Final Report

VALUATION OF REDUCTIONS IN HUMAN HEALTH SYMPTOMS AND RISKS

Voiume 4

CONCEPTS AND APPROACHES TO THE VALUATION OF SERIOUS ILLNESS

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VALUATION OF REDUCTIONS IN HUMAN HEALTH SYMPTOMS AND RISKS

This is Volume 4 of a four volume report. The project undertakes an assessment and reconciliation of attempts to value reductions in human health risks,' and it develops new methods and estimates for these values. Volume 1 is the executive summmary. Volume 2 contains a comparative assessment of work on valuing health risks. Based on the assessment, a set of interim morbidity and mortality values applicable to effects of criteria air pollutants is developed. Volume 3 reports on a study developing and applying contingent valuation techniques to the types of light symptoms often attributed to air pollution. Volume 4 reports on the design of approaches for valuing serious or life threatening illnesses.

Abstract of Volume 4

CONCEPTS AND APPROACHES TO THE VALUATION OF SERIOUS ILLNESS

Volume 4 extends the analysis of health valuation to life threatening illness.

Section 4.2 considers alternative definitions of health and, for the study of serious illnesses resulting from environmental causes, concludes that a definition in terms of absence of symptoms should be used. The potential contributions of various pollutants to the risks of serious illnesses are reviewed, in order to choose which diseases should be studied and what ranges of risks are relevant. Specific measures of health status are evaluated including symptom description, self-assessment, health risk appraisal, health indexes and multi-attribute utility functions. The first three of these are recommended for contingent valuation studies.

Section 4.3 develops a life cycle explanatory framework for valuing reductions in life-threatening illness that guides the remainder of the study. Within this framework, longevity (i.e. mortality) and quality of life (as affected by morbidity) are considered together in a unified context. Young people, presented with improved prospects for greater health and longevity only after a long period of time, will heavily discount the benefits and will pay little, even though aware that their preferences many years hence will be different. Policies that promise a near-term benefit will be valued much more highly by people of any age. If people can easily substitute near term consumption for deferred consumption, they will place less value on additions to life expectancy. The capacity for consumption changes over the life cycle. An added year of life accompanied by high income or accumulated wealth, together with a high quality of leisure time, will be valued relatively highly. Latency is modelled within the life cycle framework.

Section 4.4 develops a model of choice under uncertain

preferences, bringing utility theory to bear on the problem of valuing small changes in events that are thought of only infrequently and may involve low probabilities of occurrence. The model is applicable to eontingent valuation approaches to serious illness. The model assumes environmental health risks are unfamiliar to most people, and that because people seldom have occasion to think carefully about them they are uncertain about their preferences concerning them. The model leads to twelve theorems for stimulating people to obtain improved knowledge about their preferences and to state valid, consistent risk reduction values.

Section 4.5 applies the preceding sections to contingent valuation of life threatening illness. A structure for an intensive interviewing process is developed, based on techniques of in-depth interviewing.

The proposed interview structure contains four modules. The first module concerns the repsondent's health experiences. The defensive measures module is the second module. The third module pertains to risk perception and risk behavior. This module teaches respondents basic notions of probability and conveys information about probabilities involved in health. Information is obtained about repsondent perceptions and attitudes towards risks.

Contingent valuation questions form the fourth module. The module begins with simple questions involving certainty scenarios and mortality only, after which serious illnesses are introduced. Then life path scenarios are introduced that combine morbidity and mortality in a life cycle setting. Respondents are asked to choose among and value the scenarios, first in a certainty and then an uncertainty setting.

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4.1. OVERVIEW

Volume 4 extends the analysis of health valuation to the domain of life threatening illness. It provides an original framework that can be used to obtain values of increased longevity and reduced risks of death from serious illness.

Section 4.2 provides a discussion of approaches to the measurement of health status. This section is a pre-requisite to determining how to measure health attributes whose value is to be estimated. Simple self-rating of health, definition of health as a good or a bad, broadness of definition extending to mental well being, disease specific definitions and symptom specific definitions are among the appraoches to health measurement that are considered. A central purpose is to consider which measures should be used in estimating values connected with life threatening illness, giving particular attention to health risks due to environmental pollutants. Extensions of previous approaches to health measurement are suggested.

Section 4.3 develops an explanatory framework to guide the estimation of values that result from reductions in life-threatening illness. This framework brings out how people's decisions regarding health and longevity depend on their life situations and streams of experiences that have developed over long periods of time. An important implication is that the quality of life and longevity are part of a single decision making process, and that they must be considered together in a unified context taking account of a peron's life cycle situation. The life cycle framework is at the heart of the remainder of the study. One of the challenges brought out by the framework is how to measure the value people place-on the reduction of threats to health that have their effects only after a latency period that may be many years in duration. Analysis of this problem is one of the contributions of section 4.3.

Section 4.4 provides the theoretical underpinnings to another aspect of the problem of valuing life threatening illness. It brings economic theory to bear on the problem of how people think about and value small changes in small probabilities of large damages to health or risk to life. A clear understanding of this process is essential to determining the benefits of environmental policies if a contingent valuation approach is to be used to estimate values. The problem has been widely recognized, but heretofore procedures to deal with it have been largely ad hoc. The theoretical perspective of the present study is that environmental health risks are unfamiliar to most people, and that because people seldom have occasion to think carefully about them they are uncertain about their preferences concerning them. Section 4.4 contains a series of theorems that have implications about efficient ways of stimulating people to obtain improved knowledge about their own risk preferences and to state valid, consistent risk reduction values.

Section 4.5 brings together and applies all of section 4 research on life threatening illness. A structure for an in-depth intensive interviewing process is developed, embodying refinements based on focus group experiments. The structure is composed of four modules.

The first module concerns the repsondents' health experiences. It establishes the health endowmment and prepares respondents to give detailed thought to their health preferences and values.

The defensive measures module is the second module of the in-depth interview framework. Defensive measures, or averting behavior, are an important part of many people's efforts to increase the probability of good health over the life cycle. They are evidence of a willingness to pay for improved life prospects. Reductions in defensive measures are a part of the benefits of reducing health risks. In some cases averting behavior entails increased expenditures (for example air conditioning), while in other cases reduced expenditures occur (for example reduced smoking).

The third module pertains to risk perception and risk behavior. The first part of this module addresses the problem of teaching people to grasp the concept of probability as it is manifested in environmental health problems. In the second part of this module, respondents are asked questions about their behavior toward risk and how they perceive the riskiness of a variety of life situations.

Contingent valuation questions form the fourth module. The contingent valuation questions increase in complexity, beginning with simple questions involving certainty scenarios and mortality only. Next, serious illnesses are introduced, and respondents are asked their willingness to pay to eliminate the risks of getting diseases. These questions are followed by life path scenarios that combine morbidity and mortality in a life cycle setting. Alternative life path possibilities are presented, and respondents are asked to choose among and value them, first in a certainty and then an uncertainty setting.

It is believed that the approach developed in section 4, and the extensive preparation for obtaining expressions of willingness to pay described in the modules, constitute an advance in survey research on the values of health improvements, and that intensive empirical applications are needed.

4.2. DEFINING AND MEASURING HEALTH OVER LIFE

4.2.1 Overview

Health measurement is an essential part of any analysis of the values that people derive from policies affecting health. Several different methods of health measurement have been employed in the literature. Self-assessment is the most widely used measure of health status. People are asked to rate their own health as excellent, good, fair or poor. This approach has been used in the Center for Health Administration Studies national surveys and in many smaller household surveys.

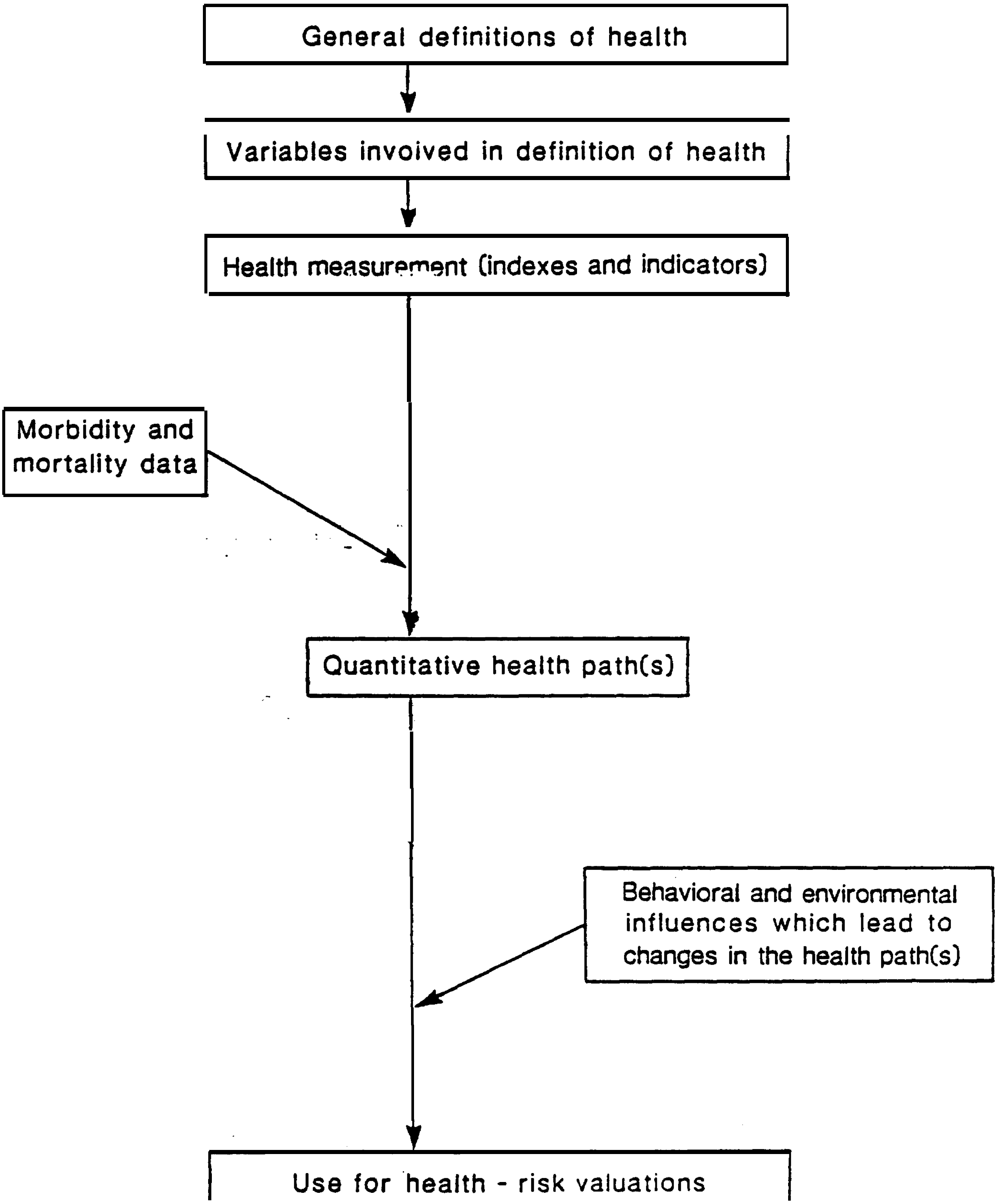
Other frequently used approaches include reports of restricted activity days, bed disability days, number and severity of symptoms experienced, number of chronic conditions, and the amount of pain experienced by the respondent during the past year. A variety of attitude questions have also been used, such as perceived effectiveness of health care [Fuchs, 1982, pp.144-145]. Studies of the demand for health care have utilized these measures of health status. These studies have included non-market health related activities as well as expenditures on medical care consumption. They have focused on such topics as price and income elasticities of demand and the effects of insurance on medical care consumption. Health status is often an important variable in explaining the demand for health care.

Recent work has emphasized that health is a multi-dimensional condition whose complexity should be represented in health studies in order to avoid bias in the measurment of price and income elasticities and other important variables. The multi-attribute utility function is an example of the multi-dimensional approach. A study of Torrence et al. [1982] represents health according to four dimensions: morbidity and physical activity; self care and role activity; emotional well-being and social activity; and health problems [Chestnut and Violette, 1984].

In studying values associated with life threatening illness in this study, it is necessary to define and measure health, choosing among the previous approaches and building on them where necessary. Figure 4-l depicts the progression from health definition to use of morbidity and mortality data and knowledge about influences on health, to measurements for health risk valuations. Drawing on this schema, the present section provides a critique of previous approaches and suggests extensions, giving attention to conceptual adequacy and practical considerations in valuing serious illness.

Section 4.2.2 considers alternative health definitions. Attention is given first to definitions that consider the dimen-

FIGURE 4-1. HEALTH DEFINITION: STEPS TOWARD QUANTIFICATION



sions of health in terms of various attributes which may be good and desired or alternatively may be bad and undesired. Definitions of varying broadness are examined. Attention is given second to definitions of health that focus in detail on symptoms or departures from good health, rather than desired attributes.

Section 4.2.3 considers the relevance to the measurment problem of causal factors affecting health. Attention to heredity* lifestyle and environment as causes of disease helps to arrive at judgments as to which health attributes should be emphasized. The view taken here is that definition and measurement should depend on the purpose at hand. In this study, the major purpose is to consider serious illnesses associated with environmental causes.

Section 4.2.4 turns to health measurement per se. Self-rating of health, the health risk appraisal approach and various approaches to measuring specific symptoms are considerd in detail.

Section 4.2.5 considers the implications of the preceding sections for empirical work on values associated with serious illness. A critique of approaches to health measurement from the point of view of their adequacy for the valuation of serious illness is given. Criteria include familiarity of respondents with symptoms, ability to encompass risk, adequacy in terms of the effects of serious illness on life cycle experiences, brevity and simplicity. Refinements and extensions to previous approaches to health measurement are suggested.

4.2.2. Alternative Health Definitions

Health is a key determinant of the quality of life. Central to the valuation of health is an understanding of the nature of health and the forces that influence it. Essential to this effort is the definition of human health such that deviations from the conditions it describes can be quantitatively described. While most people have an instinctive comprehension of what constitutes "health," few explicit working definitions are in common use. A multitude of biological, behavioral, cultural and social factors combine to shape human health--factors which act in both favorable and unfavorable ways to determine the level of well-being of a person at any point in time. "Death" is easily and explicitly defined as the end or extinction of'life. "Morbid" indicates diseased, sick, or unhealthy. But the definition of health itself is much more elusive, particularly when quantification is desired. Webster defines health as "physical and mental well-being," "soundness," and as "vitality," "prosperity," and "flourishing condition." Health is thought of also as simply the absence of illness or morbidity, i.e., a biological state dependent upon biological factors. As Banta (1981) points out, other more recent definitions of health also stress life functioning, mental state and self fulfillment. Hoyman (1965) explains that "health is a process of continous change or adaptationthroughout the human life cycle. In fact there is no single definition of health, although many definitions have been developed and are currently in use."

Carroll, Miller and Nash (1976) push the definition beyond absence of disease or discomfort to the ability "...to function effectively, happily, and as long as possible in a particular environment." A statement issued by the World Health Organization describes health as a "state of complete physical, mental and social well-being, and not merely an absence of disease" though this may be a statement of goals rather than a definition (Hanlon and Pickett, 1984). Great Britain's Royal Commission on the National Health Service aptly summed up the debate by declaring that "health itself is not a simple concept." Clearly, health is much more than mere absence of disease, and it has extremely great value.

Another related concept which is undergoing a change in meaning is that of "medical care," which traditionally has meant the provision of medical services by, or under the direction of, physicians. In recent years, the emphasis of such care has broadened to include preventive, as well as strictly curative, measures to preventive actions -- albeit still provided by the physician in a clinical setting.

Broader still is the term "health care," no longer the exclusive, province of the clinical physician. The term "health care" has come to replace "medical care" in many instances. Other new terms such as "health promotion," "health maintenance," and "disease prevention" have come into use (often interchangeably) to characterize the new preventive focus of health care which includes measures to be undertaken by individuals themselves. The Surgeon General's Report (1979) describes disease prevention as the protection of people from the harmful effects of health threats (diseases, environmental hazards). Health promotion measures are aimed, at well, as well as ill, people (promotion of activities to improve lifestyles).

Perhaps the most far-reaching of the new health concepts are "wellness" and "high-level wellness" (Ardell, 1977; Travis, 1977), which can be defined as "active processes through which the individual becomes aware of and makes choices toward a more successsful existence" (Hettler, 1981). Indeed, individuals are becoming increasingly aware of the merits of promoting their own health; sizable investments in time and other resources are being made.

Given the array of similar terms and definitions introduced above, an attempt to visualize these conceptual relationships suggests a health continuum described by Brubaker (1983). From this point of view, illness and death lie atone end, wellness at the other, while an individual's state of health is characterized by any degree of illness or wellness. Hettler offers a somewhat exapanded representation of the health continuum, adding terms to describe social well-being and ability to function within a society.

4.2.3. Role of Causal Factors

4.2.3.1 Background

Causal factors in health include hereditary, lifestyle and envionrmental factors. The causal factors are relevant to the definition and measurement of health, primarily because they determine the strength of various health attributes, which helps to distinguish the important from the unimportant. For example, if environmental change affects the incidence of cancer, then cancer symptoms and not the entire range of health attributes will be a principal focus in a study related to the environment. Among cancer symptoms, the degree of refinement of measurement of physical pain versus mental anguish will be determined by the relative strength of these attributes among cancer victims. Furthermore the causal factors determine how greatly a policy will affect health attributes, which in turn determines the range of change in health attributes that need to be studied.

As noted, health is influenced by a great number of forces, which can be described as hereditary, lifestyle, and environmental. Health can be seen as a process of continuous adaptation to the effects of these forces (Carroll, Miller, and Nash,). The nature of these influences and their relative importance to human health have been described by Hettler and by Blum . Health is described as an indivisible whole comprised of somatic (physical), social, and psychic (mental) well-being: illness in any one of the three facets affects the other two.

Of primary concern to the valuation of risk reduction are the environmental and- behavioral influences on health, and, to a limited extent, medical or health care. Heredity, though important, will not be given further attention here. Furthermore, the definition of environment outlined by Blum encompasses education, culture, and politics, factors beyond the scope of this study. For our purposes, environment consists of the interaction between human health and physical factors, such as air and water quality stressors, toxic substances present in the ambient environment, workplace hazards, radiation exposure and accidents. We assume that these aspects of the physical environment are partly under the control of an individual. Behavioral factors are under even greater control of the individual, and demonstrably influence personal health (Somers, 1980).

Some generally accepted conclusions are:

1. Everyone is endowed with certain health assets at birth. These may be above or below averages for the population in general. Regardless of initial birth endowment, however, the health of an individual is subject to change.

2. Interventions can influence the health of each individual either positively or negatively. Some interventions will have an immediate effect on health level (e.g., an automobile accident); the effects of other interventions may not manifest themselves until years after the intervention (latent effects of cigarette smoking, for example). These examples are illustrated in figure 4-2.

3. Health changes can be temporary and reversible, such as those associated with a common cold or exercise, or the health change can be permanent such as loss of a limb or contraction of emphysema.

4. Interventions may be voluntary, involuntary, or something in between. Cigarette smoking clearly is voluntary, but subjecting oneself to the risks of living near a hazardous chemical facility may be either voluntary or involuntary, depending on the amount of information available to the risk taker.

5. The health path will, at some point, terminate in death. For an individual, this termination can occur at any age, regardless of health.

