radioactive Waste
18. Military Weapons Manufacturing Facility
19. Extensive Landfills
20. Large Dam
21. Sewage Treatment Plant
22. Recombinant DNA Laboratory
23. A Main Route for Transport of LNG
24. Active Volcano (100 miles away)
25. Large Prison Facility
26. Institution for the Criminally Insane
27. Coal-Fired Power Plant
28. Hydro-Electric Power Plant
29. Overpopulation/Overcrowding
30. Water Shortages
31. Chemical Manufacturing Plant
32. High Noise Level
33. High Alcohol Consumption Rate
34. Legalized Gambling
35. Legalized Prostitution
36. Ku Klux Klan Headquarters
37. Nuclear Weapons Test Site (100 miles away)

Table 2

Hierarchy of Images Associated with an "Underground Nuclear Waste Storage Facility"

Category	Frequency	Images Included in Category
1. Dangerous	179	dangerous, danger, hazardous, toxic, unsafe, harmful, disaster
2. Death	107	death, sickness, dying, destruction
3. Negative	99	negative, wrong, bad, unpleasant, terrible, gross, undesirable, awful, dislike, ugly, horrible
4. Pollution	97	pollution, contamination, leakage, spills, Love Canal
5. War	62	war, bombs, nuclear war, holocaust
6. Radiation	59	radiation, nuclear, radioactive, glowing
7. Scary	55	scary, frightening, concern, worried, fear, horror
8. Somewhere Else	49	wouldn't want to live near one, not where I live, far away as possible
9. Unnecessary	44	unnecessary, bad idea, waste of land
10. Problems	39	problems, trouble
11. Desert	37	desert, barren, desolate
12. Non-Nevada Locations	35	Utah, Arizona, Denver
13. Storage Location	32	caverns, underground salt mine
14. Government/Industry	23	government, politics, big business

Table 3

College students' word associations to the stimulus term "Chemicals"

	Frequency	
Dangerous	59	Toxic, Hazardous, Deadly, Destruction, Accidents, Poisonous, Explosive, Kill, Harmful, Bhopal, Cancer, Bad, Noxious
Chemical Names and Elements	45	H_2SO_4, Ozone, Carbon, Dioxin, Gas, DDT, Cyanide, Methane, Hydrogen, Monoxide, Oxygen, Uranium, Acid
Pollution	29	Love Canal, Greenhouse Effect, Smelly, Teledyne Wah Chang, Air Pollution
Laboratory	30	Experiments, Science
Chemical Types	21	Herbicides, Pesticides, Preservatives, Vitamins, Fertilizer, Drugs, Medicines
Chemistry	16	
Useful	14	Beneficial, Jobs, Benefits, Valuable, Products, Helpful
Wastes	10	
Food	9	
"Paraphanelia"	11	Beaker, Bottles, Flasks, Litmus, Test Tubes, Hood, Stockroom
Burn	12	Burner, Bunsen-Burner, Burning
DOW	6	
War	11	Warfare
Technology	7	Industry

Table 4

Questions Designed to Assess Sensitivity to Degree of Exposure

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- If you are exposed to a toxic chemical substance, then you are likely to suffer adverse health effects.
- If you are exposed to a carcinogen, then you are likely to get cancer.
- For pesticides, it's not how much of the chemical you are exposed to that should worry you, but whether or not you are exposed to it at all.
- A chemical was found in a city's supply of drinking water in a concentration of 30 parts per million. Because scientists believed that there might be harmful effects from this level of exposure to the chemical, the water was filtered by a process that was able to reduce, but not eliminate, the chemical concentration in the water. Under most circumstances this means that the danger associated with drinking the water has also been reduced.
- There is no safe level of exposure to a cancer-causing agent.

FIGURE CAPTIONS

Figure 1. Profiles for nuclear power and x-rays across nine risk characteristics. Source: Fischhoff et al. (1978).

Figure 2. Location of 82 hazards of Factors 1 and 2 derived from the interrelationships among fifteen risk characteristics. Each factor is made up of a combination of characteristics, as indicated by the lower diagram. Source: Slovic (1987).

Figure 3. Relation between signal potential and risk characterization for 30 hazards from Figure 2. The larger the point, the greater the degree to which an accident involving that hazard was judged to "serve as a warning signal for society, providing new information about the probability that similar or even more destructive mishaps might occur within this type of activity." The higher-order costs of a mishap are likely to be correlated with signal potential. Source: Slovic, Lichtenstein, and Fischhoff (1984).

Figure 4. Mean perceived risk and perceived benefit for 33 activities, substances, and technologies based on a national survey in Canada. Source: Slovic, Kraus, Lappe, and Major (1989).

Figure 5. Risk perceptions of Swedish men and women. Source: Slovic, Kraus, Lappe, Letzel, and Malmfors (1989).

Figure 6. Risk perception of Canadian men and women. Source: Slovic, Kraus, Lappe, and Major (1989).

Figure 7. Location of 40 automobile defects within a two-factor space derived from interrelationships among five characteristics. Source: Slovic, MacGregor, and Kraus (1987).

Figure 8. Perceptual map of pharmaceutical products, medical treatments, and other hazards in the Swedish study. Source: Slovic, Kraus, Lappe, Letzel, and Malmfors (1989).

Figure 9. Spatial representation of perceptions among 37 unwanted environmental features. Source: Slovic et al. (1987).

Figure 10. Hazard space derived from INDSCAL Analysis. Source: Easterling (1989).

Figure 11. Subject weights for dimensions in the group hazard space. Each number represents a respondent, coded according to the number of destructive risk-taking activities that a person participated in. Source: Easterling (1989).