4.2.3.2. Role of Behavior or Lifestyle

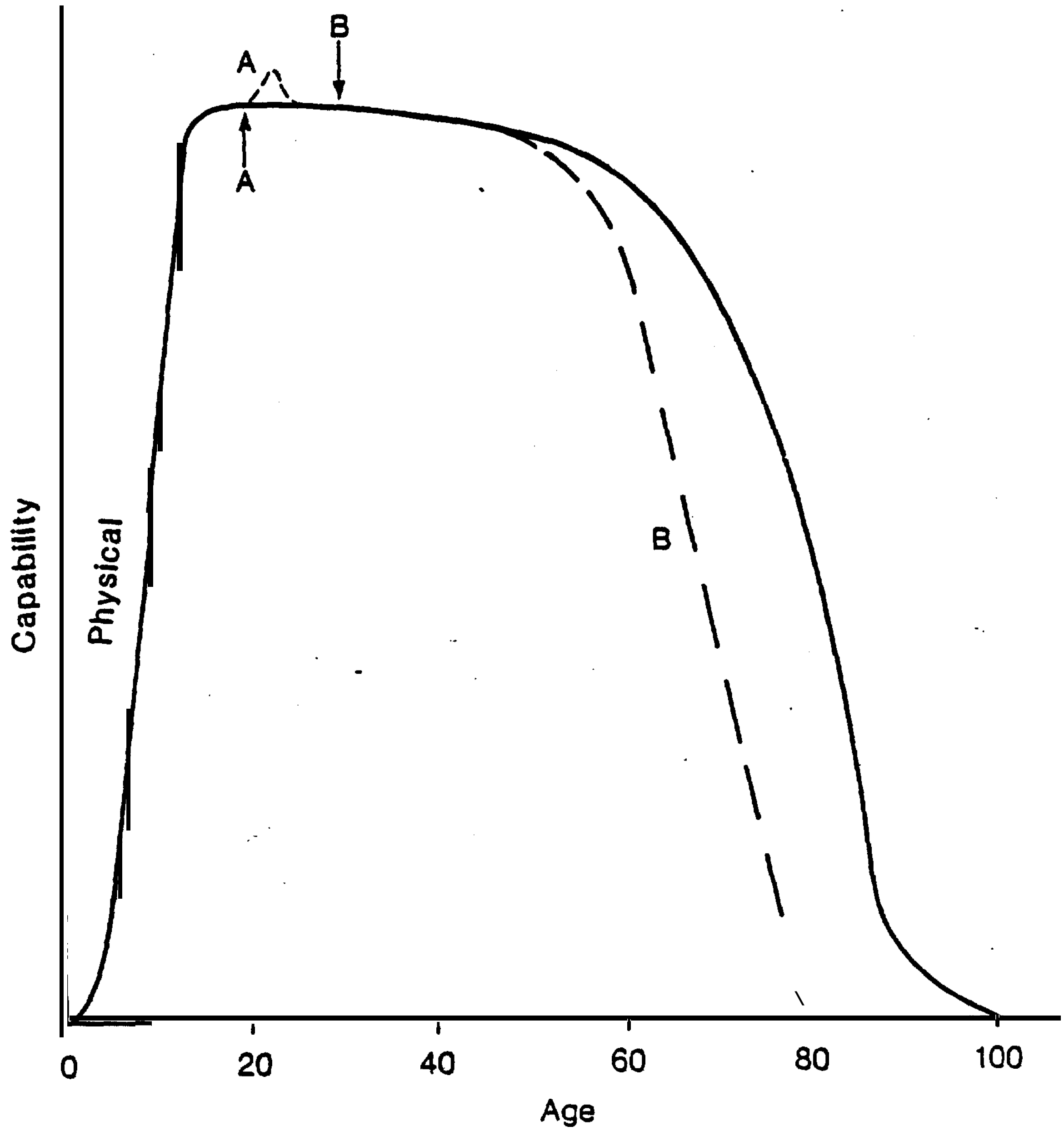
The influence that behavior can have on health has been long recognized, but systematic study and measurement of the implications of human actions on health are recent developments. Behavior patterns, or lifestyles, are at least partly under individual control. Lifestyle is intimately tied to social class and culture -- complex concepts describing characteristics of human interactions whose effect on health is not easily quantified. Nonetheless, it is clear that intervention against lifestyle-induced risk factors can reduce the probability of dying from the major causes of death (Berkman and Breslow, 1983; Klein, 1980; Mausner and Shira, 1984; Somers, 1980).

As Somers affirms, the links between behavior and health can be summarized in three statements:

1. The major causes of death, serious illness, and disability in the United States today are chronic disease and violence (see table 4-l):

2. Most chronic disease, disabilities, and premature deaths are related to a variety of environmental and

FIGURE 4-2. EFFECTS OF INTERVENTION



(A) is a short - term intervention which has an immediate short-term positive temporary effect on health (such as exercise).

(B) is another short-term intervention, but it has a latent but substantial permanent deleterious effect (such as exposure to a carcinogen).

TABLE 4-1. DEATH RATES: Leading Causes of Death, United States, 1979*

Cause	Rate/100,000 Population	Percent of All Deaths
Diseases of heart	333	38
Malignant neoplasma	183	21
Cerebrovascular disease	77	9
Miscellaneous chronic diseases**	56	7
Accidents, including motor vehicle, suicide, and homicide	70	8
Other	151	17
All causes	870	100

* Figures Rounded

** Diabetes, cirrhosis of liver, arteriosclerosis, bronchitis, emphysema and asthma, nephritis and nephrosis, peptic ulcer

From National Center for Health Statistics: General Mortality Statistics, 1979, Volume II, Part A.

behavioral factors,, which may be preventable;

3. Lifestyle pattern is the major behavioral risk factor **involved** in chronic disease contraction and disability (Somers).

No matter how comprehensive a nation's programs of enviornmental monitoring, or how extensive its health care services, the individual is ultimately responsible for minimizing threats to his health (Mechanic and Cleary, 1980). Factors such as smoking, alcohol and drug abuse, lack of exercise, reckless driving and failure to use seat belts can have considerable effects on health status and life expectancy (Breslow, 1978; Breslow and **Enstrom**, 1980; Mechanic and Cleary, 1980). This is not to say that people can easily correct negative behavior, because they are a part of the larger society and influenced by its institutions, which offer ambiguous messages about what is advisable behavior (Blum,; Surgeon General's Report,). Nonetheless, a willing individual can take steps which will measurably affect health status.

4.2.3.3. Role of Environment

Nature of Cause-Effect Relationships

Several approaches that relate environmental stressors'to health effects have been considered. While the present research is concerned with valuing health consequences, and not with environmental cause-effect relations as such, some attention to cause-effect relations is needed.

In the following sections, the source-receptor-effects system is described. Inventories of some of the pollutants receiving considerable study and public attention during the past 15 years are presented. The extreme uncertainty of cause-effect relationships is indicated. The relationship between the present section and section 3.2 on cause relations may be noted. Section 3.2 contributes to the study of light symptoms. It is more quantitative and has greater depth on a narrower range of pollutants than the present section. The present section serves as an introduction to a wider range of pollutants needed for the study of serious illness.

With few exceptions, the existence of causal relationships between pollution in the ambient environment and disease is difficult to quantify. Problems arise in attempting to relate exposure to a suspected agent with the development of illness, particularly if the illness is preceded by a long latency period (Task Force, 1982).

Figure 4-3 summarizes the complex path between a source of pollution and a variety of possible health effects including death. Moving down the diagram, the source of pollution may be industrial, residential, natural, etc. The emission may be from air, water, land, or a combination of media. The pollutants are likely to be diluted, transformed, and partially decayed before reaching exposed human receptors.

Note that defensive measures may be applied at the source to reduce the amount of, or entirely eliminate, the emission; other personal defensive measures may be applied prior to exposure (migration, air conditioning, etc.).

After or during continuous exposure it is likely there will be a finite latency period before adverse health effects, if any, appear. Uncertain and often lengthy latency periods make exposure-effect determinations very difficult.

The adverse effects, by definition, include any departure from optimal health. They range from almost imperceptible discomfort to terminal lung cancer. These adverse effects might be defined either as groupings of symptoms or as a clearly identified disease. Defensive and/or curative measures may reduce the effect of disease, but the adverse environmental effects may still be present. Adverse effects are not discretely divided into morbidity and mortality, but rather, the effects are seen to influence a health continuum which begins with optimal health (that existing in the absence of pollution) and ending with death.

Even prior to exposure, however, health can be adversely influenced by factors other than pollution, such as age and previous medical history. Each person exposed, at a different point on a different route, will die. The ch-allenge is to define the environmental influence on each path of mortality.

There is uncertainty at each linkage. Rosen (1981) concludes, "The most pressing need is for better estimates of risk valuations. That 'pressing need' would require much better data than currently are available."

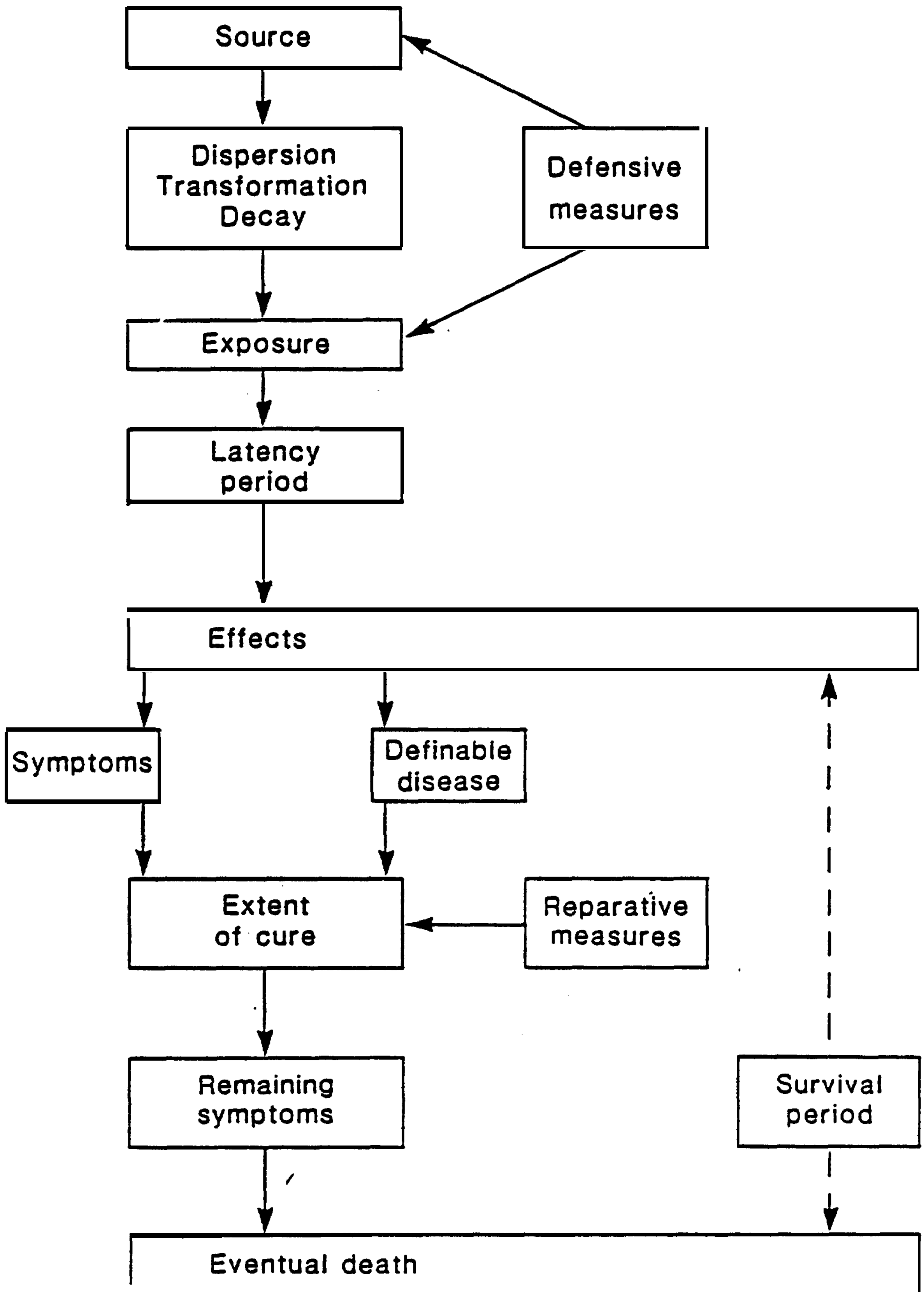
In summary, the complexities involved in establishing direct cause-effect relationships include:

Exposure to a toxic substance which may occur through direct contact with contaminated soil, water, air, food, or in the workplace;

The substance may be absorbed through the skin, ingested, inhaled;

Contact may be brief, prolonged, on single, multiple or continuous occasions;

FIGURE 4-3. POLLUTION-HEALTH RELATIONSHIP



The effects may be manifest very shortly after exposure or, as in the case of carcinogens, many years later;

The substance may act synergistically with other agents to produce illness, such as asbestos exposure combined with cigarette smoke;

The existing health status of the exposed person may affect the development of illness.

Of the harzards to human health arising from toxic substances, cancer is the target of most concern. It is the only major cause of death that has continued to rise since 1900, and is responsible for the loss of 400,000 lives each year. Some of the increase in cancer mortality since 1900 is a function of the greater average age of the population and the medical progress made against infectious diseases. But even after correcting for age, both mortality rates and incidence of cancer are increasing.

It is extremely difficult to assess the role that environmental factors play in causing human cancer because people are exposed to multiple stressors of both physical and chemical natures, some of which are related to their own behavior. Some early estimates of the proportion of cancers directly attributable to environmental agents were as high as 85-90 percent, but more recent analyses suggest that the role of environmental health pollutants is minimal (Task Force, 1982). This finding is supported by Doll and Peto (1981) who compare environmental and behavioral risks and conclude that the environmental and occuptional risks are relatively minor.

Much of what is known about the acute and chronic health effects of chemical substances has come from studies of workplace exposure. Many workers die each year as a resultofphysical and chemical hazards at work, but the exact magnitude of the long-term health effects of occupational conditions is unknown (Toxic Substances Strategy Committee, 1980).

Complex human epidemiology over a lifetime seems essential if progress at unravelling the cause-effect complexities is to be made. Animal studies are a poor substitute for human study because of the low ambient concentrations of toxics and long latency periods. In addition, animal studies cannot be used for annoyance symptoms (e.g., cough, headache).

The kinds of research needed to define environmental health risks are described in-depth in a report for U.S. EPA (Babcock and Allen, 1982).

Health Effects of Selected Environmental Contaminants

The following is a list of some of the most persistent and widespread pollutants which are of continuing concern to public health. The list resulted, from a review of (1) the first thirteen annual "status" reports of the Council on Environmental Quality, which examine the environmental issues of greatest concern to the government and public, (2) recent summary reports and literature of governmental agencies and other researchers in the field of environmental health, and (3) current toxicology references. (See Council on Environmental Quality, 1970-82; Duffus,1978; First Report on Carcinogens, 1980; Hamilton and Hardy's Industrial Toxicology, 1983; Handbook of Hazardous Materials, Fire-Safety- Health, 1983; Patty's Industrial Hygiene and Toxicology, 1978; Toxic Substance Strategy Committee, 1980; Waldbott, 1978). The inventory includes some substances which are ubiquitous in environment, but the health effects of which are uncertain, particularly with regard to long-term, low-level exposures. It must be stressed that the health effects listed below are associated primarily with chronic or acute exposure levels found in the workplace, and usually not in the ambient environment.

Asbestos is the generic name for several varieties of naturally occurring fibrous minerals which are heat, friction, and acid resistant, and are flexible and strong. They are used primarily in cement, fire-proofing, in formation of pipes and ducts for air, water and chemicals, brake pads and linings, roofing, garden ornaments, and furniture. Exposure can lead to pulmonary fibrosis (asbestosis), cancer of the lung, and the chest or abdominal cavity, and gastrointestinal carcinoma. Symptoms of respiratory illness include unexplained breathlessness upon exertion, cough, tightness of the chest, skin discoloration, enlargement of fingertips.

Arsenic is released in the combustion of coal, the manufacture of insecticides, herbicides and fungicides. It is present in the ores of copper and iron, and is oxidized during smelting. It is inhaled, ingested, and absorbed through the skin. It has been associated with cancers of the skin, lungs, and liver, as well as birth defects, nausea, diarrhea, stomach pain and constipation.

Benzene is the basic chemical of the group called aromatic hydrocarbons. It is used in the fabrication of paints, adhesives, dyes, plastics, chemicals, detergents, and pesticides, as an additive to gasoline, and in synthetic rubber manufacture. Benezene accumulates in the bones and fatty tissue of humans, and is a cause of leukemia, blood cell deformations, and is a depressant to the central nervous system. Drowsiness, headache, vertigo and nausea are associated symptoms.

Beryllium is a' metal that is resistant to heat, mechanical stress. It is both light and hard, has high conductivity, and is non-magnetic. It is used in a variety of industrial processes, aircraft engines, electric heaters, copper products, steel, cobalt, and nuclear power production. It has been associated with bronchitis, bronchiolitis, berylliosis, fibrosis, heart damage, pulmonary edema, and death. Symptoms include irritation of the upper respiratory tract, fever, chills, cough, sputum, shortness of breath, and weight loss.

Cadmium is a soft, ductile metal resistant to corrosion, and is used inelectroplating, manufacture of polyvinyl chloride, jewelry, soldering, batteries, aircraft engines, and automobiles. It is a contaminant of the soil, air, water and food. Symptoms include vomiting, diarrhea, colitis, hypertension preceding heart disease, chromosomal abnormalties, and death.

Motor-vehicle emissions are the largest source of carbon monoxide. Cigarette smokers experience extremely high'levels during smoking periods. Regardless of source, the exposures usually are temporary, with temporary displacement of oxygen in the blood stream as the primary health effect. Symptoms include headache, dizziness, nausea, impaired judgment, fatigue, and unconsciousness. Effects appear to reverse quickly at levels found in the ambient environment.

DDT is one of the group of persistent chlorinated hydrocarbon insecticides. It accumulates in the tissues of aquatic organisms, birds and other animals and plants which are part of the human food chain. It is present in soil, water, air, and food supplies. The long-term health effects of DDT on humans are uncertain, although it acts as a potent neurotoxin on insects and other animals. It is fat-soluble, and accumulates in the fatty tissue of humans, degrading very slowly over many years.

Dioxin, or 2,3,7,8 tetrachlorodibenzo-p-dioxide (TCDD), is a by-product which appears during the manufacture of herbicides. Again, its low-dose long-term effects on humans have not been established, but it is known to cause birth defects, miscarriages, fetal death and other reproductive disorders in animals. Agent Orange, the defoliant used extensively during the Vietnam War, contained TCDD. Chloracne is a skin condition resulting from acute exposure which is characterized by swollen eyelids, fingertips, and mucous membranes of the eyes and mouth.

Sources of ionizing radiation are both natural (sun, soil), and human induced (nuclear energy, weapons, isotopes from medicine and research). Exposure can result from internal or external sources, and through inhalation or ingestion. The various radionuclides can cause genetic mutation, chromosomal damage, impaired cell division, leukemia, cancers of the skin, lung, bones and genitals, cataracts, shortened life span, and death. Symptoms of radiation poisoning include loss of hair, skin ulcers, diarrhea, purpura, and skin hemorrhages.

Lead is an ubiquitous metal found formerly in paints and currently in batteries, gasoline, insecticides, pottery glaze, metal cans, and numerous industrial commercial products. It is found in the air, water, soil, and food. Lead contamination can lead to kidney disease, jaundice, gout, neurological disorders, convulsions, brain damage, sterility, premature birth of children, and death. Symptoms range from fatigue, weakness, headaches, and restlessness, to stomach and abdominal pain, lethargy, sleeplessness, vomiting, diarrhea, and hallucinations.

Mercury is found in medicine, dental fillings, fungicides, paint and paper manufacture, diapers, coal combustion, asphalt production, municipal incineration, electrical apparatus, and plastics. Health effects include visual impairment, brain damage, and fetal poisoning; symptoms such as tremors, skin eruptions, abdominal and muscle pains, and visual disturbances occur.

The principal anthropogenic sources of nitrogen dioxide are the combustion of coal, oil, natural gas, and motor vehicle fuel. Exposure can cause lung irritation, increased susceptibility to respfratory infections, pulmonary edema and death in extreme cases.

Organochlorine compounds (other than DDT) include aldrin, dieldrin, chlordane, and heptachlor, and have been used for many years in agriculture and malaria control programs. They are persistent in the environment, are biomagnified in the food chain, and are mutagenic and toxic to animal, life. The acute effects include liver damage and convulsions, with manifestations similar to those of DDT. The long-term effects of low-level exposures are not well known.

Ozone is an important constituent of photochemical smog, resulting from the reaction of nitrogen oxides and hydrocarbons in the presence of sunlight. It acts as an irritant to the mucous membranes of respiratory organs, and aggravates existing respiratory illness. Other effects include eye irriatation, impairment of cardiopulmonary function, and headaches.

PCBs (polychlorinated biphenyls) are chemical compounds which are nonflammable and highly plasticizing. They are used as heat transfer fluids and insulators, and in paints, adhesives, sealants, brake linings, flourescent lamps, electrical transformers, and capacitors. Like DDT, **PCBs** accumulate in fatty tissue and are slow to degrade: consequently, the long-term effects on humans are uncertain. The acute health effects include chloracne. Other symptoms include loss of hair and sexual power, headaches, numbness, abdominal pain and vomiting, deformed nails, joints and bones.

Soot, tar, and oil are the products of coal mining and combustion, and of the asphalt, tar and pitch industries. They usually contain polycyclic hydrocarbons and are associated with cancers of the lung, larynx, skin, scrotum, and bladder.

Anthropogenic sulfur dioxide is almost entirely a'result of combustion of coal, wood, and petroleum products. In the atmosphere, this pollutant can cause bronchial constriction, irritation of. the upper respiratory tract, eyes and ears, tightness in the chest, and can aggravate existing bronchial conditions. Damage to other environmental systems (acid deposition) **may** be the primary adverse impact.

Vinyl chloride is the main constituent of polyvinyl chloride, which is used in a variety of plastic products such as pipes, ducts, floor tiles, toys, waterproof upholstery, wrapping paper, film, records, boots, and sporting goods. Exposure to the **gas** can lead to liver cancer, acre-oteolysis, pulmonary teratogenic, mutagenic and chromosomal effects.

4.2.4. Health Measurement

4.2.4.1. Measurements in Terms of Ill Health

Levels of morbidity are commonly classified as a series of five **"D's"**: disability, discomfort, discontent, disease, and death. Available evidence argues that trace environmental pollutants have their greatest impact on the first four "D's," although they **may** contribute to premature death as well.

Nationwide surveys of Americans provide information on prevalence of diseases and various health indicators. For example, the National Health and Nutrition Examination Survey (NHANES) clinically examines 20,000 different people every four years. A variety of health, nutritional, and disease prevalence information is obtained.