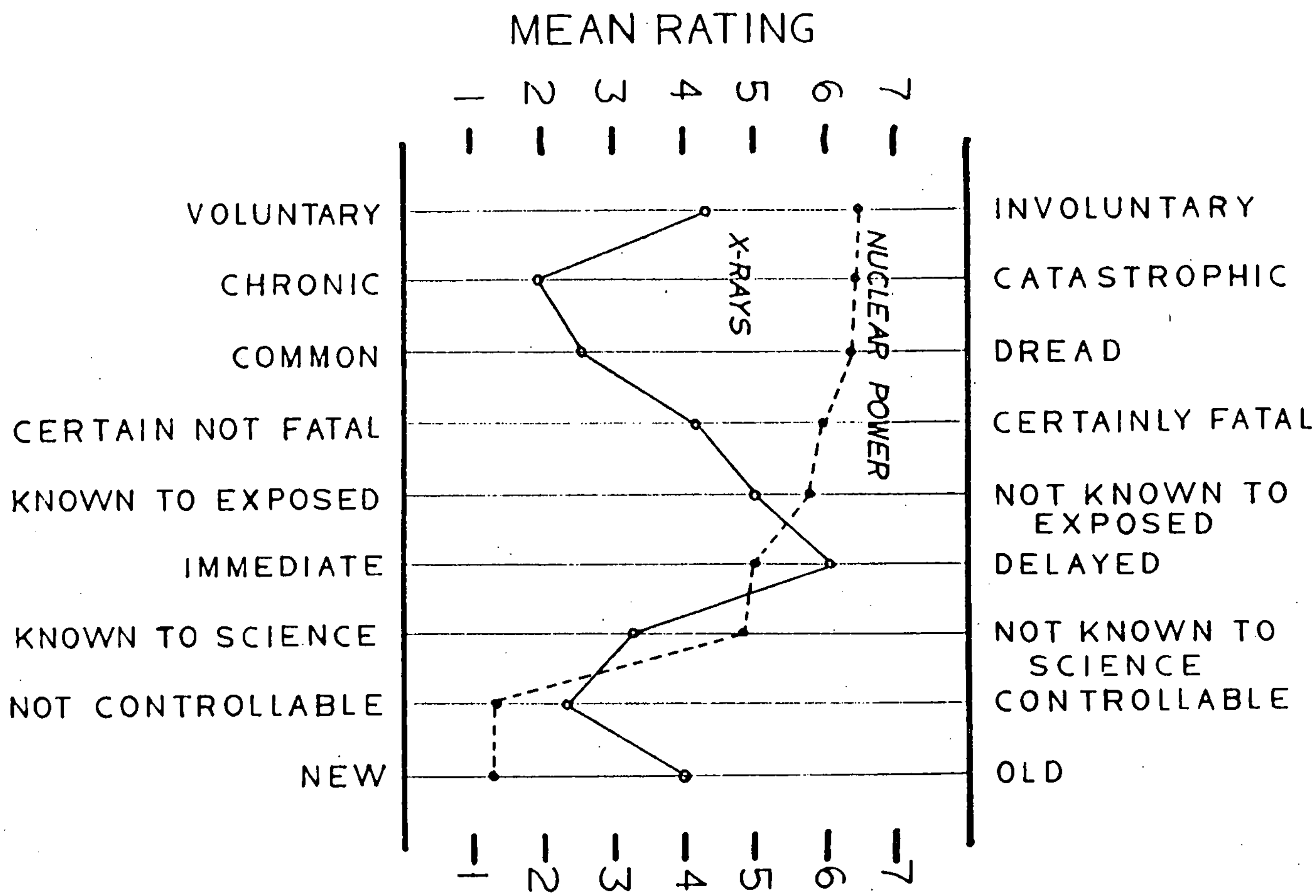


Figure 1. Profiles for nuclear power and x-rays across nine risk characteristics. Source: Fischhoff et al., 1978.

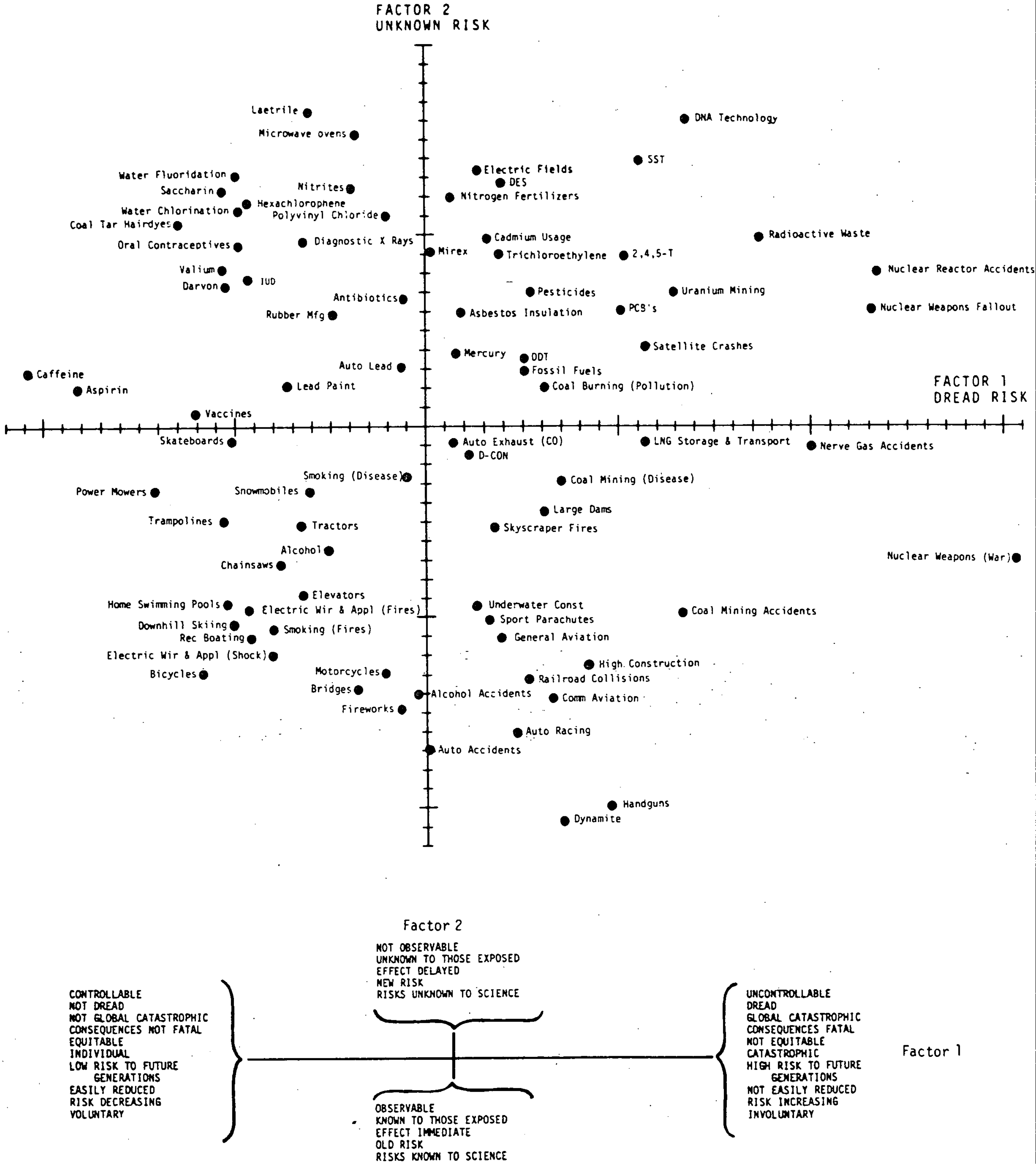


Figure 2. Location of 81 hazards of Factors 1 and 2 derived from the interrelationships among 15 risk characteristics. Each factor is made up of a combination of characteristics, as indicated by the lower diagram. Source: Slovic, 1987.

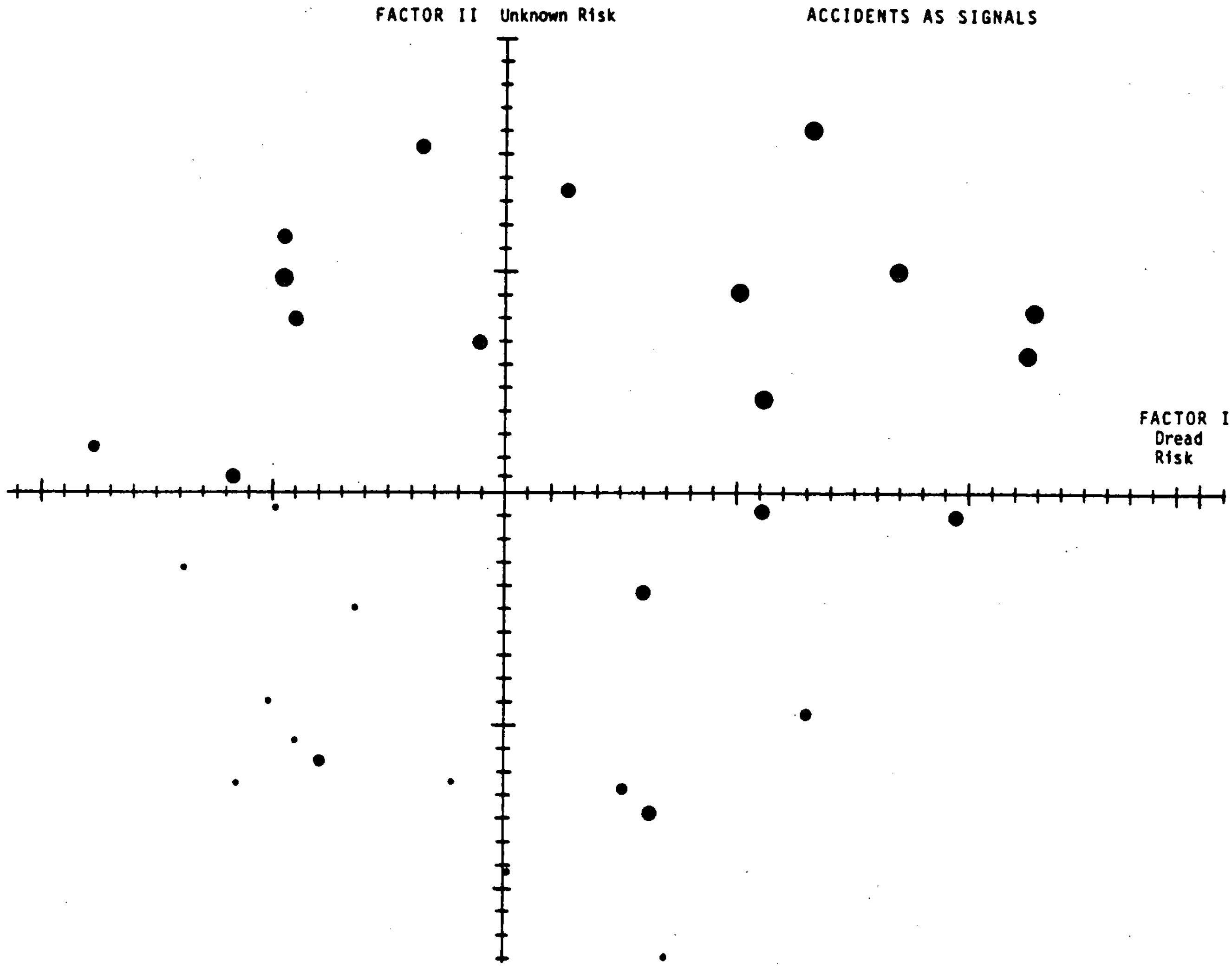


Figure 3. Relation between signal potential and risk characterization for 30 hazards from Figure 2. The larger the point, the greater the degree to which an accident involving that hazard was judged to "serve as a warning signal for society, providing new information about the probability that similar or even more destructive mishaps might occur within this type of activity." The higher-order costs of a mishap are likely to be correlated with signal potential. Source: Slovic, Lichtenstein, and Fischhoff (1984).