The National Health Information Survey (NHIS) provides data concerning the prevalence of disease. NHIS surveys more than 100,000 people per year, but the survey is restricted to question-answer interviews rather than examinations. These tabulations don't specifically indicate numbers of people who suffer from more than one malady or from the same malady more than once in a year. Likewise, there is no information about numbers of people who escape all the diseases. These surveys are cross sectional; they do not follow individuals through life. However, such information is useful for construction of likely scenarios which exhibit certain diseases during a lifetime.

In practice, many health status measurements are based on functional classification or therapeutic considerations involving diseased or disabled persons, **not** those who are well. That is, the definition is in terms of ill health, notgoodhealth.

Mausner and Kramer (1984) point out that "the development of disease is an irregularly evolving process, and the point at which a person should be labeled 'diseased' rather than 'not diseased* may be arbitrary." Left untreated, a disease may extend over time **with symptoms** changing in stages. This pattern may be **termed** its "natural history' or "clinical course." In relation to age, "...factors favoring the development of chronic disease are often present early in life, antedating the appearance of clinical disease by many years." The Mausner and Kramer framework for analysis of disease history follows.

Stage of susceptibility: Prior to the presence of a disease, factors which may increase the probability of its development may be present. These are termed risk factors. Age, sex, and race are examples which are not susceptible to human intervention, but alcohol or tobacco use can be subject to change. The presence of risk factors does not ensure disease development nor does their absence ensure freedom from disease.

Pre-symptomatic stage: Pathogenetic changes begin to occur, but the changes are not manifested in symptoms or signs which can be diagnosed.

Clinical stage: Recognizable signs and symptoms occur. It is at this point that classifications of health status based on functional or therapeutic considerations are made. Examples for categorization of cardiac disease appear below.

. Functional Classification:

Class I — No limitation of physical activity because of discomfort;

Class II — Slight limitation of physical activity; patient comfortable at rest but ordinary activity produces discomfort;

Class III — Marked limitation of physical activity; comfortable at rest but less than ordinary activity causes discomfort;

Class IV — Inability to carry out physical activity without discomfort.

Therapeutic Classification:

Class A — Physical activity need not be restricted in any way;

Class B — Ordinary physical activity need not be restricted, but patient is advised against severe efforts;

Class C Ordinary physical activity should be moderately restricted;

Class. D Ordinary physical activity should be markedly restricted;

Class E Complete bed rest advised; patient confined to bed or chair.

Descriptions of the natural history of the disease can be incorporated into indicated health effects. Lung cancer provides an example as follows:

1. The time when an individual is at no risk: either has not been exposed to the disease-causing agent (e.g., does not smoke or work with asbestos), or has been exposed the agent but is not vulnerable to it (e.g., even in the presence of smoke, newborn infants are not vulnerable to, and will not develop, lung cancer);

2. When one is vulnerable due to genetic propensities or a change in age or environment and therefore does not have an immune status;

3. When the damaging agent is present, at which time the exposed individual is in danger of acquiring the disease (e.g., anyone who smokes);

4. When an actual sign of disease is observable by a physician though not apparent to the victim (e.g., an abnormal chest x-ray);

5. When symptoms appear (severe coughing, chest pains, blood in sputum) and the individual, who knows that something is wrong, may tell a physician or other health worker; or

6. When disability, partial or complete, occurs.

The natural histories of many diseases are still unknown. In addition, some people never develop a disease despite the presence of a number of risk factors.

The listed functional classifications might be expanded into health indexes by defining various levels of minor discomfort and pain, and minor limitations of physical activity. Some health problems attributed to environmental interventions include learning impairment, peripheral neuropathy, and birth defects.

More simply, however, the history of the diseases provides descriptions of symptoms and consequences which could be quantified to a more or less exact degree depending on considerations of measurement feasibility in view of a particular study purpose.

4.2.4.2. Health Indexes

The health definitions discussed in Section 4.2.2 above suggested that a person has neither absolute health nor absolute illness (except death) but is in an ever-changing state and that one can be at any point on the continuum at any point in life (Murray and Zenthel, 1975). For some purposes it would be useful to quantify a health continuum, first numerically and then in terms of economic valuation of small increments of change. Initially efforts would focus on the simpler Brubaker health continuum, but the expansions by Hettler into risks and education might also possibly be useful in contingent valuation studies.

Howard (1984) defines morbidity as a fraction of death. This principle might be applied to a health index. Some of his methods involve trading years of life for improved health. He argues that there are no fates worse than death. Kane and Kane (1982) disagree.

Pulmonary function tests are used to measure lung capabilities (Babcock and Nagda, 1976). These and other physiological tests (exercise, work level, physical education performance, etc.) might provide another type of index.

4.2.4.3. Multi-Attribute Utility Functions

Researchers in the field of decision analysis have devised techniques for the characterization or prediction of health status (Katz et al., 1983; Wolinsky, et al., 1984), usually for the evaluation and comparison of health care treatment alternatives or medical policy decisions. Quantitative methods such as multiattribute utility functions (Keeney and Raiffa, 1976), or linear analog scales (Sutherland, Dunn and Boyd, 1983), are employed to evaluate the nature of trade-offs between quality of life and longevity (Pliskin, Shepard and Weinstein, 1980) or to measure a patient's preference for certain health states (Torrance, Boyle and Horwood, 1982). Such analytical methods may involve complex, lottery-based measurement techniques to determine probabilistic outcomes.

Boyle et al. (1982) employ a multiattribute health state classification system for use in a cost-effectiveness analysis of neonatal intensive care. Health status is defined by physical function, using measures of mobility and physical- activity; role function, or self-care, such as the ability to eat, dress or bathe with or without help; social-emotional function, measures of emotional well-being and social activity; and health problems, such as the presence or absence of a disability.

4.2.4.4. Self-rating of Health

As noted in Section 4.2.1, self-assessment is the most widely used measure of health status. The simple ranking of one's health (excellent, good, fair or poor) is crude in terms of being amenable to dollar quantification. However, the measure is simple, which makes it attractive especially for contingent valuation studies. While self-rating may not be useable for obtaining a value measure, it may be useable as a shifter in a function explaining health values, since the state of one's health is an influence onhowmuch one is willing to pay to avoid various specific symptoms or diseases.

4.2.4.5. Health Risk Appraisal

Health Risk Appraisal (HRA) is a tool for assessing the potential impact of individual behavior on the probability of dying from selected causes. In the course of an HRA, information about an individual's lifestyle and personal and family health history is elicited. This information is then compared with age, race and sex-specific mortality data and epidemiologic statistics to determine whether or not a person is a greater or less than average risk of dying from a selected cause, usually within the next ten years. Most HRAs are based on the work of Robbins and Hall and the statistical tables of Geller and Gesner (cited in Robbins and Hall). The objectives of the appraisal are to estimate individual risk with some degree of accuracy, and, by identifying risky behavior, help individuals modify or eliminate negative habits before the development of disease or disability (Dunton, 1981; Goetz, Duff and Bernstein, 1979; Hettler, 1981; Schultz, 1984).

The appraisal begins with a self-administered questionnaire. Each response is assigned a numerical "risk factor" which is then multiplied with the average risk of dying from each major cause of death. In the case of multiple risk factors for a single cause of death, a "composite risk factor" is calculated and then multiplied by average risk. The resulting disease-specific risk projections are then summed to form a "total projected risk." This is then compared to average risk to yield a new term "risk age" or "appraised age," i.e., the age of an average person with the same mortality risk as the respondent (Hettler).

This appraised age can be readily compared with actual age. If the total risk is greater than average (appraised age greater than the actual age), appropriate behavior modifications are suggested. If the suggestions are followed, the individual can hope to lower the overall risk projection, as expressed by the value of the "achievable age" (Hettler,). For example, a 34-year old may have the risk characteristics of a 30-year old (appraised age) but an achievable age of 29.

It is important to recognize that HRA instruments are, despite widespread use, still in an early stage of development. Concern has been expressed about the quality of the data elicited by a self-administered questionnaire and the accuracy of the risk (Fielding, 1981; Hettler, 1981, pp. 7-16; Sacks, Krushot, and Newman, 1980; Schoenbahh, Wagner and Karon, 1983.)

4.2.5. Implications for Valuing Serious Illness

The approaches to the definition and measurement of health that have been reviewed in this section serve to bring out the complex nature of this subject matter. The question becomes: How are we to measure health in the present study in view of the complexities?

A first implication that stands out is that measurement in terms of ill health is appropriate in view of the concern of the present study with values of eliminating undesirable environmental effects. As reviewed in Section 4.2.3, the possible diseases and symptoms caused by environmental pollutants can be described rather definitely in terms of ill health effects.

A second implication is that a broad definition of health effects is needed, extending beyond physical pain to mental well being and beyond this to the functioning of the individual. Conceptually one wants to value all the significant deleterious effects of the illnesses being studied.

Third, the fact that broad classes of illness are to be studied among many people in the population means that a basically simple approach must be followed. People must be able to think meaningfully about the measures, and it must be feasible to take the measurements and analyze them operationally as they pertain to large numbers of people. While the first and second implications go in the direction of detail and complexity, the third implication indicates that compromises with the first two implications will have to be struck.

If we look ahead to ensuing sections of this study, additional implications are obtainod. Thus a fourth implication is that the present state of health may affect values attached to contracting particular diseases. It is important to relate changes in health status to existing levels of health. A fifth implication is that a person's entire stream of life experiences with and without a disease affects hov the disease is valued. A person's age is particularly relevant, as is his expectation as to the course of events in his life without the disease. Sixth, one must look beyond health effects encountered with certainty to situations of uncertainty. Most people will never contract the diseases being considered. Environmental improvements will reduce the probability of contracting the disease. Health measurement must give attention, not only to certainty scenarios, but also to risk reduction in the context of uncertainty scenarios.

The first, second and third implications help in choosing between existing health measurement approaches. The third, fourth and fifth implications indicate needs for extensions and refinements of these approaches. Finally, the fact that the present study gives particular emphasis to devising contingent valuation approaches to serious illness affects choice of health measures.

One of the clearest conclusions from these implications is that measurement in terms of ill health effects is called for in the present study. In view of the need for operational simplicity, symptom descriptions in terms of average conditions brought about by a disease are the basic approach recommended here for studying values connected with serious illness. The symptom descriptions need to be supplemented by allowance for full effects of the symptoms on mental well being and functioning of individuals. In a contingent valuation approach, this can be done by making the respondent aware of a wide range of effects of the symptoms.

For getting at the effects of existing health levels on valuations, self rating of health has much to offer. It is more readily available than more sophisticated measures, and the need for precision is less great for measuring the existing health level than the specific effects of the disease being valued.

The health risk appraisal approach, which takes the trouble to relate highly specific individual characteristics, including age and lifestyle factors to health prospects, is highly congenial to the framework of the present study which stresses the importance of life experiences and alternative future life path scenarios. It plays a prominent role in some of the approaches to health valuation developed later in this study.

The multi-attribute utility function approach has much to recommenditconeptually for some purposes, but it is not used in this study, largely because it apears operationally too complex for this study. Respondents in contingent valuation experiments can and should be encouraged to take account of the multi-faceted nature of health effects in framing responses, which is consistent with multi-attribute utility functions. But to quantify the utility function as such is not attempted in this study, which is concerned with going directly to dollar valuations of the sum of all the effects of an illness.

The later parts of this study build on the choices among existing health measures implied by the above remarks. Refinements to the health measurement approaches are developed takfng account of individual circumstances in a life cycle context with certainty and uncertainty scenarios.

4.2.6 References

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4.3. THE QUANTITY AND QUALITY OF LIFE: CONCEPTUAL FRAMEWORK

4.3.1. Introduction

Serious professional interest in cost benefit analysis of projects involving safety, illness and death probabilities has its origins in environmental concerns beginning in the 1960s as a practical policy matter, and in the work of Schelling and Mishan as an intellectual one. These authors showed how to put the problem into the "willingness to pay" framework of applied welfare economics, which has been the guiding principle in economic research in this area ever since. Subsequent research has followed two distinct conceptual lines. Beginning with the important paper by Usher, one line has followed a strictly life cycle framework. Building on the paper by Yaarf, work by Cropper, Conley, Ehrlich and Chuma, and Arthur (this the only general equilibrium paper in the literature) have built increasingly elaborate models of life-cycle valuation criteria. Another line, and one which has tended to guide most empirical work, uses a simplified single period model without explicit regard for life cycle considerations (e.g., Jones-Lee, Rosen, Thaler and Rosen). The single period models are conceptually simpler than life cycle models, but may miss some important considerations that arise in the fully dynamic life-cycle setting which the problem obviously requires.

This section is concerned with life cycle models of safety and health evaluation. One of its goals, at least by implication, is to show the close relationship between life cycle and single period models. This is achieved by stripping away many of the detailed complexities of life cycle dynamics to reveal the internal structure of the problem most clearly and in the most elementary manner. In fact this is most easily done in a deterministic setting, in which a person has a fixed longevity and is allowed to optimize consumption and labor supply decisions over his fixed length of life. The solution to the optimal program naturally leads to a simple formula for putting dollar values on suitably small increments of longevity, using the principles of duality theory. Models of this type are discussed in the following two sections. First a simple consumption allocation problem is analyzed and the valuation equation exhibited. Then the model is complicated in a number of ways. It is shown that most of the principles underlying the simplest model carry through for all variations on the theme. This model may be extended to include valuation of morbidity as well as of longevity.

While deterministic models are useful in their great simplicity, they suffer obvious defects in terms of realism.

Therefore the remainder of the paper turns to stochastic models using actuarial calculus and the insured-consumption-loans device for dealing with intertemporal budget constraints introduced by Yaari. The insurance features of these schemes allow the analysis to separate allocation decisions regarding consumption and labor supply from uncertainty regarding length of life. The exposition brings out the intimate connection between deterministic and stochastic models and shows that the same types of parameters are relevant for both. Chief among these is a parameter which is naturally interpreted as reflecting the inherent substitution between "quantity" (or longevity) and "quality" of life. It is closely related to the economic concept of intertemporal substitution. Estimates of the "values of life" from existing empirical studies allow rough imputations of this parameter, which ultimately relate to the question of how much of the economy's wealth should be spent on safety, health and longevity concerns. Other relevant factors are shown to include the rates of interest and time preference, the level of wealth and the person's stage in the lifecycle.

An interesting implication of this analysis is that personal valuations of life expectancy inevitably vary over the life cycle. This important point is the inevitable consequence of the finiteness of life itself and the effect of discounting. Hence a person who chooses an action when young that affects subsequent mortality may life to regret it-later, in the sense that in the circumstances he finds himself in later he would have somehow "preferred" not having taken the earlier action. However, there is nothing either inconsistent or irrational in this type of behavior, since by hypothesis, the full future consequences of current actions are foreseen when they are chosen. It does mean, however, that the benefit side of any cost-benefit calculation on these matters must take account of the life cycle structure of valuations and will be sensitive to the age and demographic composition of the population and how it changes over time.

4.3.2. The Value of Longevity: Deterministic Model

In this section we consider a deterministic problem which sets many of the essential ideas for the valuation of life expectancy. Consider a person with time-seperable preferences for consumption over a lifetime of length T:

$$U = \int_0^T U(c(t))e^{-at}\,dt, \qquad (4\text{-}1).$$

where the concave function u(c) evaluates the utility of consumption c at time t and a is a fixed and constant rate of time preference. The person is endowed with a fixed wealth W at the beginning of life and has a fixed investment opportunity which yields a return of r. The problem to be considered is how the person would allocate his fixed wealth over consumption at each point in the life cycle. The solution to this problem yields the valuation we seek.

Let W(t) represent remaining wealth at time t and let dW/dt be the change in wealth at time t. Then the budget constraintfacing this person may be written in flow terms as

(4-2) $$dW/dt = rW - c,$$

which has a ready interpretation. rW is the income from investing current wealth at rate of return r and c is the amount that is consumed out of this income. If consumption falls short of current income the person's wealth must be increasing, while if current consumption exceeds current income his wealth must be decreasing.

The formulation of preferences in (4-l) is consistent with the situation of an unattached individual who has no heirs and therefore no bequest motive. We impose the condition that the person cannot die in debt, and since he does not wish to leave wealth (there are no heirs), we have a boundary condition for the differential equation in (4-2) that W(T) = 0. The person will obviously wish to consume all endowed wealth over the entire life cycle. Using this boundary condition and integrating (4-2) yields an equivalent budget constraint in terms of stocks:

(4-3) $$W = \int_0^T c(t)e^{-rt}\,dt$$

Initial wealth equals discounted lifetime consumption.

Consider the problem of maximizing U in (4-l) subject to constraint (4-3). Let V(T,W;r,a) denote the maximum of U given that the sequence c(t) is optimally chosen. Clearly V is a function of the parameters of the problem, which are T, W, r and a. This value function allows us to calculate the value of longevity. Let L denote the value of longevity, defined as the maximum amount of wealth a person would willingly give up to extend his life by a small increment dT. In exchange for an increment dT, the person would be willing to pay as much wealth as would keep V at its initial level. This is therefore nothing more than the marginal rate of substitution between T and W implicit in V. Totally differentiating V and setting the result equal to zero, we have

(4-4) $$V = -dW/dT = \text{partial of } V \text{ w.r.t.} / \text{partial of } V \text{ w.r.t. } W$$

To evaluate this expression it is necessary to first solve the maximum problem.

Associating a Lagrange multiplier **m** with constraint (4-3), first order conditions for maximization of (1) subject to (3) are

(4-5) $$u'(c)e^{-at} = me^{-rt}$$ for all t.

The marginal utility of consumption is proportional to the positive multiplier **m**, suitably discounted by' the difference betweem r and a. To simplify even further, let us analyze the leading case where r = a. Then (4-5) implies u'(c) = **m**, which in turn implies c(t) = c, a constant for all t on [0,T]. That is, lifecycle consumption is "flat" and the same at all ages, an especially pure form of the permanent income hypothesis. Using this result and substituting into (4-l) defines V as (since r = a).

(4-6) V = Integral from 0 to T $u(c)e^{-rt}$ dt = u(c) integral from 0 to

= u(c) integral from 0 to T e^{-rt} dt = $u(c)(1/r)(1-e^{-rT})$

= (by definition) u(c)A(T),

where $A(T) = (1/r)(1-e^{-rT})$ is simply the value of an **annunity** received for T periods at rate of interest r. A(T) is the "correction factor" for finite life.

Now from the budget constraint, after substituting c(t) = c, we have

(4-7) $$W = (c/r)(1-e^{-rT}) = cA(T) .$$

Therefore c = W/A, which is just the finite life-corrected level income which exhausts the endowment W at T exactly. Putting (4-6) and (4-7) together, we have

(4-8) $$V = u(W/A(T))A(T) .$$

There are two immediate consequences of (4-8). First, V is strictly increasing in W:

$$V_W = \text{partial of } V \text{ w.r.t. } W = u'(W/A) > 0;$$

greater wealth makes a person better off. Second, the effect of T is confined to its influence through A. Now A is increasing in T, since an annuitythat lasts longer has a larger value. But A has two effects on V. It has a negative effect through its influence on the first term in u(.) in (4-8) but it also has a direct positive effect through the multiplicative second term in (4-8). Concavity of u(c) implies that the second direct effect dominates and that V is increasing in A:

$$(4\text{-}9) \qquad V_A = \text{partial of } V \text{ w.r.t } A$$

$$= -(W/A)u'(W/A) + u(W/A) = u(W/A)(1-E)$$

where $E = cu'(c)/u(c)$ is the elasticity of the function u(c). We require $0 \leq E \leq 1$ for the problem to be well conditioned and for the marginal condition (4-5) to characterize the optimum. Therefore VA > 0. Though there is no direct value of length of lifetime T in preferences in this problem, its value is induced by its effect on A. From the definition of A(T), we have $A'(T) = e^{-rT} > 0$.

We are now prepared to evaluate v. Totally differentiating (4-8),

$$(4\text{-}10) \qquad dV = u(W/A)A\{(E)dW/W + (1-E)(A'/A)dT\}.$$

Setting (4-10) equal to zero, the value of longevity is

$$(4\text{-}11) \qquad v = -dW/dT = A'(T)[(1-E)/E](W/A) = e^{-rT}[(1-E)/E](W/A)$$

(4-11) displays some interesting properties:

(i) v is increasing in wealth (given E). Longer life is more valuable to wealthier persons and they are willing to pay more to extend it. This is one reason why life expectancy is longer in societies with greater wealth, which spend some of it on safety devices and living styles that promote longevity. Notice however, that in this formulation $-d\log W/dT$ is <u>independent</u> of W: all individuals are prepared to pay the same percentage of their wealth to extend life when preferences are of this form.

(ii) An especially interesting and unusual implication of (4-11) is the role of the term in E, which relates to the curvature properties of the function of u(c). This in turn is related to the question of intertemporal substitution possibilities in consumption. To see this most clearly, let us examine some limiting cases. First, look at what happens in the limit as E goes to unity, so that u(c) goes to a linear function of c. Then according to (4-1), we have that U is essentially summable in c(t) and all that matters to the person is total consumption over the life cycle, andnotatallhowa given total is distributed over ages. One big consumption bash at some time is equivalent to many periods of much smaller consumption levels, for example. Here we have VA = 0, so v goes to zero as well. A person is not willing to pay to extend life when E -1 because the increasedhorizonis completely offset by lower per period consumption: V = W in this case, which is independent of T. This is a case of perfect substitution between the "quantity" and "quality" of life, equivalent to perfect intertemporal substitution in consumption across periods.