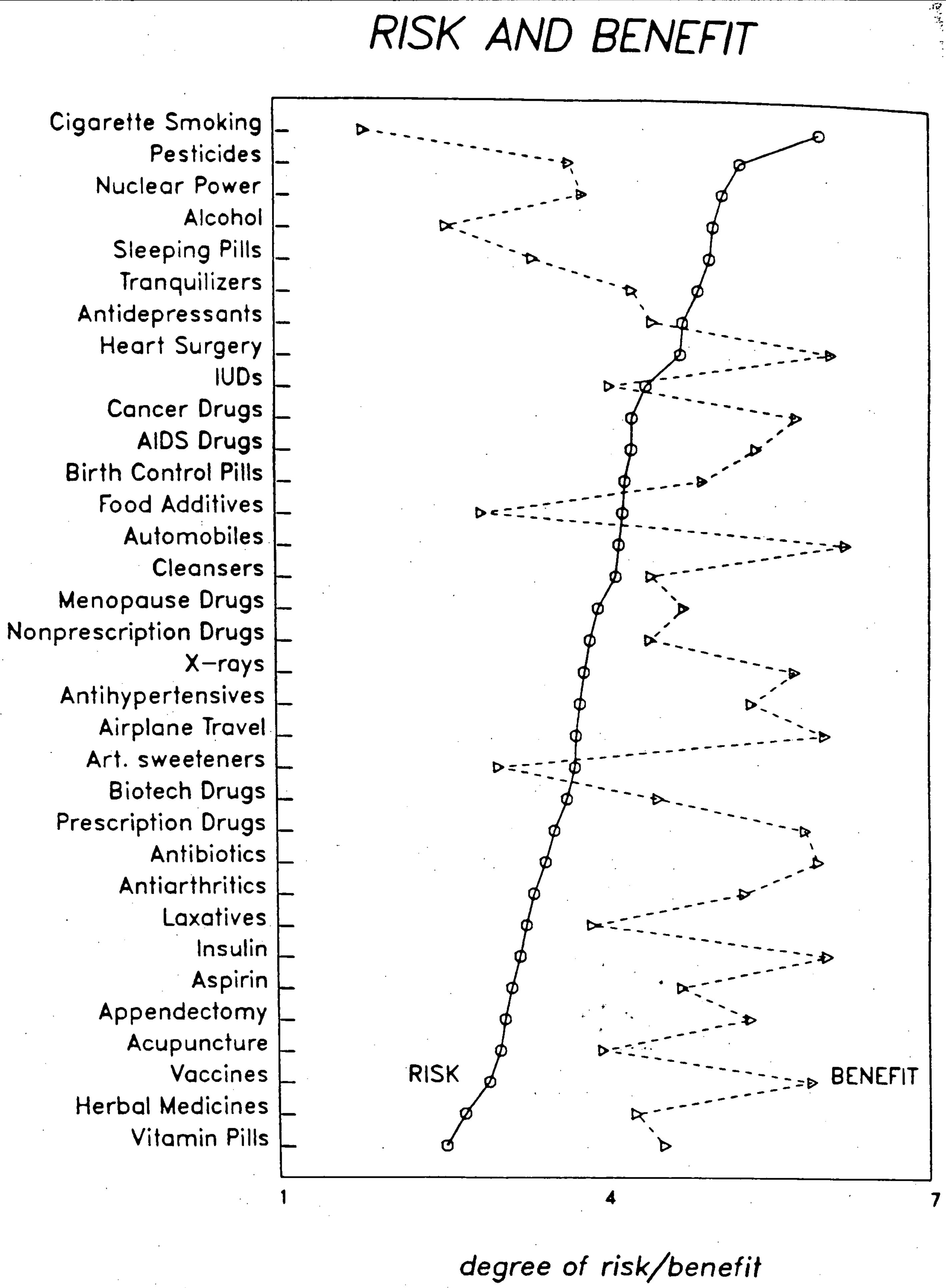
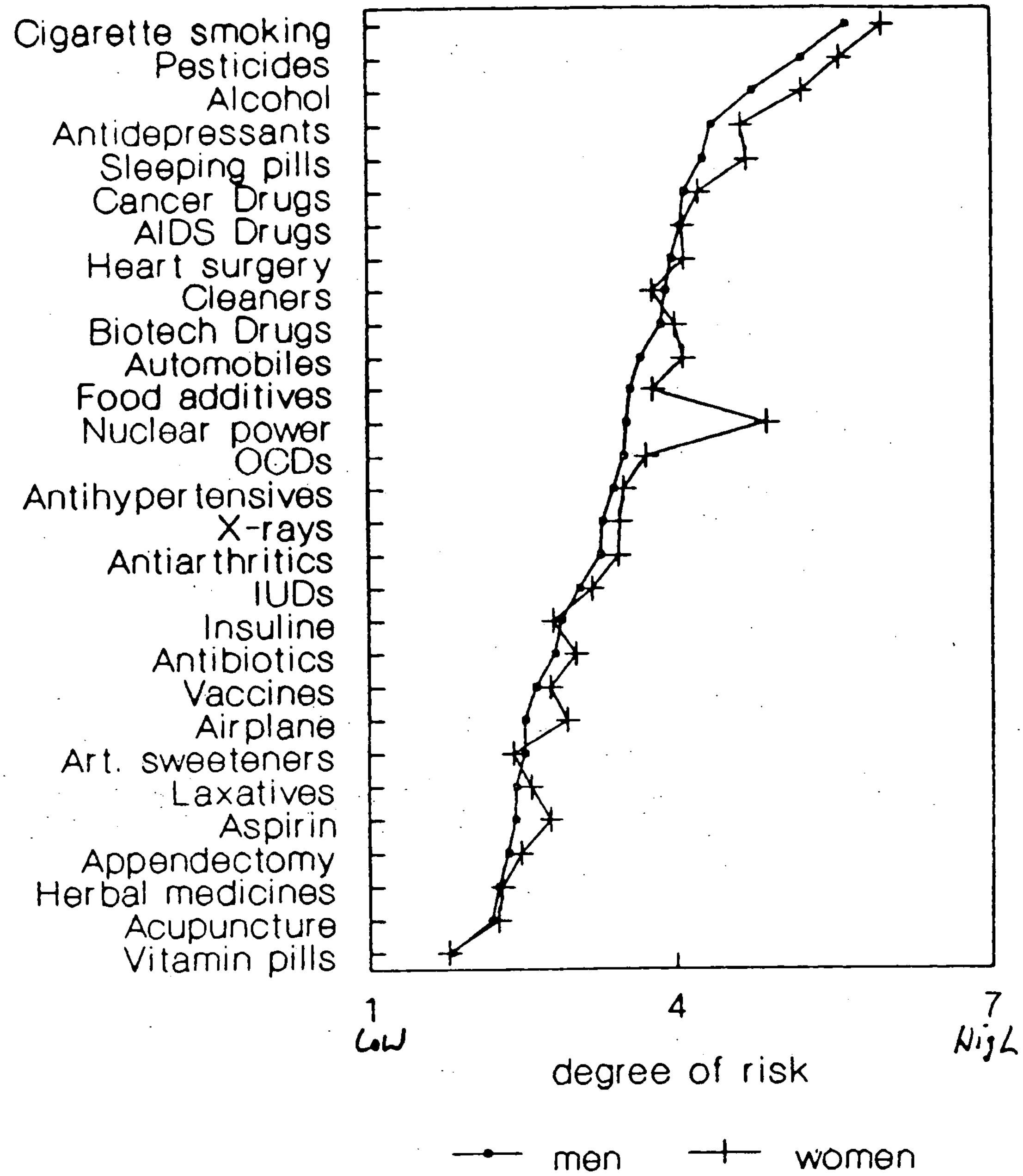


Figure 4. Mean perceived risk and perceived benefit for 33 activities, substances, and technologies based on a national survey in Canada. Source: Slovic, Kraus, Lappe, and Major (1989).

RISK PERCEPTION BY SEX
Men versus Women



Basis: men n=473, women n=481
(without missing data)

Figure 5. Risk perceptions of Swedish men and women.
Source: Slovic, Kraus, Lappe, Letzel, and Malmfors (1989).

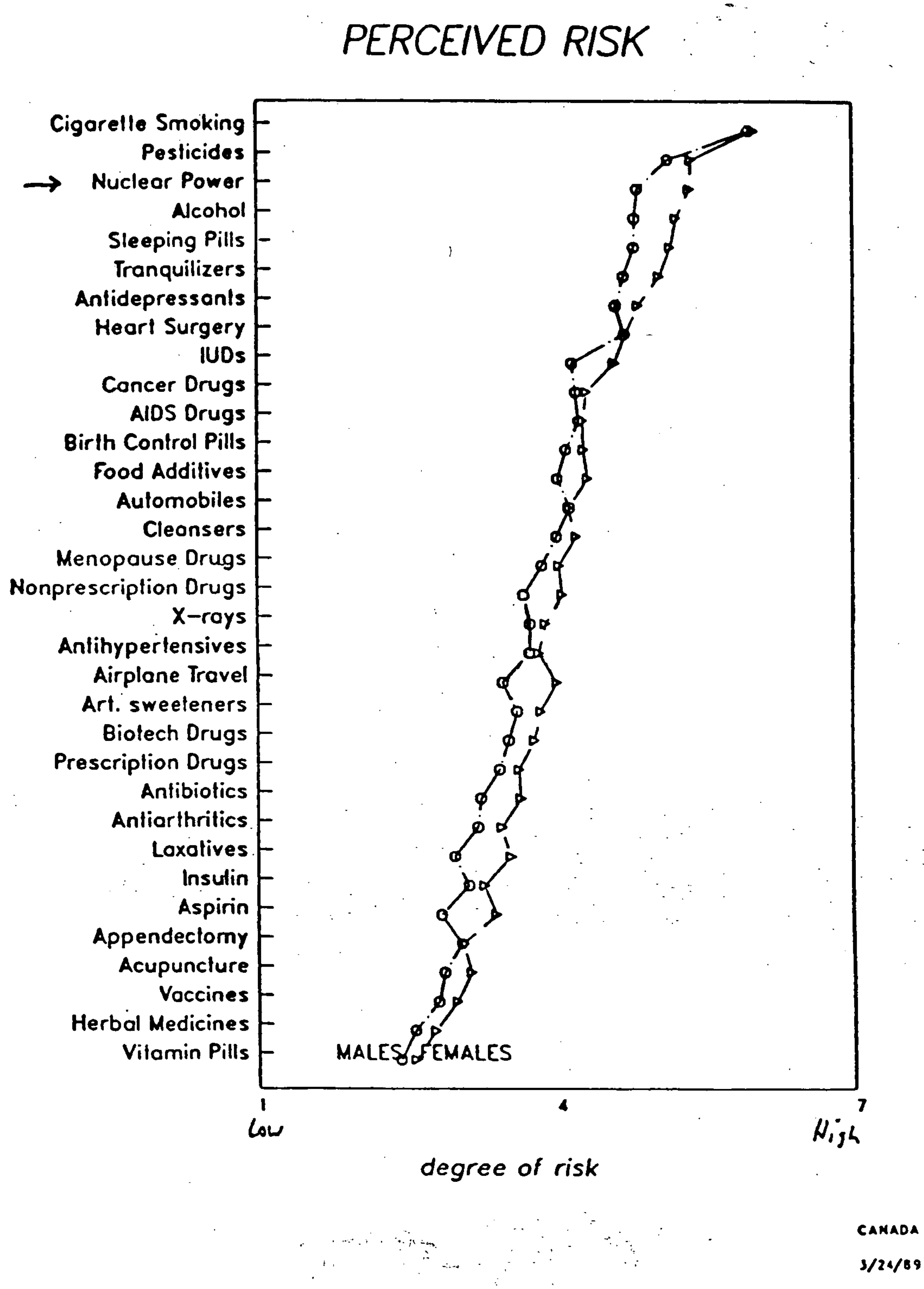


Figure 6. Risk perceptions of Canadian men and women. Source: Slovic, Kraus, Lappe, and Major (1989).

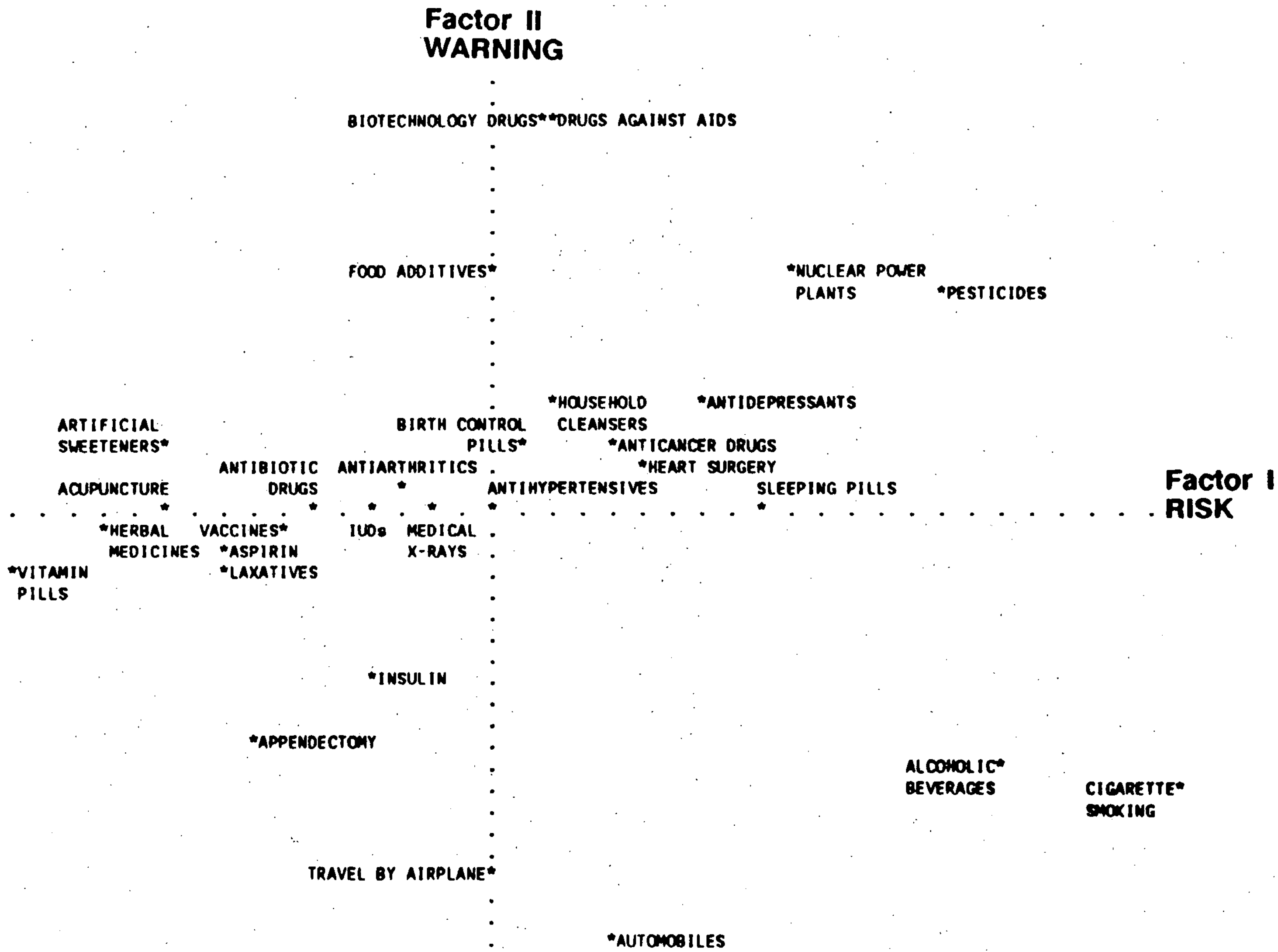


Figure 8. Perceptual map of pharmaceutical products, medical treatments, and other hazards in the Swedish Study. Source: Slovic, Kraus, Lappe, Letzel, and Malmfors (1989).