At the opposite extreme, consider what happens when E goes to zero. Here the indifference curves in the c(t) hyperplane exhibit "elbows" and fixed proportions (in the E = 1 case they are straight lines), so intertemporal substitution possibilities are nil. Now the person is willing to pay large amounts for greater life expectancy, since each year of life becomes "essential." The main point is that limited substitution of consumption across years of life implies that quantity and quality of life are imperfect substitutes for each other. There is an inverse relation between the value of longevity and the degree of intertemporal substitution in consumption in lifecycle preferences.

(iii) Substituting for the definition of A(T) in (4-11) we have

$$v - e^{-rT} / (1-e^{-rT})[(1-E)/E]Wr,$$

and it follows that partial of v w.r.t. T C 0. Hence a person with a smaller horizon is prepared to pay more to extend life than a person with longer horizon. In particular, this result implies that other things equal, younger persons are willing to pay less to extend their life than older persons are prepared to pay. That L itself changes over the lifecycle may cause a person to, in some sense, regret past decisions. However, there is nothing inconsistent with this when preferences are time-separable and discount rates are constant over age.

(iv) v is not necessarily decreasing in r (given that a adjusts conformably). This experiment applies to a comparison of two societies, one in which persons are impatient and have high rates of time preferences, and one in which they have more foresight. In both, however, the interest rate adjusts to the rate of time preference. There are two effects: On the one hand the term in the exponentials in the expression under (iii) is decreased by an increase in r. On this account the value of longevity tends to fall. But on the other hand, the term in Wr is increased and real income is larger. The second effect dominates if T is short enough, but if T is sufficiently long then v will fall. It is surprising that the effect of a change in time preference and interest rates (together) cannot be signed.

Let us now examine the internal consistency of the solution. Suppose that the program derived above has proceeded for s periods. From that point on the person has $T' = T-s$ years of life of life left and has already consumed a fraction of initial endowed wealth. Let W' denote current wealth (after s periods have passed by). Then

$$W' = \text{integral from 0 to } T' \text{ of } (W/A)e^{-rt}\,dt = (W/A)B,$$

where $B = (1/r)(1-e^{-rT'})$ is the value of the remaining annuity for T' periods. Now it is clear that the optimal program from time s onward remains the same as before, because the budget constraint becomes, from point s onward, integral from 0 to T of $c(t)e\,dt = cB = (W/A)B$ and we have already determined c to be equal to W/A. Another way of saying this is that the new budget constraint becomes $W' = cB$, so $c = W/A$ also solves the "new problem" from s forward. The person doesn't change his plan. However, the value function changes as the person ages:

$$V' = \text{integral from 0 to } T' \text{ of } u(W/A)e^{-rt}\,dt = u(W/A)B$$

so the value V' when there are T-s periods left is smaller than the value V when there are T periods remaining because $B < A$. That the value function is decreasing with age (reaching its minimum at the age of death T) is due to the fact that terms are continually lopped off the sum of discounted utilities of further consumption as the person ages. Now in terms of remaining wealth, we have $c = W/A = W'/B$, so $V' = u(W'/B)B$ is precisely of the same form as (4-8) above, with B replacing A. Substituting from the above, we find

$$v' = ve^{rs},$$

so the value of life grows exponentially with age (s) in this case.

The relationship between v' and v in the expression immediately above makes clear the economic rationale for increasing value of life with age. In this deterministic problem, the the experiment tacks on extra years at the end of the program, and these terms are necessarily discounted-to present value. Something might have very large value at the time it occurs (as it does, for example, for a person at death's door, so to speak. in this problem). However, if the event will only occur sometime in the future, its current value is greatly reduced by discounting. Even though a young person and an old person will have the same value of longevity when they actually reach age T, at their current ages, this is discounted by a different amount due to horizon differences.

This simple point has some important practical implications, and even survives to stochastic models where the length of life is random rather than deterministic. It means that risks and actions which have long latency periods and which are long deferred can have small value to many people, especially young people. The young may appear "reckless" on this account, but such "recklessness" is rational. To illustrate the point further, suppose there is an opportunity to extend life by dT which costs a fixed amount independent of age. Then, since L is increasing in age, there is a threshold age, call its* such that people who are younger than s^* do not purchase the opportunity, while those whose age exceeds s^* purchase it. Similarly, if the market provides an opportunity to trade money and wealth for shortened life expectancy (as in risky jobs, for example) there is another threshold age s^{**}, such that people who are younger than s^{**} voluntarily make the trade and undertake the risk, whereas those who are older than s^{**} do not do so.

4.3.3. Extensions of Deterministic Model

4.3.3.1. Nonconstant Consumption

The strong result that $c(t) = c$ in the model above derives from the assumption that $r = a$. It is well known that when these two parameters are unequal then c(t) is either decreasing or increasing. To illustrate, consider an example in which r exceeds a. Then application of (4-5) shows that c(t) is increasing. To make further progress we need to be more specific about u(c), so assume the constant elasticity case where $u(c) = c^E$, with $0 < E < 1$. Detailed analysis reveals that the relevant discount factor in this case is $q = (a - Er)/(1-E)$. Defining $A^* = (1/q)(1-e^{-qT})$ we obtain the following expressions for V.

In the case where $q = 0$, V becomes

$$V = W^E T^{1-E}.$$

In this case there is direct valuation on T itself, because the effective discount rate is zero (and only sums matter, not discounted sums). Here we find

$$v = [(1-E/E](W/T),$$

which is increasing in W and decreasing in E and T, much as before. In the more probable cases where q RO, we find

$$v = W^E \quad (A+ \quad ^E = (W/A^*)^E \quad A^* = u(W/A^*)A^*,$$

which has a form very similar to the simpler case where r = m in all cases therefore the conclusions are very similar to the analysis above and need not be repeated.

4.3.3.2. Age-Dependent Preferences and the Quality of Life

The model so far has assumed that the utility function u(c) is constant over life and has no age-dependent factors built into it. However, it is intuitively clear how the presence of such factors would affect the analysis. Suppose for example that the quality of life deteriorated with age, so the utility function u(c) is decreasing over time. Then the value function would be adjusted conformably and the value of life calculation would take this into account, e.g., if life got progressively worse with age then a person would not pay as much to extend it, obviously.

For example, introduce the age-dependent factor in a multiplicative way as follows:

$$U = \text{integral from 0 to T of } u(B(t))c(t))e^{-at}.$$

Here the term in B(t) represents a consumption correction factor to make "real" consumption equivalent across ages. For example, if B(t) is decreasing in age, it takes an ever increasing amount of consumption to make up for the lower "efficiency" of consumption as a person ages. In this case the marginal condition, in (4-5) above is simply altered by multiplication of the left hand side by B(t). If we also assume that $B(t) = e^{-Bt}$ then the analysis is virtually identical to that of section) 4.3.3.1 (where the discount rate of time preference does not necessarily equal the rate of interest). Again, the refinement is a minor one.

4.3.3.3. Bequests

Suppose now that the person has heirs and that at the time of death all remaining wealth is transferred to these heirs. The standard way to incorporate a bequest motive into a life cycle problem is to introduce a bequest function into the utility function. Thus write

$$U = \text{integral from 0 to T of } u(c(t))e^{-at}\,dt + e^{-aT} f(Wb),$$

where the first term is identical to that above, and the second term reflects the person's utility of bequests. The amount of bequests are W_b which yield utility (discounted to present value) of $e^{-aT} f(W_b)$. Now the wealth constraint becomes

$$W = \text{integral from 0 to T of } c(t)e^{-rt} + W_b e^{-rT}$$

and the necessary conditions to the maximum problem are

$$u'(c)e^{-at} = m e^{-rt},$$

$$f'(W_b)e^{-aT} = m e^{-rT}.$$

Assuming $r = a$ again for simplicity, we have

$$u'(c) = f'(Wb) = m$$

and the constraint becomes

$$W = cA + Wb A'$$

where A and A' $= dA/dT$ were defined above.

Using these conditions and applying the envelope theorem to v, we find

partial of V w.r.t. $W = m$

partial of V w.r.t.

$$= [u(c) - m]e^{-rT} - re^{-rT} [f(Wb) - mW_b].$$

Using the simplified first order conditions and simplifying yields

$$v = -dW/dT = e^{-rT} [c(1-E)/E - rW_b (1-E^*)/E^*],$$

where $E^* = f'(W_b)W_b / f(W_b)$ is the elasticity of the bequest function. Thus the presence of bequests and bequest motives reduces the value of life in and of itself, because of the offsetting benefit to heirs of the person's demise. Of course this strong conclusion is built on some special assumptions, of which two are particularly important. One is that the utility of own consumption may itself be affected by the presence of heirs and children in the household. People tend to have children because they want to and because it increases their own utility over and above any affect of bequests. Hence the presence of heirs may make life itself worth more to the person, which tends to increase the value of longer life rather than to reduce it. Second, the. heirs may suffer a loss of utility from the person's death, and this utility loss should be valued by the person himself if he is altruistic (really, a form of reciprocal altruism). This factor would also tend to increase the value of longer life.

4.3.3.4. Labor Market Activities

Let us now consider a person who has endowed wealth W, as before, but who also has the opportunity to work at an hourly wage rate w. It is necessary to alter the utility function to handle this case because some valuation must be placed on leisure. Let L be leisure and normalize so that $0 \leq L \leq 1$. Then (1-L) is the amount of time devoted to work. Maintaining time seperable preferences as before, write the utility function as

(4-12) U = integral from 0 to T of $u(c(t),L(t)e^{-at}$ dt,

where the utility function $u(c,L)$ has conventional properties. The person has two sources of income in this problem. One is endowed wealth and the other is (endogenously chosen) earnings w(l-L). .The intertemporal budget constraint equates the present discounted value of earnings plus endowed wealth to the present discounted value of consumption over the life cycle:

(4-13) u = integral from 0 to T of $w(t)(1-L(t)e^{-rt})dt$

= integral from 0 to T of $c(t)e^{-rt}$ dt.

Optimality conditions for choice of c(t) and L(t) which **maximize** (4-12) subject to (4-13) are

(4-14) $U_c(c,L)e^{-at} = me^{-rt}$,

$U_L(c,L)e^{-at} = mwe^{-rt}$.

Solving these two equations along with the budget constraint yields the optimal **trajectories** for L and c.

We can place this problem in the context above by making the simplifying assumption that r = a and that w(t) = w. Then (4-14) implies

(4-15) $U_L(c,L)/U_c(c,L) = w$.

$$U_c(c,L) = m,$$

which imply that $c(t) = c$ and $L(t) = L$ are constants over the life cycle. Therefore, we may write

(4-16) $$V = \max_{c,L} \{u(c,L)A + m(W + w(1-L)A - cA)\},$$

where again A is the present value of an annuity that lasts for T periods. Using the envelope property of a maximum., we find

(4-17)
$$V_W = m,$$

$$V_W = m(1-L)A,$$

$$V_T = [u(c,L) + m(w(1-L) - c)]A',$$

$$= [u(c,L) - m(W/A)]A', .$$

where the second equality in the last expression follows from the budget constraint.. Therefore

(4-18) $$v = V_T/V_W = [u(c,L)/u_c(c,L) - (W/A)]A',$$

since $m = u_c$ from the marginal conditions, Defining the elasticity $E = cu_c/u$ as before, (4-18) becomes

(4-19) $$v = [c/E - (W/A)]A'.$$

This may be written in yet another way: solving for c from the budget, we have $c = W/A + w(1-L)$. Substitute this into (4-18) and rearrange:

(4-20) $$v = [(W/A)(1-E) + w(1-L)]e^{-rt}/E .$$

Look at (4-19) first. The value of longevity has both a posit'ive and negative term (of course suitably discounted-- $A' = e^{-rT}$). The positive term is the level of consumption adjusted by the inverse of E, and since E cannot exceed unity. the actual value of consumption is a lower bound for this term The negative term in W/A, which is just the level income available from an endowment of nonhuman wealth W available at interest rate r from T periods. This must be subtracted from the adjusted consumption level because an increment of life T lowers the annuity value of income available from W because it must be spread over a longer interval and consumption in earlier periods is lowered on that account.

The second form of **v** in (4-20) shows that the value of longevity has a relationship with observed income as well as with observed consumption. The first term in this expression is $(W/A)(1-E)e^{-rt}/E$, precisely the same as when leisure is not considered in the problem. To this we need to add the extra income available from work when the person lives longer. However, it is not the extra earnings alone that must be added, but that amount divided by E. That is, observed earnings is a lower bound to the extra adjustment and is only an unbiased estimate when E is very close to unity. Again, this adjustment reflects imperfect substitution between quantity and quality of life when consumption and leisure are not perfect substitutes intertemporally.

4.3.3.5. Retirement

The model in section 4.2.3.4 assumed that the person worked over his whole life, and would be relevant for a situation of "early" death. However, for most people work patterns over the life cycle follows a systematic course of full time work up to a certain age followed by a full time retirement. The model above may be extended to cover this case most easily be assuming that the wage w is available up to some retirment age, say T*, at which time w drops to zero and the person consumes full time leisure. 'The the utility function must be written

u = integral from 0 to T* of $u(c_1(t),L(t))e^{-at}$ dt

+ integral from T* to T of $u(c_2(t),1)e^{-at}$ dt,

where c_1 denotes consumption during the years in which a person works and c_2 denotes consumption when the person is retired and leisure is fully consumed (L = 1). The budget constraint is conformably altered to

w + integral from 0 to T* of $w(t)(1-L(t))e^{-rt}$ dt

= integral from T* to T of $c_1(t)e^{-rt}$ dt

+ integral from T* to T of $c_2(t)e^{-rt}$ dt

and the optimal program chooses L(t), $c_1(t)$ and $c_2(t)$ to maximize U subject to the budget constraint as before. Omitting details and making the same simplifying assumptions as above yields an expression for **v** of the form

$$v = c_2\ [(1-\hat{a})\hat{a}]A',$$

which looks very much like the first problem considered here. There are two minor differences. First, the relevant consumption level is that applicable to retirement rather than to pre-retirement. The second is that the adjustment factor--the elasticity term $\hat{E}$ is calculated at the retirement utility level of leisure where L = 1: $\hat{a} = c_2 u_c(c_2,1)/u(c_2,1)$. It is not at all obvious whether or not $\hat{a}$ falls short of or- exceeds the corresponding elasticity calculated at the preretirement optimum utility: this would depend on the precise form of preferences. Nor is it entirely obvious, without more structure on preferences, whether c_2 exceeds or falls short of c_1. This would depend on the nature of complementarities and substitution between consumption and leisure, about which little can be said in general. However, the budget constraint does imply

$$c_2 = [(W/A^*) + w(1-L) - c_1] / (A - A^*)/A^*,$$

where A* is the annuity formula for T* periods and A is the formula for T periods. It is clearthatthe longer the period of retirement, the smaller is c_2 and the lower the value of v, ceteris paribus. It is also clear that v is larger for people with greater nonhuman and human wealth, because retirement consumption will be larger in these cases.

4.3.4. The Value Of Morbidity

The ideas in the last two extensions provide a basis for beginning to evaluate morbidity. Imagine the following situation: The person is ill for exactly S periods, after which time he becomes "whole." During the period of illness, utility is $G(c_1,L_1)$, while during the normal (well) period utility is $u(c_2,L_2)$ as before. Here the subscript 1 refers to these variables in the well-state. For the demarcation of illness to make any sense, we must have that $G(c,L) < u(c,L)$ when both functions are evaluated at the same arguments. Then illness makes the person worse off. In addition, a person who is ill cannot work on the same terms as one who is well. Represent this by a drop in the wage: if the wage in state 2 is w, then the wage in state 1 is aw, where a < 1. In addition, medical and other expenses may be required if the person is ill. Denote these, as a flow, by D.

The budget constraint for this problem is

(4-21) W + integral from 0 to S of $aw(1-L_1(t))e^{-rt}$ dt

+ integral from S to T of $w(1-L_2(t))e^{-rt}$ dt

= integral from 0 to S of $(c_1(t)+D)e^{-rt}$ dt

+ integral from S to T of / $c_2(t)e^{-rt}$ dt .

Of course it may turn out that the person chooses not to work in state 1, in which case the first earnings expression in (4-21) is zero. Again, maintaining seperability for analytical convenience, lifetime utility is

$$(4\text{-}22)\quad U = \text{integral from 0 to S of } G(c_1(t),L_1(t))e^{-at}dt$$

$$+ \text{ integral from S to T of } u(c_2(t),L_2(t))e^{-at}\,dt.$$

If we assume that r = a and that w is independent of t, we again find that the c's and L's are constant in the optimum program, so that

$$(4\text{-}23)\quad V = \max\{G(c_1,L_1)A_S + u(c_2,L_2)(A_T-A_S)$$

$$+ m\,[W+(aw(1-L_1) - cl - D)A_s$$

$$+ (w(1-L_2) - c_2)(A_T - A_S)]\},$$

where A_t is the annunity formula for t periods. We are interested in how much wealth a person would be prepared to pay to reduce the period of illness by an increment dS. This again is a marginal rate of substitution calculation comparable to the definition of v. Hence define M as the corresponding value of morbidity:

$$(4\text{-}24)\qquad M = (dW/dS) = V_S/V_W.$$

From (4-23) and the envelope theorem'it follows that

$$V_S = (G - u)A_S + [y_1 - y_2 - (c_1 + D - c_2)]A'_S,$$

$$V_W = m,$$

where $y_1 = aw(1-L_1)$ and $y_2 = w(1-L_2)$ are earnings in states 1 and 2 respectively. Applying the definition (4-24),

$$(4\text{-}25)\quad M = \{[u(c_2,L_2) - G(c_1,L_1)]/m + (y_2 - y_1) + c_1+ D-c_2)\}A'_S.$$

This expression shows that the value of morbidity reduction is composed of three distinct parts. One part is the difference in earnings between the two states, or “foregone earnings" commonly found in practical work. To this must be added the cost of medical care and related expenses (D), which is also commonly incorporated in empirical measures. However, these measures usually excluded two other components which are more difficult to measure. The first of these is the dollar value of the utility loss of illness, reflected in the first bracketed term in the expression for M- -division by the marginal utility of wealth converts the utility difference to an equivalent dollar magnitude. This term would be related to the concept of "pain and suffering" associated with personal injury litigation. Its magnitude obviously varies with the degree of debilitation, and also with the extent to which the relative marginal utilities of consumption and leisure are affected by the illness and the extent to which "leisure" and consumption in the ill state are complements or substitutes. Little can be said about this in general, and it must be analyzed on a case-by-case basis. The. third term is the difference in consumption between the two states, and this is almost always ignored in empirical work. To the extent that consumption in the ill-state falls short of consumption in the well. state, that difference should be subtracted from a willingness-to-pay measure. To the extent that was true, the "pain and'suffering" term would be offset.

To understand this last adjustment a little better, write the two components combined:

$$(u(c_2,L_2) - G(c_1,L_1))/m - c_2 + c_1$$

$$= \{[u(c_2,L_2) - m\ c_2] - [G(c_1,L_1) - m\ c_1]\}/m.$$

Now m equals the marginal utility of consumption in each state, by the first order conditions of the maximum problem, and can be thought of as the shadow price of consumption in each state. Then each of the terms in square brackets above is total utility in the state minus the utility cost of consumption in that state, or a measure of "rent" in that state. It is the difference in these rents between states that must be imputed to the valuation of morbidity. It seems clear that the rent in the well-state would exceed that in the ill-state, so foregone earnings and medical bills would understate the true cost of morbidity. The extent to which it would understate the truth, however, would depend on the precise properties of preferences and how the illness affects $G(c,L)$.

4.3.5. Value Of Life Expectancy: Stochastic Model

4.3.5.1. Preliminaries

In this section we examine a stochastic decision problem in which life expectancy is uncertain. While this changes some of the details of analysis, the main thrust of the deterministic model carries through with minor alternations.

Analysis of the stochastic case requires some attention to the statistical description of life chances, and a brief review of some actuarial concepts for describing probability distributions over length of life. Let F(t) be the probability of surviving until age t at most. Then 1 - F(t) is the survivor function, the probability of surviving to at least age t, or more. Define $f(t) = dF(t)/dt = -d(1-F(t))/dt$ as the density function of length of life; the probability of surviving to age t exactly. The age specific death rate or hazard rate, is the probability of death at age t given that one has survived up to that age. It is a conditional probability: Denoting the hazard or death rate at age t by h(t), it is $h(t) = f(t)/(1-F(t))$, or from the relationship above:

(4-26) $$d\log(1-F(t))/dt = -h(t) .$$

Integrating (4-26) and using the boundary condition $F(0) = 0$ (we are only looking at survivors at birth), yields the fundamental relationship between the hazard rate and the survival rate

(4-27) (1 - F(t)) = exp {- integral from 0 to t of h(z)dz},

where exp means the exponential <u>e</u>.

The importance of equivalence (4-27) lies in its relation to the problem at hand. The hazard h(t) is naturally associated with the undertaking of risks to life and is the natural primitive for studying the valuation of life-threatening actions. However, the survivor function is the natural primitive for studying expected utility and expected wealth. Equation (4-27) shows precisely how the two are related.