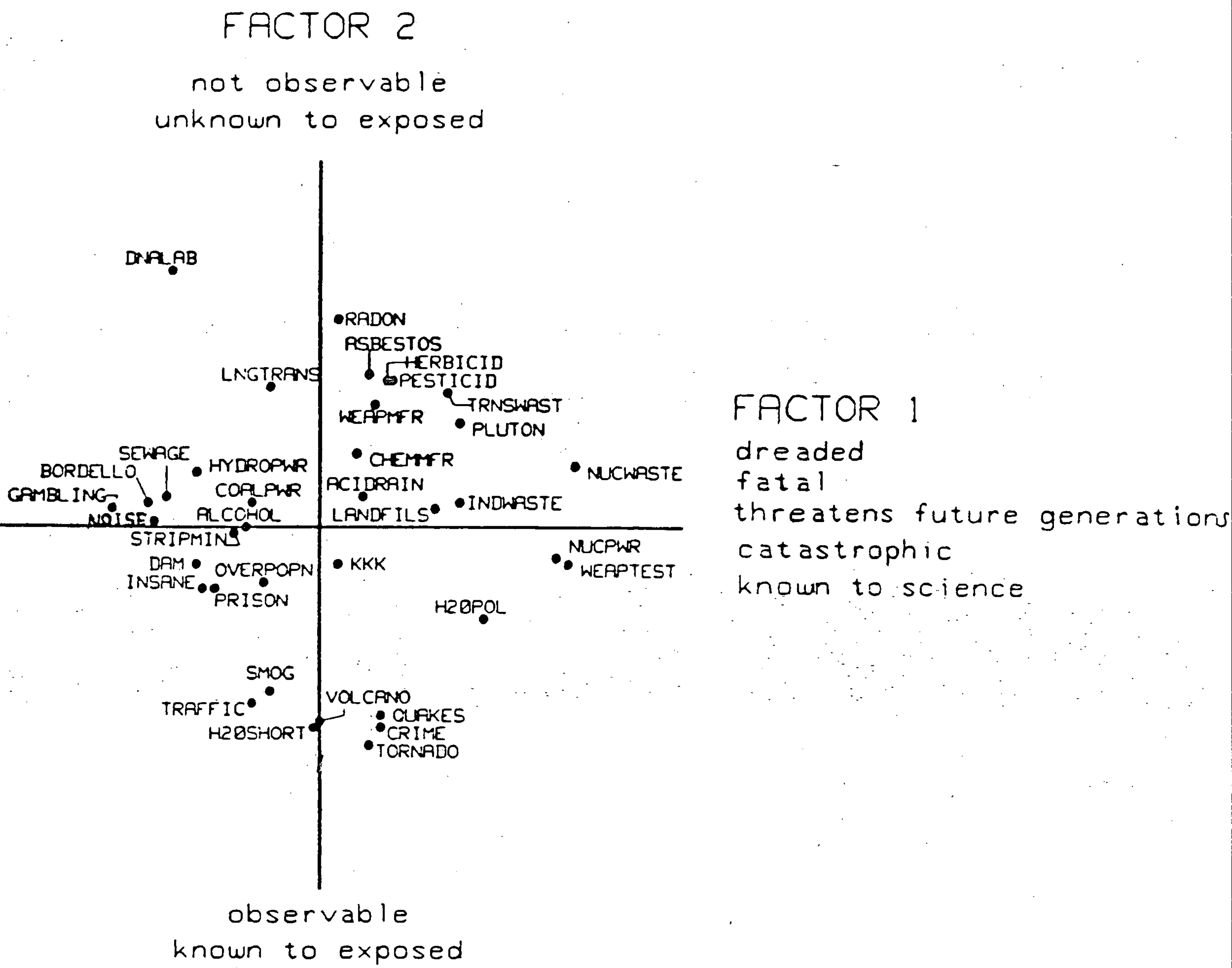


Figure 9. Spatial representation of perceptions among 37 unwanted environmental features (Slovic et al., 1987).