At some cost of realism, great simplicity in understanding the nature of the problem is achieved by studying some special cases. In particular, assume $h(t) = h$, so the death rate is constant at all ages (the case of constant hazard). Then it follows directly from (4-27) that

(4-28) $$F(t) = 1 - e^{-ht},$$

$$1 - F(t) = e^{-ht},$$

$$f(t) = he^{-ht}.$$

The probability density of length of life f(t) is exponential in this case. Furthermore, life expectancy itself, call it E(t) is simply related to the death rate as

E(t) = integral from 0 to infinity of tf(t)dt

= integral from 0 to infinity of hte^{-ht} = l/h.

= l/h.

Note that life expectancy is independent of current age in this case. No matter how long one has lived there is always 1/h years left! The system has no memory. This is of course highly unrealistic, but the convenience of analysis more than makes up for this defect. The more general case in analyzed by Arthur, to which the reader to referred for details.

Suppose now that the hazard rate is a step function. That is, it is $h(t) = h_1$ for $t < T$, but then jumps to a higher level beyond some age T: $h(t) = h2$ for $t \geq T$. Then application of (4-27) yields

(4-29) $$1 - F(t) = \exp(-h_1 t) \text{ for } t < T$$

$$= \exp\{[(h_2 - h_1)T] - h_2 T\}.$$

Now the survival function is exponentially declining at rate h_1 for $t < T$, but its slope shows a point of discountinuity at T. It declines at a larger rate for $t > T$ than for $t < T$. Here we would find that life expectancy is decreasing with age, so long as $t < T$.

Any pattern of h(t) could be approximated in this way as a sequence of step functions. Since the mechanics of this are straightforward, they will be omitted here. Instead we turn to the choice problem.

4.3.5.2. Optimal Choices

The fundamental method follows the deterministic approach above. Let us begin by ignoring work decisions and describe tastes by an intertemporally separable utility function in the sequence of consumption c(t). If a person lives exactly t years then his utility is postulated to be

$$U(t) = \text{integral from 0 to infinity } u(C(z)\ e^{-at}\ dz,$$

which follows precisely the form of the deterministic model. However, in an uncertain world a person lives t years only with probability f(t). Therefore apply the expected utility theorem to U(t). A person's expected lifetime utility is

(4-30) $$EU = \text{integral from 0 to infinity of } U(t)f(t)dt$$

$$= \text{integral from 0 to infinity of } u(c(z))e^{-az}\ dzdt$$

$$= \text{integral from 0 to infinity of } u(c(t))e^{-at}$$

$$= \text{integral from 0 to infinity of } f(z)dzt$$

$$= \text{integral from 0 to infinity of } (1-F(t))u(c(t))e^{-at}\ dt,$$

where the second to last equality follows by a change in the order of integration. We see that the relevant utility expression incorporates the survival rate l-F(t) and that is why it is a fundamental concept for the problem. Substituting from above, preferences follow

(4-31) EU = integral from 0 to infinity of

u(c(t)exp(- at - integral from 0 to T h(z)dt)},

so the hazard rate works exactly like a discount rate. To make this even more transparent, suppose h(t) = h is constant. Then EU = integral from 0 to infinity of uc(t))$e^{-(a+h)t}$ dt. and the "effective" discount rate is a + h. The force of mo'rtality h makes a person act more "impatiently" and to weigh the future less heavily.

Budget constraints in problems such as this create a host of conceptual difficulties revolving around the question of how to cope with the fact that the person might die in debt. These issues have been thoroughly explored by Yaari and there is little to add to that discussion here. Hence we adopt a natural solution in which a person is not allowed to die in debt and can borrow and lend on a perfect capital market at rate of interest r. The constraint of budget balance at each possible point in the life cycle is enforced by an actuarial insurance-debt system. It amounts to the following. Whenever a person makes a loan he is compelled to at the same time take out an insurance policy of equivalent value such that if he dies at any time during the course of the loan, the insurance indemnity is sufficient to pay off the remaining balance. As is well known, this is basically an actuarial annunity system in which a cohort of identical individuals turn over their wealth to the insurance-finance company and contract for their optimal consumption bundle c(t) which persists as long as and for however long they live. Those who die early effectively subsidize the fund ex post, since their assets have exceeded their consumption claims. These subsidies are used to pay the consumption claims of those individuals who survive longer than average. We can represent this in a simple manner as follows.

If a person lives for exactly t periods and contracts for c(z), the present discounted value of his claims is integral from 0 to t of c(z)e^{-rz}dz. The probability of surviving for exactly t periods is f(t), so the expected discounted value of the claim c(z) is equated to the person's initial wealth W under an actuarial, no-load system. The budget constraint is

(4-32) W = integral from 0 to infinity of f(t) times

integral from 0 to t of c(z)e^{-rz} dzdt

= integral from 0 to t of (1-F(t))c(t)e^{-rt} dt, where the second equality follows from the same change in order of integration as above. Again, it follows that the influence of the survival term (l-F(t)) in this expression is to increase the effective discount rate. It is interesting to note that even if r and a are zero, there is a well defined optimization problem, something that isn't true in a deterministic problem with an infinite horizon (because the objective function becomes unbounded in that case).

The economic problem is to choose c(t) to maximize (4-30) subject to the constraint in (4-32). Associating a multiplier m with the constraint and noting that the term in (l-F(t)) is common to both the objective function and the constraint and therefore factors out of the optimality conditions, first order conditions for the problem duplicate those of the deterministic problem. We have

(4-33) $$u'(c(t))e^{-at} = m\, e^{-rt} \text{ for all } t.$$

The interpretation is straightforward. The life insurance features of the annuity arrangement allow the person to do whatever he would have done in the deterministic problem and to insure the death risk over consumption streams by the law of large numbers applied to his cohort. In particular, assume r = a. Then (4-33) implies c(t) = c, a constant, and the person contracts for a constant-consumption stream up to the point of his death and no matter how long he lives. From the budget constraint we have that c = W/integral from 0 to infinity of (1-F(t))e^{-rt} dt, so the amount of consumption available under this scheme depends on the person's wealth, the rate of interest, and the precise age-pattern of survival probabilities.

4.3.5.3. Valuation Formulas

Consider the case where h(t) = h. Then (4-32) implies W = c/(r+h), just the formula for the value of a perpetuity of c at discount rate (r+h). In this case (4-30) becomes EU = EU = u(c)/(r+h), or instantaneous utility discounted at rate r+h forever. Therefore

(4-34) V = EU = u(W(r+h))/r+h .

This looks very similar to the deterministic problem. Define v' as the value of changing the probability of death, h. Then

(4-35) v' = - (partial of V w.r.t h)

/ partial of V w.r.t. W = dW/'dh.

v' is amount of money the person would have to be paid to increase the death rate confronting him by dh. From (4-34)

$$V_W = u'(c),$$

$$V_h = [(r+h)Wu'(c) - u(c)]/(r+h)^2 .$$

Therefore, in the constant hazard case with $r = a$,

$$\text{(4-36)} \qquad v' = [u(c)/u'(c) - (r+h)W]/(r+h)^2$$
$$= (W/(r+h))(1-E)/E,$$

where again E is the elasticity of u(c) with respect to c, and $0 < E < 1$. Comparing this with equation (4-11) of the deterministic model, we see that the term in h serves as the correction factor for finite life, rather than the annuity term A in (11). Otherwise, the expressions are identical and have identical implications. v is increasing in W and decreasing in E for the same reasons as were spelled out above. In particular, the role of quantity versus quality of life substitution as reflected in E remains exactly the same as before. It is also true that v' is decreasing in r, and is also decreasing in h.

We can find an equivalent expression in terms of the expectation of life, $\bar{t}$, since $\bar{t} = 1/h$ when the hazard is constant. Then $dh = -d\bar{t}/\bar{t}^2$ so

$$dW/d\bar{t} = [(W)/\bar{t}(r\bar{t}+1)]\ [(1-E)/E].$$

A person with a longer life expectancy is willing to pay less to extend it.

4.3.5.4. Valuations of Workers

Let us now extend the stochastic model to include choice of work and earnings as well as consumption. Then, similarly to the deterministic models, the one-period utility function must be written $u(c,L)$, where L is leisure. This function replaces u(c) in the definition of expected utility in (4-30). A worker has a source of earned income as well as endowed wealth. If he can earn w(t) per unit of time, earned income is w(t)(1-L(t)), which when discounted to present value and including allowances for mortality becomes infinity of 0 to infinity of $w(t)(1-L(t))(1-F(t))e^{-rt}dt$ and which must be added to the term in W on the left hand side of the budget constraint in (4-32). The first order conditions for choice of c(t) and L(t) duplicate equation (4-14) in the deterministic model. With $r = a$ and $w(t) = w$, the value function becomes

(4-39) $$V = \max_{c,L} \{[u(c,L) + m[w(1-L) - c]]$$

$$\text{integral from 0 to infinity of } (1-F(t))e^{-rt}\, dt + m\, W),$$

since c(t) = c and L(t) = L under these circumstances.

Assume h(t) = h. Then the integral term in (4-39) is merely $1/(r+h)$ and maximum expected utility is the perpetuity value of $u(c,L)$ held at its optimal values of c and L, at discount rate $r+h$. In this case we find

(4-40) $$-V_h / V_W = [c(1-E)/E + w(1-L)]/(r+h)^2$$

as the capital sum the person would be willing to give up to reduce the death rate by dh. This expression is similar to (4-36) with the addition of the earned income term; since the opportunity to work has value.

Expression (4-40) does not closely relate to empirical work in this area. Much of the empirical work on the value of life uses labor market data and estimates the risk premium necessary to induce a worker to undertake a risky job. For the problem at hand, the relevant risk premium is nothing more than $-V_h / V_w$, which is, in this case

(4-41) $$-V_h /V_w = [c(1-E)/E + w(1-L) - c]/(1-L)(r+h).$$

From this expression we may infer something about the intertemporal substitution parameter E.

As an example, consider the study of Thaler and Rosen (Ippolito and Ippolito produce a similar estimate from much different data.) Thaler and Rosen estimate $- V_h /V_w$ in terms of the weekly wage as $3,520 in 1968 dollars. In their sample average weeks worked are approximately 50 and the average worker earned about $6,600. Since this is a low income population, the bulk of consumption expenditure must have come from earnings, so ignore savings and assume c = w(1-L) = $6,600. Substituting this and (1-L) = 50 into (4-41) and rearranging, we have

$$E = (6{,}600/176{,}000) / (r+h) .$$

Hence the estimate of E depends on assumed values of r and h. In the Thaler and Rosen sample, h is about 2.5 per 1,000, decomposed into 1.5 per 1,000 normal life table experience plus an additional 1.0 per 1,000 excess risk from working conditions among people in hazardous jobs. Hence any realistic interest rate swamps the effect of h. For this population r = 10% would appear to be a plausible lower bound. If so than E = .39. If r = 15% the estimate of E drops to .26. Presumably these are upper bound estimates among the population at large, because most workers are not found in risky jobs through selection: ceteris paribus their value of E must be no greater and most probably lower than indicated if they find it advantageous to work on safer jobs at lower rates of pay. Hence from this evidence, we get an upper bound of E in the .25-.40 range.

Now return'to equation (4-36) and convert it into logs:

(4-42) $$d\log W/d\log h = [h/(r+h)](1-E)/E.$$

Substituting the values above yields as estimate for dlog W/dlog h in the range .04 to .05. That is, the people in this sample would have been willing to give up one-half percent of their wealth for a 10 percent reduction in the death rate. Presumably the equivalent sum for the average person in the population is larger than this because of the selection effect mentioned above. Notice however, that the term in $h/(r+h)$ is even smaller for such persons (because their values of h are smaller) and this dampens any effect of a smaller value of E. Notice also, as a rough and ready approximation, the term in h would be much larger for older persons, so they would be willing to pay a much larger fraction of their wealth.

Now consider an experiment related to the specification in (4-29). This is interesting because it is closely related to long term hazards with a latency period of length T. Thus, for example, a person with a "normal" risk exposure h_1 may undertake some action now which has no effect on death probabilities until periods later, at which time the death rate jumps to h2. Exposure to chemical substances may take this form. Again maintaining r = a for simplicity, from (4-29) and (4-30) and (4-32) we have

(4-37) $$v = \max (u(c) \text{ integral from infinity of } (1-F(t))e^{-rt}\, dt$$

$$+ \quad m[W - c / (1-F(t))e^{-rt}\, dt]$$

$$= \max [u(c) - mc][(1/(r + h_1))(1-\exp-(r+h_1)T)$$

$$(1/(r+h_2))\ (\exp\ (-(r+h_1)T),$$

from which it follows by the now familiar manipulations

$$(-V_{h_2})/V_w = [c((1-E)/E)\exp\ (-(r+h_1)T)]/\ [(r+h_2)^2]$$

(4-38) $V_T/V_W = [c((1-E)/E)\exp(-(r+h_1)T)]\ [(h_2-h_1)/(*r+h_2)]$

$V_T/V_{h_2} = (h2 - h_1)(r + h_2)$.

The first expression in (4-38) shows how much the person is willing to pay to reduce the later hazard. This again depends on the intertemporal substitution parameter E and the level of consumption, as before. It also depends on how far away the hazard is from the present--the further away it is the smaller the willingness to pay to reduce it--and on the rate of interest. The second expression in (4-38) shows how much the person would be willing to pay to push the increased hazard a little bit further away from now. This also depends on c and E, and is decreasing in T and increasing in the difference $h_2 - h_1$. The third expression, written for completeness, is the marginal rate of substitution between the level of the new hazard and the time of its occurrence.

The most important thing to notice about these valuations is that they are time or age dependent. The willingness to accept risks of this form is largest for younger people and the willingness to pay to avoid them is largest for older individuals (when the person is old enough to have passed beyond $t = T$, the formulas revert to the form of (4-36)). This is basically due to the force of discounting, which includes not only the interest rate but the hazard rate itself. Furthermore, these expressions make no allowance for pain and suffering and the manner of death, but including such factors would have the effect of increasing their absolute values without affecting their intertemporal patterns.

Changing valuations over the lifecycle raises some tricky issues for risks that are irreversible. Thus suppose the market provides an opportunity for undertaking a risk exposure of the type above which increases wealth or utility in other ways. Then we would again find some critical age, beyond which a person would not undertake the risk, but before which he would. Suppose this action affects h_2 permanently, so there is no going back on the decision once it has been undertaken at the early age, and the person is stuck in a permanently high risk class at some time in the future. Then as the person ages, he would perhaps have ex post regret about his earlier actions. However, there appear to be no inconsistencies (in the sense of intertemporal irrationalities) in this type of behavior, because, by hypothesis, all these affects are foreseen in the first instance. The point applies to any type of gambling behavior. A gamble may appear to be very favorable ex ante, but ex post realizations often lead to regret, about which nothing can be done and which is already factored into the initial decision to undertake it. The same is true in this case when all the information is on the table.

Nonetheless, in evaluating such hazards for the purposes of social policy and cost-benefit analysis, one would certainly like to take account of different valuations by people of different **ages**, since it is the sum of all valuations whichmatter. That a person might have a different valuation at different points of time and age is properly accounted for in these sums, and no allowance need be made for the fact that the person will change his valuation at some future time. This conclusion is of course conditioned on the manner in which the problem has been set up, which assumes perfect information and a perfect capital market. If capital markets were imperfect and the insurance charge did not fully reflect the increased future risk for any given person, there would be a moral hazard effect and the social value of risk would exceed the private value, because individuals would have a tendency to shift risks excessively to the insurance fund. Too many risks would be undertaken. And of course similar statements apply if assessments of future hazards are biased (in either direction) by the persons undertaking them.

4.3.6. Interpretation and Applications

4.3.6.1. Major Results From The Life Cycle Model

Section 4.3 has been motivated by the question "How much of the economy's wealth should be spent on safety, health and longevity concerns?" The answer depends on the way individuals (or households) appraise their own life situations. and how they make decisions they judge to be optimal in light of those situations. This section has provided a framework that identifies the underlying decision variables and guides the valuation of policy decisions designed to improve people's life prospects.

A life cycle frameworkhas been seen to be appropriate, and the intimate relation between quality of life and longevity, or quantity of life, has emerged in the **development** of the model. Valuations of increases in life expectancy, in reductions in periods of illness, and in reductions in risk of death have been explored. Labor force participation and the value of increased longevity are taken into account. Results derived from the model include widely recognized effects such as foregone earnings and medical expenditures, and also more frequently overlooked effects such as the utility of consumption and leisure and differences in the utility of consumption and leisure and differences in consumption between various states of wellness.

Several parameters play key roles throughout the development of the model, and others are important to the development of special parts of it. Perhaps of greatest interest among the former is the elasticity of lifetime consumption. This relates to intertemporal substitution and reflects the close relationship between the quality and quantity of life. Other parameters in this category are the rates of interest and time preference, the level of wealth and the person's stage in the life cycle.. Of interest in the other category of parameters, pertaining to special parts of the model, is a "consumption correction factor," which takes into account the fact that people's capacities change over their life cycles. This is particularly important, in empirical work because it pertains to people's endowments, which are important in explaining their valuations. Another special parameter is the hazard function parameter, which measures an individual's probability of dying at any given age. This is another aspect of endowment. It is central to the treatment of the effects of uncertainty on choice and is of particular interest in valuing threats to health that involve latency, which is represented by a discrete increase in the hazard of death after a number of years elapse.

One of the results is that younger prople are willing to pay less to extend their lives than older people. The primary reason is that the return to a younger person is deferred so far into the future that its present value has been largely wiped out by discounting. It is quite possible that the person when older will regret actions taken earlier in life because extended longevity has become more important in the meantime. Nevertheless the now regreted actions must be regarded as rational when preferences are time separable. A similar result is obtained in the analysis of risks to health which change the probability of death after an intervening period of latency. Once again the farther into the future the increased risk is deferred the less a person is willing to pay now for its reduction.

Maureen Cropper has added a comment regarding the effects of age on willingness to pay for risk reduction. One must distingusih between the age of the respondent at the time the question is asked and the age at which the risk occurs.

To illustrate, consider two men, one 18 and the other 45, who have identical preferences and lifetime earnings streams. The distribution of date of death conditional on reaching age t (t-18,...) is the same for both persons. The only difference between them is that the 45-year-old has followed for 27 years the consumption path which the 18-year-old will eventually follow. There are three willingness to pay to compare:

(1) The amount the 18-year-old will give up today to avoid a marginal increase in his conditional probability of death at age 18.

(2) The amount the 18-year-old will give up today to avoid a marginal increase in his conditional probability of death at age 45.

(3) The amount the 45-year-old will give up today to avoid a marginal increase in his conditional probability of death at age 45.

With perfect annuities markets and a rate of time preference equal to the market rate of interest, (1) > (2) and (1) > (3). The fact that (1) > (2) means that a reduction in risk of death 27 years hence is less valuable than a reduction in current risk of death. This point is made in this section and has obvious relevance for valuing risks with long latency periods.

The fact that (1) > (3), i.e., that the 18-year-old will pay more to reducehis current risk of deaththanthe 45-year-old (at least according to the theoretical model) needs to be made clearly. One can reverse this inequality by assuming imperfect capital markets, which constrain the individual to consume no more than his income when he is young, and a hump-shaped earnings stream; however, under the assumptions of this section, (1) > (3).

V. Kerry Smith comments "on the possibility of considering a'changing framework,' that is, a framework which allowed the individual to change his or her plans over time. The current framework seems to assume there is one optimal plan which is in not allowed to change with respect to changes in the parameters of the individual's situation. The actual model is probably much more like a situation in which the individual makes a plan and then takes one step along that plan, updates, and utilizes a new plan."

The elasticity of the life cycle consumption function, which is closely'related to the intertemporal substitution of consumption, has a strong bearing on both the value of extended life and the value of reducing hazards that occur later in life. The greater a person's ability to substitute present consumption for future consumption the less interest that person has in providing for the future. The value of the intertemporal substitution parameter is a key importance in understanding tradeoffs between the quantity and quality of life in this framework.

Elasticity of consumption is estimated to have an upper bound of 0.25 to 0.40. This rather low elasticity implies that quantity and quality of life are poor substiutes for each other, which in turn varies the value of extra years of life.

Allowing for reduced capacity for consumption during later years of life requires a consumption correction factor. The implication of diminishing capacity is that unless real consumption can be maintained the value of longevity is reduced. This is an important implication because people's consumption-capacity prospects and expectations can be approximated empirically.

The fact that people value extensions of life the older they get has implications for labor market behavior. Supposing that opportunities to extend life a given amount have a constant cost independent of age, then there is a threshold age belov which people are willing to accept shortened life expectancy in exchange for increased money return, whereas people above the threshold will not accept the trade.

Application of the framework to some available sample evidence yields the result that people would give up one-half percent of their wealth for a ten percent reduction in the death rate. The equivalent amount for an average person in the population would probably be greater.

4.3.6.2. Life Experiences and the Willingness to Pay to Avoid Serious Illness

The life cycle approach to serious illness was applied in later parts of this study in experimental focus group sessions. It was hypothesized and found to be the case that age makes a great difference in the way a person perceives the consequences of risks to health, either with certainty or varying degrees of probability. Focus group explorations of hypothetical life path experiences showed graphically that people in their twenties have little or no interest in their health propsects for their seventies or even their fifties. A different picture emerges from the responses of people in their fifties or sixties. The theoretical contributions of this section provide the rationale for this behavior and point the way to empirical solutions to the problems raised by these focus group encounters.

The contingent valuation questions to be considered in Section 4.5, which grew out of the framework here and learning from focus group experience, emphasize comparisons between life paths. In some cases individuals are required to rank alternative paths which embody different tradeoffs between suffering and life expectancy. Different kinds and durations of suffering are considered. Finally, uncertainty is introduced and valuations of risks are sought within streams of experience that embody both sickness and death.

Perfect health is generally not the alternative to symptoms, diseases or health risks that are reduced by successful public policy. The value of improved prospects must be weighed against alternatives that carry risks of their own. Thus a person is generally trading one stream of illnesses for another, less undesirable one. It is this change, rather than a transition to perfect health, that constitutes the benefit of the public policy.

The life path approach constitutes in a number of ways a departure from conventional methods of valuing health benefits. The distinguishing feature of the approach is its treatment of the whole stream of experience as the focus of analysis. Good health, illness and death are viewed as inseparable in analysis as in life. As in other areas of life people make choices for more or less health and longevity. To an important degree people choose greater or lesser amounts of health and longevity depending on their values for these goods relative to their other wants and needs. The life path approach is an appropriate means of obtaining health values because it is based on willingness to pay in view of the totality of substitutions that people make over time in resonse to changes in health risks. Methods that attempt to value health or longevity as one period events, and especially methods that disregard age, run the danger of missing important determinants of health values.

4.3.7. References

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4.4. MODELLING OF CHOICES WITH UNCERTAIN PREFERENCES

4.4.1. Backgrond

People have many occasions in their lives to take actions to avoid or reduce risks. In order not to spend all their resources on risk avoidance, they implicitly consider what the value of risk reduction is, and they try with more or less success to carry risk avoidance only to a point justified by the costs. This point is often unconscious or subconscious. It is carried out imperfectly and is beset by lack of information due to the fact that, while the events to be avoided involve very great values, the probabilities are small and outside the realm of everyday experience. Knowledge about risks is important. This is particularly the case for environmental risks. Thus people tend not to know their own minds on the subject of risks. Section 4.4 addresses the problem of making choices about risky alternatives in view of knowledge imperfections. Section 4.4.2 introduces the difficulties for benefit-cost analysis caused by risk, and the approach taken to solve them. Section 4.4.3 discusses relevant issues in the theory of expected utility. Section 4.4.4. introduces the concept of uncertain preferences. Section 4.4.5 critiques the literature on risk from psychology and relates the concept of uncertain preferences to the economic literature of behavior towards risk. Following introductory comments in section 4.4.6, section 4.4.7 and 4.4.8 produce a series of theorems that indicate how people process information and make choices about low probability events on the basis of the results. Section 4.4.9 compares the effects of using comparison questions versus. realing questions. Section 4.4.10 introduces the realistic assumption that respondents' answers to certain questions are interrelated, and examines its implications. Sections 4.4.11 through 4.4.13 discuss the effects of limited memory and bias in the answering of questions about risky events. Section 4.4.14 draws implications of the theorems for the study of serious illness, giving particular attention to contingent valuation.

4.4.2. Apprpach Taken in This Section

A major benefit of air pollution regulations is the reduction in health risks. If the govenrment wishes responsibly to decide on the correct level of standards to impose, it must attempt to determine what value individuals place on health risk reduction. Ultimately there are only two ways to gain this information. One is to observe market behavior and, through the logic of revealed preference, to make inferences about individuals' tastes. The other is to ask individuals directly about their preferences. In the case of most public goods, including air quality, there are few markets in which individuals can reveal their preferences--indeed, this scarcity of markets is the reason government must be concerned with the problem in the first place. Thus it appears that surveys and interviews are likely to be necessary in any attempt to assess the public's demand for reduction in health risks.

Researchers have, however, run into serious difficulties when they have attempted to interpret individuals' responses to questions about their preferences in risky situations. Many economists are suspicious of survey responses about willingness to pay, feeling that they are subject to strategic manipulation by the respondents. In the case of survey data on risk tolerance, there are much more immediate problems: Answers elicited appear to be at odds with the standard economic theories of risk aversion. Worse, they appear to be inconsistent with the fundamental assumptions of rational decision making.

Therefore, to be able to use survey data to establish the value of the benefits from risk reduction, we need a framework that will enable us to interpret that data consistently in a cost-benefit analysis. Section 4.4 will attempt to provide the conceptual basis for such a framework. The framework we propose is one in which it is costly for individuals to determine their own preferences and therefore unlikely that their responses to survey questions will reflect their true choices with absolute accuracy. We will demonstrate how cost-benefit analysis can be interpreted in such an environment and briefly indicate some implications for the handling of surveys of individuals' risk tolerance.

This approach is consistent with much recent work in cognitive psychology, and can in fact be understood as a economic reinterpretation of some of that field's analysis. It differs, however, from the approach taken by much recent work in economic theory. We will begin therefore by outlining the recent theoretical alternatives to expected utility, the reasons why they have been advocated, and the reasons why we feel these approaches are not adequate to handle the problems inherent in the use of surveys. Then we analyze the conceptual problems with cost-benefit analysis when individuals are uncertain about their own preferences, and the limitations of and uses of surveys in those circumstances, Next we briefly review psychological models of decision making of relevance to our problem. Finally, we develop a model of uncertain preferences which translates the psychological models into a cost-benefit framework. We use the structure briefly to examine the methods by which surveys may most effectively be used to gather information about the true underlying preferences.

4.4.3. Expected Utility Theory and Its Critics

For more than two decades expected utility theory has been the dominant paradigm in economics for modeling individual decision making under uncertainty. The main appeal of the formulation has been theoretical; the axioms from which the expected utility theorem is derived are simple, elegant, and for the most part intuitively unobjectionable. The framework has proved to be a solid foundation on which to develop both macroeconomic and microeconomic theories, and to be a handy and reliable maintained hypothesis in empirical work examining markets in which uncertainty was a consideration.

While the theory has been dominant, it has not been without objections and challenges, both on theoretical and empirical grounds. The theoretical objections have centered on the so-called independence axiom. The independence axiom, as illustrated in figure 4-4, says that lottery A is preferred to lottery B if and only if a compound lottery in which A is the prize with probability p and C is the prize with probability (1-p) is preferred to a lottery in which B is the prize with probability p and C is the prize with probability (l-p), for all A, B, C and p. Although this assumption seems a priori reasonable, it is not as fundamental as the other axioms upon which expected utility theory is based. The main objections to it have arisen from empirical results in which individuals' stated preferences appear to violate this axiom. Among the earliest examples of this violation are those by Allais (1953).

A simple version of the phenomenon noted by Allais can be described as follows.. In Figure 4-5 virtually all individuals of moderate income prefer $10,000 with certainty (call this outcome A) to a 50 percent chance at $30,000 (and a 50 percent chance of receiving nothing. Call this lottery B). On the other hand, as illustrated in Figure 4-6, many individuals prefer a .001 percent chance at $30,000 (call this X) to a .002 percent chance at $10,000 (call this Y). Holding to both of these announced preferences violates expected utility theory. To show this it is only necessary to realize the the distribution of outcomes in lottery X is equivalent to the distribution in a compound lottery where at the first stage there is a .002 percent chance of winning, where the prize is a ticket to lottery B, while lottery Y is a compound lottery in which there is a .002 percent chance of winning the prize, which is a ticket to A.

Allais cited the independence axiom as the weak link in the chain and called for its abondonment. Striking as examples of this form were, they had little effect on-the mainstream of economics, because Allais built no coherent theoretical structure to set as a rival to expected utility theory. The first completely developed analysis which dropped the independence axiom is by Machine (1982), who also surveys the empirical

Figure 4-4.   INDEPENDENCE AXIOM

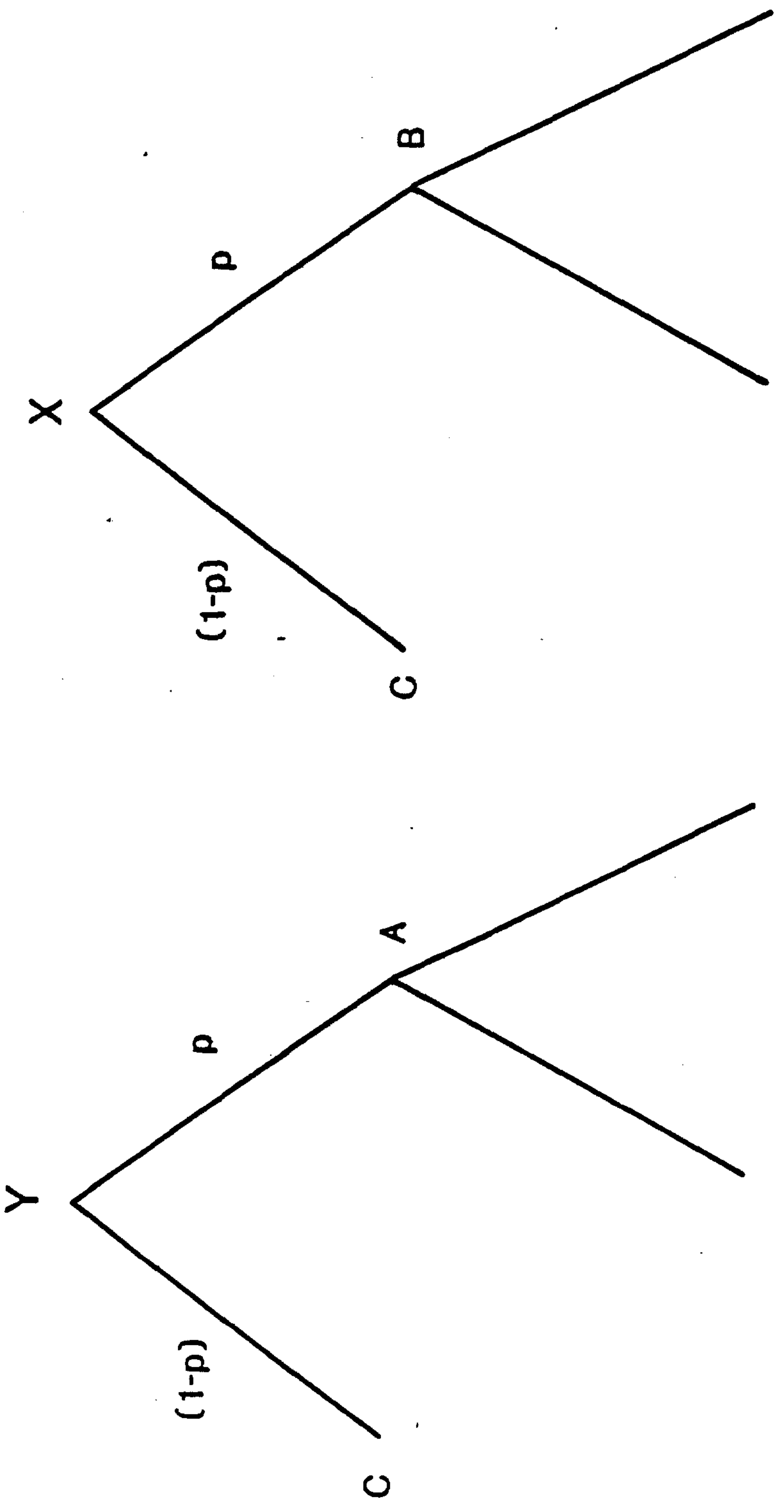


Figure 4-5. **ALLAIS** PARADOX (A)

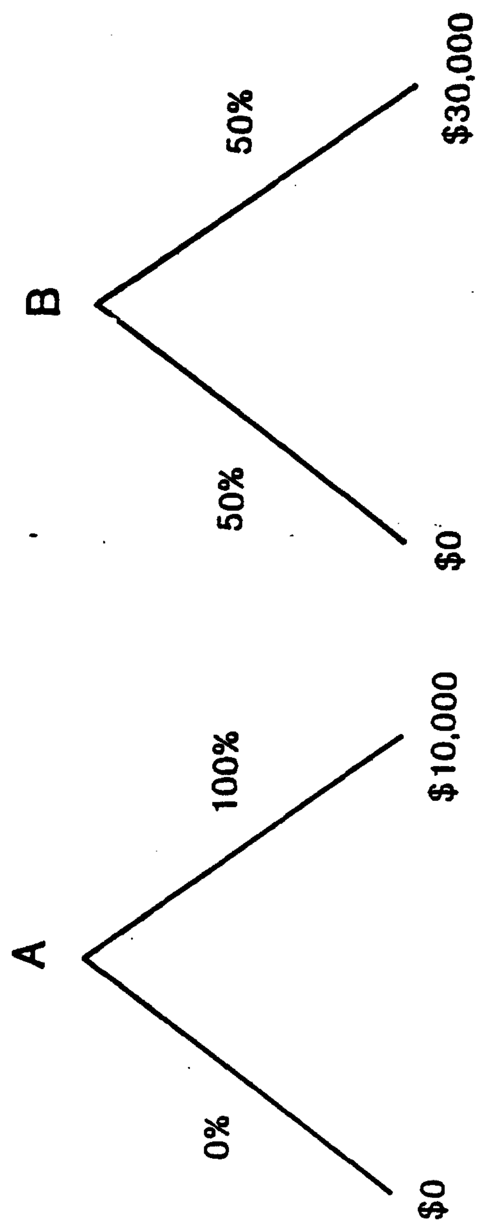
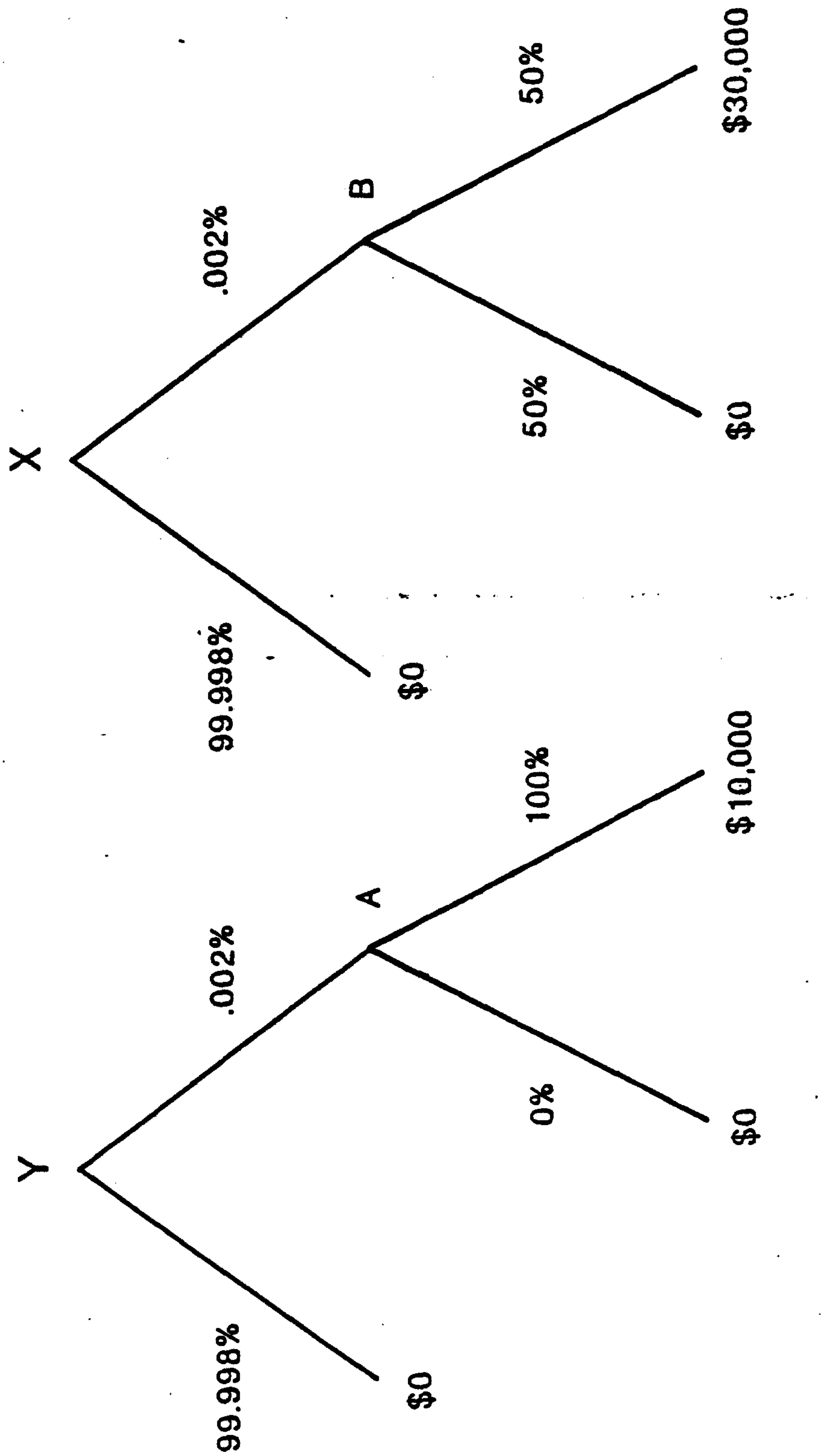


Figure 4-6. **ALLAIS** PARADOX (B)



objections to expected utility and indicates which of them his extended theory can address.

Machina analyses the extension of expected utility theory results when the independence axiom is replaced with the less-restrictive assumption that preferences are smooth in changes in gambles. He demonstrates that expected utility theory still holds as a local approximation describing individuals' tastes for relatively small changes in gambles around a (possibly random) initial wealth level. Any properties which we wished to attribute to expected utility functions, for example declining risk aversion, or regions of relative risk loving, can now be attributed to the so-called "local utility functions" at various initial wealth levels. This is valuable for it permits us to rationalize not only the Allais paradox, but also the observation by Markowitz (1952), that individuals continue to buy both insurance and lottery tickets as their wealth changes. Expected utility theory can rationalize purchases of each by postulating regions of risk aversion at levels of wealth below the initial wealth, and regions of risklovingat levels ofwealthabove the initial wealth. However, as the individual's wealth changes, and he moves out of the initial boundary level between these two regions, one sort of behavior or the other should be abandoned according to the simple theory, and this does not appear to happen. Machina resolves the problem by appeal to variations in the local utility function as the individual's wealth changes.

A similar type of analysis can rationalize the Allais paradoxes: the local utility function is again not independent of the entire set of outcomes available to the individual at the time the decision is made. Thus there is nothing unexpected in the fact that the existence of a chance at C affecting the preferences for A versus B.

However, as Machina himself notes, there are several observations in the experimental work on risk preferences that cannot be squared with expected utility theory even when extended in the Machina manner. Most of these are violations, not of the independence axiom, but of the assumption that preferences are dependent only on the distribution of outcomes that the lottery yields, not the form in which the lotteries are presented. In the language of psychology, stated preferences appear to depend on the context in which the alternatives are "framed."

A striking example of this phenomenon appears in the work of Kahneman and Tversky (1979). They build examples in which preferences are altered when initial wealth is increased by a fixed amount, and the outcome of the gambles offered is decreased by the same amount in all realizations. Note therefore that the assumption that is being violated is an extremely basic one. namely, that preferences depend only on the final distribution of outcomes. Another, equally basic situation of inconsistency of preferences is described in the work by Grether and Plott (1979). who trace the evidence of their particular "preference reversal phenomenon" through several experimenters' works. This phenomenon is the fact that individuals, when asked to state a certainty equivalent for a 'gamble, will often choose a value which is greater than the dollar value they will in fact choose in preference to that same lottery. That is, given a lottery A, an individual will claim that he is indifferent between A and some dollar payoff D, and then in fact if offered a choice between A and some lower payoff L, choose L. This observation apparently violates no less an assumption than the transitivity of preferences; no extension of "expected utility" theory can adqequately handle it, and in their survey Grether and Plott conclude that the explanation must lie in. some sort of information processing problem.

However, once we have decided that it will be necessary to include the difficulties of information processing as part of our modeling of the decisions made by individuals facing risk, then these same difficulties can be used to explain the other phenomena which the dropping of the independence assumption was intended to address (see below). Nor is the dropping of the independence assumption without cost. Observers have generally agreed as to the normative disirability of the independence assumption. If we are trying to develop a framework for cost-benefit analysis, these normative arguments carry considerable weight. For if we drop the independence assumption we will be faced with a certain time-inconsistency in our subjects' preferences over lotteries. While there is nothing self-contradictory in this fact, we will then discover that we can change individuals' welfare simply by restricting their ability to change their minds about which choices they will make,

For instance, suppose we use the lotteries described in figure 4-6. Suppose we start by only allowing the individual lottery B in the event that the .002 percent chance arises. Then before the outcome of this chance, the individual's utility is equal to the utility associated with lottery X. Now suppose we expand the choices available to include the choice either of lottery B or lottery A in the event that the chance arises. The result is a decrease in the individual's current utility from X to Y. The individual's reasoning against the increase in his choice set is as follows: "Should the chance arise I know I will pick lottery A, because as of that date I will prefer it to lottery B, but in fact, from my current perspective I prefer lottery A to lottery B, thus my utility has decreased by my not being able to prevent myself from picking this currently-less-desirable alternative."