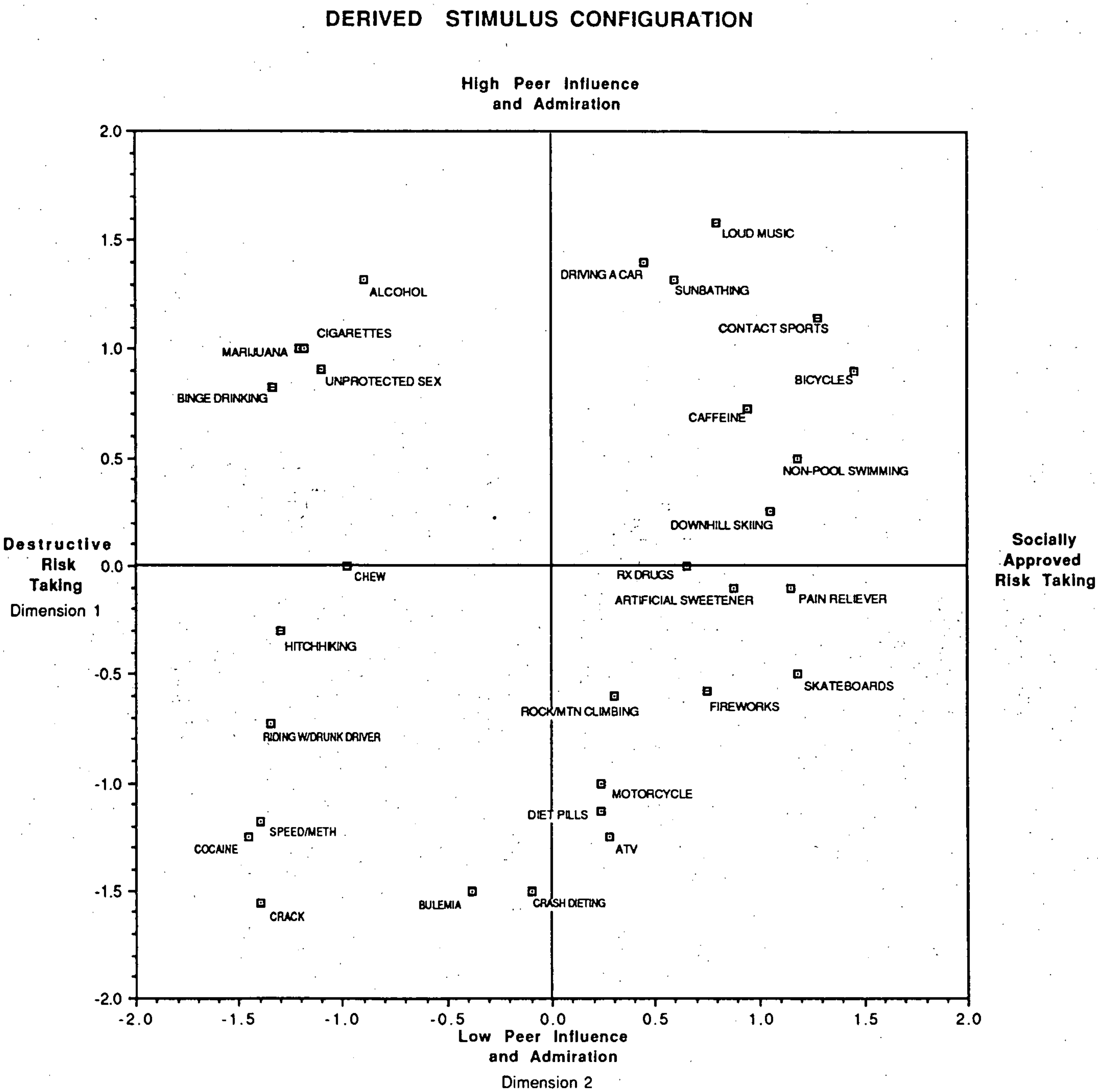
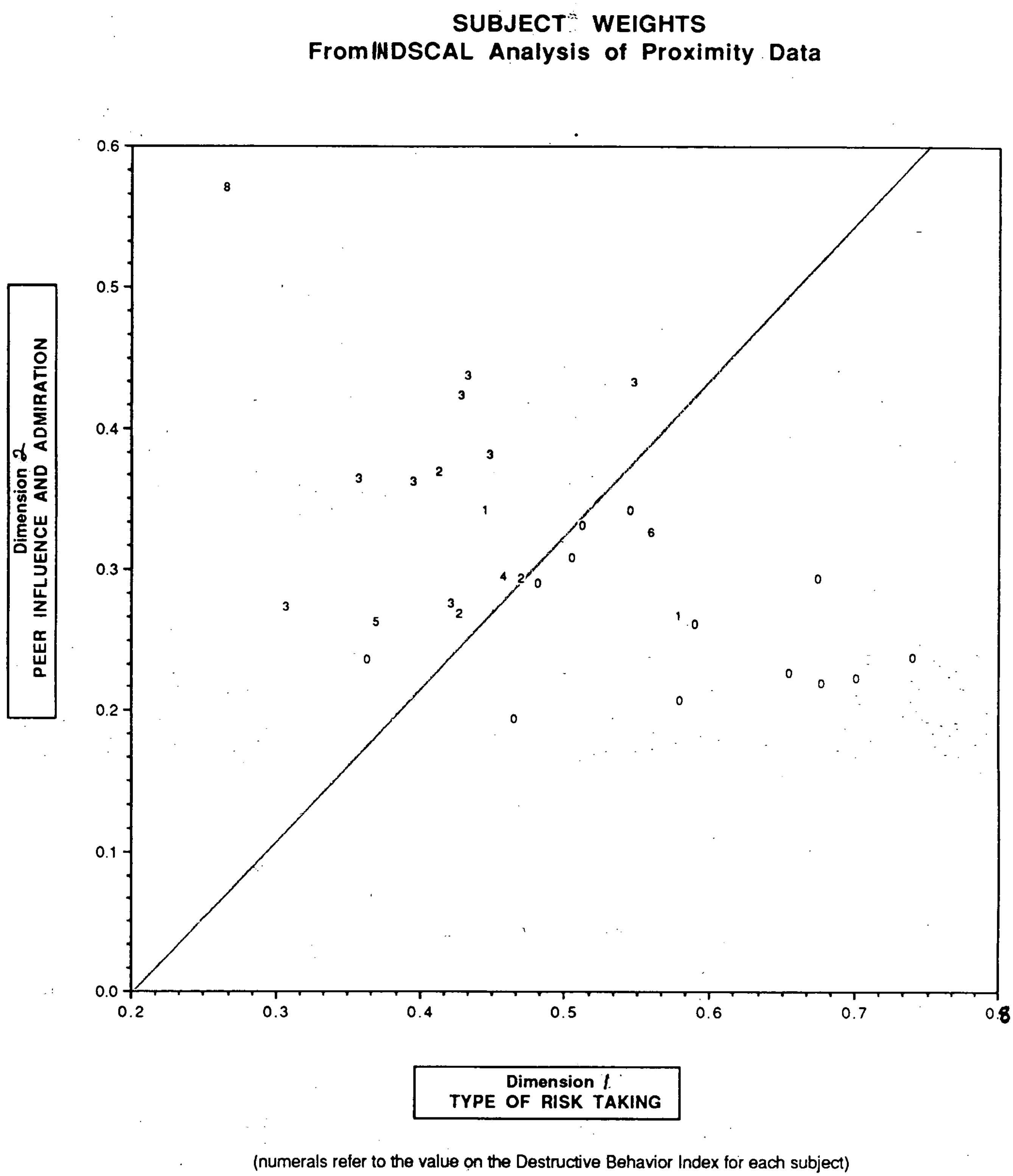


Figure 10. Hazard space derived from INDSCAL Analysis (Source: Easterling, 1989).



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