Another recently revived alternative to expected utility--regret theory--generates similar difficulties. This alternative theory assumes that the individual decision maker makes choices based not on the distribution of outcomes, but on the distribution of the difference between the chosen outcome and the outcome not chosen. This approach, based in minimax strategy game theory, was a popular early rival to expected utility theory, and it has recently been advocated by Loomes and Sugden. A major difficulty with the theory is that it implies an intransitivity of preferences, since individual preferences are not independent of the set from which the choices are made. The authors of the article argue eloquently that there is nothing "irrational" about such a model of behavior, nor is there any logical inconsistency in the structure. Although this is true, allowing this assumption does equal damage to the welfare analysis. For if we let the government expand the set of available choices we again find that utility can decrease, as individuals choose less preferred alternatives because of the intrusion of seemingly irrelevant alternatives.

In short, it appears to us that the price in terms of difficulties with welfare analysis is too high to pay, especially given the less drastic modifications that can be made to rationalize the observed responses to risk surveys and still maintain the fundamental welfare-economics structure intact.

4.4.4. Conceptual Problems with Welfare Analysis When Tastes Are Uncertain

Thus we conclude that the best way to procede in trying to interpret surveys of individuals' attitudes towards risk is to retain the independence axiom but admit that individuals do not know their own tastes with certainty. There should be nothing counterintuitive in this position: Most people do not deal regularly with issues of risk; most people therefore are not likely to be very expert in stating their preferences over risky alternatives. Under the circumstances, it is not surprising that when presented with a complicated set of alternatives among which to choose, most people make choices thatseemto implythattheir preferences are intransitive. However, we would expect the same thing to happen if we presented real world consumers with multivariate bundles of goods and asked them to choose among them. As long as we kept the bundles the same in most dimensions and only varied a few at a time, we might have reasonable hope to obtain a consistent ranking. But when we ask individuals to rank among pairs of highly dissimilar bundles, we would not be surprised to find apparent inconsistencies in their preferences. Individuals are likely to make mistakes, and to be subject to the utility-equivalent of "optical illusions" when describing their preferences.

The crucial test is the subject's reaction if confronted with the apparent inconsistency of some set of preferences. Suppose we say to a particular individual after an interview "you have said you prefer A to B, you prefer B to C and you prefer C to A. Do you see any inconsistency in these statements?" If the individual's answer is "yes, upon reflection I prefer A to C: we are home free. If his answer is "yes, I see a problem there, but I cannot tell which of my statements are incorrect." Then we too have a problem, since the decision task is so difficult for the individual that he cannot straighten out his preferences even upon reflection. Nonetheless, our hypothesis of consistency of preferences is still intact. Only if the individual says "no, I see no problem at all with those statements" are we in deep trouble, for then the individual must mean by the word "preferences" something quite different from what we mean by the word. In the case of Grether and Plott's preference reversal phenomenon it is extremely likely that if confronted with the apparent contradictions in their statements the subjects would agree that their preferences would need revision. It is less clear from the evidence that this is the case in the Allais paradox cases. But at least in multiattribute problems, descriptions of individuals' decison making processes seem to indicate that transitivity of preferences are an underlying assumption in their own actions (Payne et al.).

To summarize, our position is the following: if individuals do not have consistent preferences and deny that their own preferences need be consistent, we cannot do welfare economics. If preferences are asserted by individuals to be consistent then there is at least the possibility that progress can be made. However, given we can no longer assume that individuals know their preferences, the question remains, "what is the correct set of criteria for making welfare judgments?"

One approach is to argue that the correct criterion is the criterion that would be used by the politician hoping for reelection. Voters make their decisions as to whom to reelect without being forced carfully to think through their casually stated preferences. If they do not know what their preferences would be if they had thought through the situation sufficiently, it is of no concern to the politician--those "true" preferences must be irrelevant for reelection. If that means that different preferences might be elicited by stating the decision problem in different ways, then so be it; we must state the decison problem in the form that the politician in power chooses to state it, and then record the answers as accurately as possible.

The drawbacks of this point of view are obvious. Presumably if the approach were explained to any voter, he would prefer that alternative criteria be adopted by the investigator. One alternative appraoch is the following: the problem stems from the difficulty in eliciting individual preferences--this is always a costly matter, as polling organizations insist. It is particularly difficult if individuals themselves find it costly to determine their own preferences. Under the circumstances, a voter might prefer that the investigator use more extended surveys, spending sufficient time and resources with each indivdiual interviewed. Care should be exercised by going through the initially stated preferences of the individual in sufficient detail to determine if there are any inconsistencies in them, by double checking those inconsistencies with the individual, by presenting the decision problem in several different formulations to double check that the individual is not being swayed by illusions of the presentaiton, and finally by giving the individual sufficient practice at answering decision problems of the sort we are dealing with to allow him to train himself in determining his own preferences.

This approach, if explained to the average voter, would presumably draw greater support than the initial one. Even if the voter himself is not picked for the interview, if he regards himself as sufficiently typical in his tastes, he will prefer having a proxy go through this more extensive interview to get at what his own true preferences are likely to be. Nonetheless the average voter is still likely to have reservations about this procedure. The extensive interviewing is largely a matter of "education." From the investigator's point of view, it is the individual educating himself about his own preferences. From the point of view of a suspicious outsider, it could easily be the interviewer educating the subject as to what his preferences should be. These suspicions are likely to be particularly strong if the conclusions of the investigation go against the surface preference of the outside observer. In short, the procedure must be carefully tailored to ensure that there is no presumption as to what are the "right" or "wrong" preferences in the situation--beyond the basic requirement of transitivity.

This is particularly difficult to achieve since people will be dealing with questions to which moral strictures are commonly placed. Many people believe gambling to be morally wrong, and maintenance of health at all costs morally correct. In assessing the value to one individual of another individual's health, moral perceptions will play even greater a role. One way of characterizing the difficulty is to describe an individual as having two sets of preferences--the preferences of his "selfish self" and the preferences of his "socially conscious self"-- and then trying to decide, not which preferences actually count in individual decision making, but which should count for welfare analysis. Another, probably more fruitful way of describing the situation is to say that individuals' stated preferences depend on their audience. Many of the causes of this dependence can be reduced to a desire for various sorts of approval--desire to appear to be a sophisticate, a moral individual, a member of the team. Nonetheless, we do not need to distinguish between the various reasons for stated preferences to vary. Our operational definition of "true" preferences is those that would dominate in the privacy of one's own home-- or in the privacy of the voting booth. It still then is an open question as to whether the normative standard ought to be the sum of individuals' private preferences but as a practical matter it should not be surprising to find that indivdiuals will report different preferences to an interviewer than they will declare to friends or through their actions. Although this difficulty of moral overtones on prferences is not a primary focus of this work, it is a problem which will inevitably arise in the interviewing procedure. Ultimately there is probably no resolution of the issue and the only procedure open to the investigator will be an examinaton of the extent to which individual preferences are influenced by the groups in which they find themselves during the interview.

4.4.5. Psychological Studies

Cognitive psychologists have not been concerned with the ethical/public policy question of which statements of preferences should be taken into account in the determination of public policy. On the other hand, they have studied much more carefully the question of what structures we can use to model preferences which underlie the apparently inconsistent choices individuals make.

An early version of a formulation which allows for inconsistent answers to choice questions is the random utility model (Thurstone), which in effect posits the existence of a distribution over possible consistent underlying preferences, and then assumes that each question is answered with respect to a draw from one of the distributions. Note that the random utility model is not, easily reconciled with economic models of decision making. For instance, it is not equivalent to a model in which the consumer has Bayesian priors about his own preferences. Such an account would instead yield a more complicated, but still perfectly consistent set of preferences over lotteries--indeed the structure could be aggregated into a state preference model in the ordinary way,

The assumption underlying the Thurstone model is that there is a difference between the purely intellectual question "which do you like better?" and the economic question, "which will you take?" (compare Little). The random utility model simply assumes that over time an individual's preferences change randomly so that the answer can vary stochastically' to the question when repeated. An alternative formulation, and one much more useful from our point of view, is that the underlying preferences are constant but the structure by which these preferences are translated into ‘decisions is stochastic (Luce, Tversky). There has been much concern in that literature with the equivalences or non-equivalences between various formulations of the random utility model. For our purposes, however, the issues are two: what rational calculus can underly such a model and what implications will it have for welfare economics? Our job as economists is to delve through the stochastic portion to the underlying preferences; our task in a survey then is to minimize the noisiness of the response, and it therefore becomes important to understand where the noisiness comes from.

This investigation belongs to the subfield of psychology known as decision research. Its investigation involves several methohologies not normally used in economics, including such techniques as "verbal protocols" (the investigation of subjects' reports of their own behavior) and records of subjects' use of information in the decision process (Payne et al.). A useful distinction made in this field is between decision making based on alternative ranking versus decison making based on attribute rankings. Alternative'ranking involves the process normallv treated in economics--all alternatives are measured in some common scaling and the highest of these scalings indicates the preferred alternative1 In, attribute processes the various attributes attached to the alternatives are ranked and then these rankings in various dimensions are compared to determine an overall ranking. The latter is useful when the tradeoffs between the different attributes are difficult for the individual to determine, but the cost is that such systems of decision making easily result in intransitive rankings. Various authors in this literature have focused on various procedures by which attribute rankings are accomplished (a brief survey is included in Aschenbrenner). Kahneman and Tversky focus on the various considerations that arise in the process of decision making in complicated situations.

Among them are the "isolation" phenomenon and the "anchoring" phenomenon. By "isolation" is meant the focusing on the aspects that are perceived as the main contrasts between the two available alternatives, treating as precisely equal the aspects perceived as of smaller difference. Thus the Allais paradox can be explained as an approximation'error due to the decision maker's initial estimate that there is relatively little difference between probabilities of .002 and .001 as opposed to differences between outcomes of $10,000 and $30,000. The phenomenon of "anchoring" is a perceptual dependence on initial conditions, a tendency to estimate values as closer to values already examined. Grether and Plott's preference reversal can then be rationalized as a tendency for certainty equivalents to be anchored to the winning payoff in a gamble.

Thus it would appear that the phenomena most likely to pose problems in interpreting surveys of risk preferences can be understood without abandoning the independence assumption. Our job is then to provide an economic basis which can rationalize the use of such structures.

4.4.6. Components of an Economic Model

The basic component of the model is a set of prior preferences', which describe the individual's beliefs about his own tastes in the event that he makes no expenditures to examine those tastes.

The individual can also expend an amount of psychic costs to improve the sample of his tastes. The expenditure gives him a draw as to his own tastes, which in conjunction with his priors can be used to derive new tastes. Each new draw can be added to the set.

We then need memory to store the draws. The simplest story is that memory is infinite, so that each draw is stored and we can at any point find the set of consistent preferences representing an individual's beliefs at that point. The more difficult, but possibly more interesting model, has finite memory, so that after some point more draws can only be added by dropping the information in earlier draws.

The next step is to allow degrees of investment in reducing the uncertainty over the prior preferences. Greater investment entails a greater psychic cost, but allows a sharper prediction as to preferences. Given previously learned information we can imagine the individual as choosing to think more or less carefully in attempting to answer the latest question. This is a useful distinction for understanding the problems of "anchoring," since individuals' initial response will make it worthwhile not to spend as much energy in attempting to answer subsequent questions, relying instead on the initial answers to provide clues. It also has testible implications in the case where memory is limited, since the anchoring should diminish as the length of time between related questions on the survey increases.

So far we have not discussed the role of the closeness of one outcome to another. To do so requires the addition of a metric to the problem, which metric describes the "similarity" between outcomes, and therefore the degree to which the guess on one outcome affects the likelihood of responses on other outcomes. Once this metric is established it becomes useful to describe the situation where different questions elicit different sorts of investments in introspection, some being more useful to anwering one, and some to answering another question.

Finally, we will drop the assumption of unbiased estimating by the decision maker, and consider the effects of limited forms of bias on the outcomes. This last modification will be necessary to understand preference reversals due to "framing."

4.4.7. Formal Model Statement

Suppose that there are I alternatives being considered, each with an unknown utility U_i. Let U be the vector of these utilities, and let F(U) be the joint probability distribution over U. To begin with we will take the U_i to be i.i.d. Throughout the the paper our examples will assume that the U_i's vary normally and independently, with prior means m_i and precisions h_i (i.e. l/variance).

The individual can, by spending a psychic cost of k, receive extra information about his true preferences. We assume that the extra information gained by this "introspection" is a draw of two random variables which are estimates of U_i and U_j which we call V_i and V_j respectively. We assume

$$V_i = U_i + e_i,$$

where e_i is measurement error which in our examples we will assume is distributed as a normal with mean 0 and precision g_i, and independent of all other errors e and of all U_i's (and similarly for the distribution V_j).

Given any string of information $\{V_1, V_2, \ldots\} = S$, we can derive posterior distributions of the' utilities of the alternatives $F(U|S)$. In the case of normal distributions, a simple application of Bayes's rule shows that, given a draw of V_i, the posterior distribution of U_i is normal with mean

$$m_i^*(V_i) = (m_i h_i + v_i g_i)/(h_i + g_i)$$

and precision

$$h_i + g_i.$$

If no draw is made, the individual's expected utility if given a choice between U_1 and U_2 is

$$\max(m1, m_2).$$

If the draw is made, utility is

$$\max(\{m_1^*(V_1), m_2^*(V_2)\} - k).$$

The first model we will consider is to solve the following Bayesian decision problem: The individual is presented with a series of alternatives, where each alternative is a pair of outcomes, one of which he will receive. He is asked to make his choice. For simplicity we will assume that at each instant he treats the question being asked him as the last problem he will face. (In fact, the problem is more complicated since an individual might be expected to anticipate that a series of questions will occur and modify his introspection accordingly. We will ignore this refinement. If the reader wishes, he can assume that the survey is structured so that at each stage there is an extremely low probability of any one participant's receiving an additional question. This makes it possible to ignore the likelihood of extra questions at every stage.)

The decision problem for the individual, namely how many draws to invest in, can be formulated either sequentially or non-sequentially. These formulations mirror the strategies analyzed in the research literature. The non-sequential formulation (Stigler, 1961) has the individual precommit to a fixed number of introspections. The sequential formulation (Kohn and Shavell, 1974) allows the individual at every step to consider further expenditure on introspection based on the results he has learned so far. Although the specific optimal strategies differ between these two formulations, the general outlines are similar. Since our problem is a specific version of the search problem, we will consider ourselves free to switch back and forth between the two formulations in the examples that follow, depending on which yields the more tractable analysis in any specific application.

In this structure. it will not generally be optimal for the individual to eliminate all uncertainty about his own tastes -- indeed it will not generally be possible. It can be shown that:

Theorem 4-1: Less information is acquired

1) The greater the difference between prior estimates of the m_i's.

2) The lower the variance of the prior estimate of either U_i.

3) The greater the variance of the noise in any estimate.

4) The greater the cost of information acquisition.

On the other hand, the posterior announced preferences are more accurate

1) The greater the difference between prior estimates of of the m_i's.

2) The lower the variance of the prior estimate of either U_i.

3) The lower the variance of the noise of any estimate.

4) The lower the cost of the acquisition of information.

In actual experiments, it is often the case that instead of receiving the payoff with certainty, the subject only receives it with some probability less than one. For this modification we have:

Theorem 4-2: When the probability of actually receiving the payoff decreases, subjects

1) expend less effort in determining their own tastes, and

2) give less accurate ex post predictions of those tastes.

These conclusions are immediate from the model, but they do lead to some natural considerations for survey design: Difficult questions will simply not be given much consideration. Questions which yield potentially great payoffs in that it is costly to answer incorrectly will be given more consideration, but ex post are still likely to lead to inaccurate answers. Questions which the individual considers easy to answer ex ante will not be given much additional consideration by the individual.

Next we consider the effects of the answer to one question on the answer to subsequent questions. Note that in this model, repeating the same question several times in succession yields no new information, since the individual has already optimized and thus has no reason to make further introspections. However it turns out that expending information on answers to one question will, in general, yield information useful to answers to other questions.

Suppose we ask the individual about a completely new pair of alternatives. In the model in which all alternatives have independent distributions, previous introspection has thrown no light on his preferences with regard to these new alternatives. Thus his behavior is the same as if the questions had never been asked. However, consider the case where the second question gives us as an alternative one of the options already considered in the first question. Now previously gathered information becomes useful and the subjects' responses will be affected.

There are two considerations. First, having answered one question already means that the answer to the second question will start from a more accurate assessment of the beliefs than would otherwise be obtained. This decreases the likelihood of extra investment but increases the expected accuracy of the ex post announced choice.

The second consideration depends on the realizations actually obtained in response to the first question. If the realization causes expected values of the two alternatives in the second question to move further apart, then the likelihood is that there will be less investment in examining the second question. However, if the realizations bring the values of the two alternatives closer together, then investment in answering the second question will tend to increase. On average, these two possibilities balance and we have the first. consideration dominating. Therefore although the presence of preceding related questions on a survey may in any instance increase or decrease the amount of investment used in determining the answer to subsequent questions, we can nevertheless conclude that:

Theorem 4-3: Expenditure on introspection on average decreases through the survey, while accuracy increases.

'Among other things, this result predicts a decline over time in the attention paid by respondents to questions within a survey-- a tendency often observed-- without needing to postulate a fatigue factor.

More generally this interrelationship will be observed in any model in which answers to one question help answer another We will consider in more detail below the case where priors for various alternatives are no longer independent. But the phenomenon can occur when priors are independent as long as there is some dependency in the'sampling. The example of this discussed above is the simplest one. Another case occurs when introspection reveals information not about the 'two alternatives independently, but only about the difference between their values

$$U_j - U_i + e$$

(We will call this the case of "Sampling of differences.") In this case, whenever we find that an individual indicates that i is preferred to j, it means that we can expect that i has a higher value than initially anticipated, and therefore is more likely to be preferred to other alternatives as well, and conversely for j. Thus even in the case of independent valuations, a primitive form of anchoring emerges.

4.4.8. Answering a Series of Questions

Given this structure,. there will be nothing paradoxical about 'a sequence of answers to questions leading to apparent intransitivities; it will simply be the case that between answers additional information has been derived. It will also be perfectly possible for individuals to reverse their answers on subsequent repetitions of a question, provided that other questions have intervened which have led the individual to seek more information.

Suppose we now consider asking a third question and that there are only the three alternatives U_1, U_2, U_3 under consideration. If preferences are perfectly known, then the entirety of the information can always be revealed with three questions, and often with two. If preferences can only be determined with a cost, there may be a gain from asking an apparently redundant question. In our model we have:

Theorem 4-4: Suppose the first question determines that U_1 is preferred to U_2 and the second question determines that U_2 is preferred to U_3. Then

1) In response to the third question "Do you prefer U_3 to U_1?" there is a finite possibility of the answer exhibiting an apparent intransitivity.

2) In response to the third question "Do you prefer U_2 to U_1?" there is a finite probability of the answer exhibiting a reversal of preferences.

In any case, later answers are more likely to reflect true preferences than are early answers in the list.

Theorem 4-5: Suppose furthermore, that we continue to cycle through the questions in the same order indefinitely. Then the probability is zero that there is no number n such that for all questions beyond the nth no further investment in introspection is made. In order words, responses eventually settle down and preference reversal ceases. Moreover, at the point where further investment has ceased, there will be no intransitivities in the response.

In short, this model with infinite capacity for recall allows preference reversal and intransitivity, but only as transient phenomena. Once further investment in introspection ceases, preferences are stable and transitive. This result, although useful as an insight, is not as strong as it might appear, for it is not possible based solely on the responses to determine whether investment in introspection has ceased. In our normal distribution model we have the following result as well:

Theorem 4-6: For any number n there is a finite probability of obtaining unchanged results through n cycles with no intransitivities, and a preference reversal in the n+1st cycle. The proof of this theorem depends on the fact that normal distributions are unbounded. We conjecture that if the model is modified to deal with bounded distributions, this last theorem will no longer hold and more positive results can be obtained.

So far none of our conclusions are altered if we use the "comparison" formulation for introspection (recall that this is the formulation in which draws give not two values V_i and V_j, but merely the difference between them). The following result depends specifically on using the comparison formulation.

Theorem 4-7: Suppose that the initial question determines that U_1 is preferred to U_2 and the second question determines that U_3 is preferred to U_2. Then if investment yields only an estimate of the difference between the valuations of alternatives, it cannot be the case that a third question reverses the answer to the first question.

Proof: There is no incentive for further investment in response to the third question, since the second question only reduces the estimate of U_2.

If introspection gives estimates of both U_i and U_j, the conclusion of the theorem is weakened:

Theorem 4-8: Suppose the initial question determines that U_1 is preferred to U_2. Then preference reversal in question 3 is more likely if question 2 determines that U_2 is preferred to U_3

than if it determines the reverse.

In the case where two questions have already been asked, we are now in a position to compare the relative usefulness of various possible third questions. Here are the two relevant cases to consider:

Case I: Suppose the first question reveals Ul is preferred to U_2 and the second question reveals that U_2 is preferred to U_3. Then the most useful third question is to compare Ul with U_2 again, rather than to compare U_1 with U_3. In.both cases it is optimal for the investigator to base his predictions of true underlying preferences on the last two of the three responses; however, these optimal predictions are more accurate when question 1 is repeated than when the new comparison is made.

Case II: Suppose the first question reveals U_1 is preferred to U_2 and the second question reveals U_3 is preferred to U_2. Then the most useful third question is obviously to compare U_1 with U_3.

The resultant principles can be summarized quite neatly: Redundancy in questions can be useful. If redundant questions are used, it is more useful to doublecheck the earliest questions and the ones which full ranking indicates represent the closest calls. When redundant questions are used, rely on later rather than earlier answers.

4.4.9. Comparison Versus Scaling Questions

For the purpose of this section, we will assume that introspection yields an estimate of the value of only one alternative. We now wish to consider the difference between the effects of the following two questions: comparison questions ("Which alternative do you prefer?") and scaling questions ("How much do you value alternative X?") Both are commonly used in risk analysis and risk surveys and some of the difficulties with the results stem from the non-comparabilities of the two sorts of questions.

We need to establish some payoff associated with the answer to the latter question. In actual surveys this is typically accomplished by announcing to the individual that he will participate in what is equivalent to a second-price auction (Vickrey) with his announced valuation as his bid. Since truth-telling is a dominant strategy in such circumstances, in the case where introspection is costless, this gives the individual an incentive to answer correctly.

Giving the individual whichever alternative he says he prefers is also an incentive to answer accurately. The issue then is which format leads to greater introspection and therefore greater accuracy in answering. In fact, comparison **questions** are special cases of scaling questions, since the second price auction framework in effect chooses the **value** of the alternative randomly and then presents the individual the realization, if the individual's bid indicated he would prefer it, and the initial alternative otherwise. A comparison question is thus a special auction in which the bid which will win is known with certainty beforehand.

Therefore the relative merits of the two forms of question can be determined by resolving the following: Which random distribution of alternative valuations induces the individual to invest most in determining his valuation of a specific alternative? The answer is the following:

Theorem 4-9: Investment in introspection in evaluating a propose offer is greatest when the value of the alternative to receive-if the offer is refuse has a distribution with mass concentrated at the expected prior utility of the proposed offer.

Proof: (Outline) By the results of the initial section, we know that among offers with identical variance, the one giving the closet mean utility to the proposed offer elicits the greatest investment. Thus concentrating all mass at the mean is of greater value than dissipating it across alternative possibilities.

If we know the individual's prior mean, then the best way to elicit accurate preferences is to have the individual choose between the alternative and the certain offer of the prior mean utility. In any application, of course, we will not know the **decison** maker's priors. Thus **making a** fixed alternative offer will yield variable amounts of investment across individuals depending on how close it matched each individual's prior mean. One approach then is to ask casually what the mean valuation of the individual is ("how much is this offer worth to you?") and then to **give the** offer or the estimated value to the individual, whichever he prefers. The paradox of the difference between estimates made in some of the preference reversal literature is partially resolved then by the fact that greater investment is made when the actual offers are in prospect. This framework does, however, yield refutable propositions, since the initially stated preferences should be reversed about half of the time. If reversal occurs more than half the **time**, we must assume biases in the individual's initial estimates. Analysis of this situation must wait until the final section.

In any event, this analysis also gives **a** useful rule of thumb for scaling the distribution of offers in the alternative used in **a** scaling question: **They** should mirror the investigator's **estimate of** prior means in **a** population sample.

4.4.10. More General Distributions of Priors

Thus far we have assumed a great degree of homogeneity: All alternatives and all estimations have been assumed to have independent distributions. In fact, much of the richness of a real decision problem comes from the non-independence of these distributions.

The structure we have developed allows for outcomes to be "similar" in several senses. First, two outcomes may have the same expected utility. Second, two outcomes may be considered similar if it is relatively easy to tell which one is preferred to the other. Finally, outcomes may be similar because there is a correlation between information about one of them and information about the other -- so that one becomes a useful predictor of the other. Each of these notions is important in describing the effects of learning about preferences and the relationship between learning about one alternative and learning about the next. In this section we begin to establish a framework which will enable us to explore this relationship.

To consider the effects of non-independence, we will assume that all alternatives have a factor representation, so that the utility associated with any alternative is

$$U_i = \text{Summation of } b_i X_i,$$

where the b's are weights and the X's are i.i.d. underlying factors. If we make this assumption, then we will describe one alternative U_i as a good predictor of another U_j if the two are closely correlated. In this framework correlation is simply

$$\text{Summation over i and j of } b_i b_j (\text{Summation over i of } b_i^2$$

$$\text{summation over j of } b_j^2)^{1/2}.$$

In this framework, the answers to a question about an alternative are affected similarly by having asked previous questions about it or by having asked previous questions about a good predictor of it. In either case, the variance of estimate of the alternative is reduced, answers become more accurate, and the likelihood of further investment in introspection declines. In particular, any conclusion from preceding sections about the behavior of multiple questions applies approximately when all the alternatives in one of the questions in the sequence is replaced by a good predictor of those questions with mean utilities scaled up or down proportionately.

A second form of interdependence is attributable to interrelations in the error structure in the sampling. Suppose again that all the U_i's are independent, but that the e's in the various draws have a factor representation:

$$e_i = \text{Summation } a_i x_i.$$

The closer th'e correlation for any two alternatives i, j, the more can be learned from a given attempt to compare them. If we identify the x_i's with various measurement errors associated with the forms in which alternatives are presented, it is apparent that we desire a presentation which is as consistent as possible across alternatives. Moreover, if questions are designed to give the individual aid in learning about the forms of measurement error, then we can hope that associated errors may disappear in subsequent questions, as values of particular x_i's are learned.

So far we have assumed that the individual is passive in his choice of alternatives upon which to make introspections, only choosing the number of examinations to make of any given alternative. As long as homogeneity assumptions are maintained, there was little cost associated with this additional simplification; in answering a question about preferences between U_i and U_j it was always more useful to introspect on those two alternative than upon any other set. Once homogeneity is dropped however this need no longer be the case, as the following example demonstrates:

Example: Suppose there are three alternatives U_1, U_2, and U_3 and that U_1 is a good predictor of U_2 while U_3 is independent of either. Suppose furthermore that the error structures for U_2 and U_3 are highly correlated, while.the error structure for U_1 is uncorrelated with the other two. Then if the correlation between U_1 and U2 is sufficiently high, it is optimal for the individual to decide between U_1 and U_3 by introspecting on U_2 and U_3.

In other words, the structure is now sufficiently rich to rationalize the use of proxies and heuristics. If a decision is to be made where the measurement problems are sufficiently difficult, then the decison maker finds it advantageous in his work to substitute for the initial decision a set of alternatives which are good predictors but for which the measurement problems are less acute -- for instance, to simplify a complex lottery by substituting certainty equivalents for certain branches.

Note that although this structure can explain the use of heuristics, it cannot explain any biases observed in the heuristics used. For example suppose w.e structured a problem so as to make one set of heuristics most natural in one instance and a second set in a second instance. The model as it stands would not predict that every individual's answer be identical in the two instances, but it would predict that on average stated preferences would be the same in either realization.

4.4.11. The Effect of Limited Memory

It is important to realize that the framework as it has been described so far still has a significant limitation. An important simplifying assumption we have used is that of "perfect recall." No experiment, once made, is ever forgotten. Information becomes more and more precise as more and more questions are asked. This simplifying assumption leads to testable implications. As noted before, preference reversals and intransitivities occur in the model, but as transient phenomena. As more and more questions are asked, the number of reversals becomes rarer and rarer, and the effects of anchoring to the previous questions dies out.

If these predicitions are not upheld by the data, a natural way to keep preference reversals occurring is to allow for imperfect memory. We simply need to assume a limited memory capacity, so that records can only be kept for a fixed number of experiments. If the number of examinations made exceeds this fixed limit then each new examination replaces an earlier result. Beyond that point, we simply condition priors only by the last N observations (where N is the capacity of memory) rather than by the entire history.

Note in particular that this model is an extension of the basic random utility model. In our new framework we would interpret the random utility model as a special case in which memory can only contain one experiment at a time. A limitation of the simple random utility model is that responses cannot be autocorrelated, as they can when memory is allowed. On the other hand, in a finite memory model there is no tendency for preference reversals to die away or expenditure on introspection to cease. The following results are immediate:

Theorem 4-10: The smaller N, the more common are preference reversals, and the more likely are observed intransitivites.

Theorem 4-11: For a given question let R(n) be the fraction of the times that the answer is reversed between instances of posing the question, when the number of intervening questions is n. Assume that for some n, say n^*, there is no memory--i.e., none of the introspection that entered into answering any question is left n^* questions later. Then any period n less than n^*, $R(n)/R(n^*)$ measures the extent to which memory endures n periods.

Again, these results, although useful conceptually, are of less use in empirical implementations if the acutal capacity of memory is large. For if it is, the interview session would have to continue sufficiently long to gather a large amount of data relative to the memory capacity. Some investigators have attempted to overcome this limitation by posing some questions in several sessions with large amounts of time intervening. The theorems may serve as a basis of determining the success of this technique.

4.4.12. Biases

In the previous sections we considered several cases where inconsistencies resulted; however the Bayesian structure left as an implication that the inconsistencies could not systematically be weighted in one direction or another. In this final section we develop models 'which will allow for systematic biases in individuals* estimates.

It is extremely difficult to develop a Bayesian account in which individuals are subject to bias. For example, consider a problem in which an individual is paid a reward for correctly estimating the length of a line. Suppose he has a measuring stick which is biased, and suppose he has had previous experiences with the biases of this measuring stick. Then his estimates will be made so as to undo any such biases. The only waythatthere will be a biased estimate is if the individual has not yet learned the biases of his instruments; once learned, rationality requires that they be compensated for.

In the case of estimating the utility of prospects, it is easy to believe that individuals have not yet learned all of the biases in their measurements. It is also easy to believe that unless they experience the gambles they are estimating their preferences over, they will not learn these biases during a questioning session, except inasmuch as these biases lead them into a logical contradiction.

On the other hand, we will wish to be extremely careful in incorporating biases into the model. The difficulty with assuming them is that they are too powerful. By assuming sufficiently complicated forms of bias it is possible to rationalize any sequence of preference announcements. Therefore in this section we will content ourselves with modeling the biases as occurring only in the priors and not anywhere else in the description. At one point we will demonstrate that for a certain class of examples this is informationally equivalent to assuming that the biases occur elsewhere.

The introduction of biases imposes a conceptual problem: In what sense can we obtain evidence of biases? We propose the following interpretation: Biases can be evident from a systematic set of information which influences tastes. For instance, if the data show a systematic tendency for alternative 2 to be valued more highly than alternative 1 at the beginnning of an interview than at the end, then this is evidence of some bias; individuals in initial periods might be expected to take advantage of this statistical regularity as a source of exploitable information about true preferences.

These biases can be incorporated by assuming bias In the individual's priors. Let us suppose that individual preferences are drawn from a population with some given distribution. If individuals' priors are unbiased, then their priors as to their own tastes equal this population distribution. More generally, in cases where not all individuals are identical a priori, prior beliefs are defined as unbiased if for any particular prior, the sample distribution of, true beliefs of individuals holding that prior is identical with the prior.

We consider only the case of infinite memory. In this case "true" preferences are simply the asymptotic distribution after infinite numbers of samplings. Moreover, in this case, since the influence of priors dies out with time, biases disapppear. The existence of such biases can easily be tested, by comparing distributions of preferences implicit in initial questions on a survey with those implicit in final questions on a survey. The result of such an investigation will be of use in adjusting the results of short surveys to correct for prior biases.

A second way of formulating the account is to assume the biases are not in the priors but in the process of introspection. For instance, imagine that in introspections about one outcome U_1, the mean of measurment error e_1 is not zero, while in the corresponding outcome U_2 the mean is zero. However suppose that both e_1 and e_2 are treated by the decision maker as being zero-mean variables. Then the greater the amount of introspection that has occurred the more likely alternative 1 is to be preferred to alternative 2. Of course identical results would be obtained if priors were biased against alternative 1 and introspection were unbaised. Thus we will continue to use the 'formulation in which we ascribe all bias to the priors.

Similar, but more subtle forms of bias can be demonstrated through over-dependence on initial introspections, over-valuation of current information, and so forth. In all cases, the test of bias boils down to a claim that statistically, the answer to a question conditioned on any information set or a set of previous questions should equal the answer to the question conditioned on any additional information. If not, then, the earlier estimates were not making use of the available information. To have anchoring in this sense will require bias.

For our purposes, the most interesting example of bias is the case where the conditioning event is the form in which an alternative is presented. If there is no bias in the preference priors then statistically about as many people should prefer an alternative independent of the form of its presentation. In what follows we will generate an account within which biased priors can account for the inconsistencies and therefore can generate preference reversals of the form described in Grether and Plott.

4.4.13. Example of Biased Priors Generating Preference Reversals

Suppose U_1 is a complicated ● lcornative which has a factor structure

$$X_1 + X_2 + X_3 .$$

Suppose U_2 has the structure X_1+X_2; and, suppose U_3 has the structure X_1+X_3; also, suppose we wish to compare U_1 with U_4 which has the structure X_4. All X's are i.i.d. normal.

Suppose that the measurement error structure for the U's is

$$V_1 = U_1 + e_1$$

$$V_2 = U_2$$

$$V_3 = U_3$$

$$V_4 = U_4 + e_4 .$$

Suppose that e_1 is large compared to X_2 or X_3 so that it makes sense to compare U_4 with one of the predictors U_2 or U_3 rather than directly with U_1.

Suppose that U_2 and U_3 are ex ante identical so that it does not matter which the comparison is made with and finally suppose that the costs k are sufficiently great that a single draw is optimal.

Under these circumstances, without bias we would predict that statistical results would pick U_1 or U_4 with frequencies independent of whether V_2 or V_3 were used as the predictor. On the other hand suppose the true distribution for U_2 is

$$X_1+X_2+h$$

where h is positive. Then although the indivdiual treats the predicting alternatives as equivalent to alternative U_1, alternative 2 is likelytobe preferred to 1. The result is that U_1 is announced as preferred to U_4 more often if the comparison is carried out by means of U_2 than if it is carried out by means of U_3.

If the biases in individuals' estimations enter through the priors as we have described them here, then we have a testable implication. Questions asking the individual to compare U_1 with U_2 or U_3 will cause the individual to invest in introspection along those dimensions, reducing the influence of the priors and making it more likely that h is included in the measurement Thus we have:

Theorem 4-12: If biases occur in the priors then they will be reduced by questions which focus on the comparisons in which the biases occur.

In this example, if two presentations of the data apparently lead to different preferences, then the biases might be reduced by asking directly for comparisons either of the two presentations, or of each with the predictor which we expect has been derived from it.

4.4.14. Summary and Impliciations for Contingent Valuation

The model of uncertain preferencess in section 4.4 provides a framework to guide the application of contingent market methods to estimate the value of health risk reduction. Following a critique of expected utility theory and a discussion of the theory of individual values and behavior towards risk, a series of theorems have been developed that resolve difficulties with survey responses in terms of the behavior of a rational respondent making a costly examination of his own preferences when faced with questions that call them into play perhaps for the first time.

The key to the problem of obtaining consistent, valid measures of risk values, according to the theory that has been developed in section 4.4, is dealing with the fact that people are often highly uncertain about what their risk preferences and values actually are. This is to be expected because people infrequently have occasion to think carefully about risky events. They seldom have occasion to examine their own reactions to the influences to opinion-molding surface events. Careful, systematic reflection is required, just as is required before deciding on an operation, a risky investment, or other difficult decisions that arise from time to time in everyone's life. While bias may enter into the valuation process, the economic approach of section 4.4 postulates that people learn to correct for the influence of their own biases when they become aware of them. A model has been developed and a series of theorems derived that have implications applicable to the task of eliciting consistent, valid risk reduction values.

The propositions of this section coming from a model of rational behavior replace assertions from the psychology literature that apparent preference reversals and sensitivity to framing show that people are irrational. In the present section, these phenomena are viewed as being due to the costliness of information.

Theorem 4-l concerns reducing an individual's uncertainty about his own preferences. The question posed is how an individual can make the best choice when faced with a pair of alternatives. The theorem says that less new information is required the greater the difference in the value received from each available choice. It also says that the more certain the individual is about the values of the alternatives, the less new information is required to make the right choice. Finally, less new information will be acquired the greater the cost of acquisition.

The reminder of theorem 4-l contain several propositions about the accuracy of preferences that are stated after an individual has acquired additional information. The theorem holds that announced preferences are more accurate the greater the difference in value received from each available choice. Preferences are stated more accurately the more certain individuals are about the value of the alternatives they face. Finally, announced preferences are more accurate the lower the cost of acquiring new information.

An application of theorem 4-l is found in the use of the floating starting point in sequence of iterative bids. Consider the 7-symptom Health Questionnaire: One day, reproduced in Appendix A.1 of section 3. The sequence proceeds from an arbitrary startingbid of $100 to get rid of the least bothersome symptom. The starting point for the next bid, concerning the most bothersome symptom, is set at twice the first bid, based on the guess that such a value might be a fairly close approximation to the respondent's value. The theorem says that the respondent will think more carefully about his preferences at the outset the closer the guess is to his value for the contingent market product.

Theorem 4-2 concerns outcomes of risky situations in which the values associated with alternatives may not actually be received, but are received only with a probability less than one. The theorem states that people expend less effort in getting to know their own preferences the smaller the probability of actually receiving the stated values of alternative choices available to them. It also states that actual expressions of their preferences are less accurate the more uncertain it is that they will receive the payoff.

The fact that no actual transactions occur in the contingent market surveys is a disincentive to careful thought on the part of respondents. This has been recognized by researchers for a long time. The disincentive is partially overcame in public policy applications by appealing to respondents' willingness to cooperate in accomplishing an important endeavor.

Theorem 4-3 pertains to the way people allocate their efforts to know what their risk preferences are. If people reflect on a series of alternatives, they will devote less and less effort and attention to later alternatives to the extent that they are related to alternatives previously considered. A similar result occurs when there is dependence in the sampling and people discover the values they place on differences.

One of the most difficult decisions in the construction of the health surveys is to decide on the number of contingent valuation questions to ask. Expertsnce reveals that there is a tradeoff between the quality of responses and the volume of information sought. Theorem 4-3 explains this experience. When long' question sets are asked about similar contingent products, people tend not to think independently about each of them. It tends to be their reliance on previous introspections rather than often-postutated fatigue that produces this result, according to the theorem.

The theorem implies that a series of related questions can lead people to think about the differences between contingent goods rather than considering them as independent alternatives. This behavior can be exploited by encouraging people to think about differences as they express their values for programs. For example in the '/-symptom health questionnaire of section 3, people were asked to carefully consider each symptom in turn and rank them from least to most bothersome. Bids were then obtained for the two extreme symptoms; iteration was used to encourage as much thought as possible. Bids for the five intermediate symptoms were then written down directly on the assumption that the comparison exercise had made their values apparent.

Theorem 4-4 addresses the problems of preference reversal and intransitivity that are frequently observed in expressed valuations of risky outcomes. If preferences are uncertain and information is costly to obtain, inconsistencies or outright reversals may occur as individuals reflect upon their preferences. True preferences are more likely to be stated during later stages of reflection. A related theorem states that if reflection on the same list of risky alternatives continues, a point is reached where further reflection will not be attempted and expressed inconsistencies are eliminated. This result depends on several assumptions, among which is that the individual does not forget any of the earlier steps in the reasoning process. If the reflection process produces only estimates of the 'differences in outcomes, then further probing of preferences can not produce preferences reversals, simply because there is no incentive for such further probing of these outcomes.

An effort was made in constructing the health questionnaires to utilize apparent preference reversals as part of the process of respondent introspection about preferences. For example, in thinking about how much they would be willing to pay to relieve symptoms respondents sometimes change their minds about thefr beliefs when they were working out their rankings. Accordingly they were encouraged to change their responses, several times if necessary, until they arrived at a set of rankings and values that satisfied them.

The following theorems suggest additional approaches to stimulating introspection about preferences where preference reversals and intransitivities are present in survey responses These hold considerable promise for further work.

The practical content of theorems 4-5 through 4-8 is that repeated questions concerning preferences are often useful. If repeated questions are used in the reflection process, it is most useful to doublecheck 'the earliest questions and the ones in which the earlier rankings suggest the closest calls.

Reflection about preferences frequently takes one of two forms: comparison- -which alternative do I prefer?; and scaling--how much do I value alternative X? The question that induces the greater amount of investment in additional information is the superior question to use in any given circumstances, Theorem 4-9 states a condition on the most effective way to stimulate effort to get new information. Suppose one constructs an offer of alternatives: one whose value is sought and another whose value is fixed at some given stated value. The best given stated value is that closest to the prior value of the alternative of interest, i.e. the value before new information has been acquired.

Theorem 4-9 has a very important lesson for the construction of contingent market goods. It received careful application in the 7- symptom questionnaires of section 3. This was accomplished by framing willingness to pay questions in terms of the respondents' endowments, with which they were familiar and presumably had clear ideas about in utility terms. Additional amounts of symptoms were then added to those they already experienced. Thus respondents were presented with two alternatives: Alternative X- -their current situation; and alternative Y- -the situation with added symptoms. They were then in affect asked a scaling question- -how much do you prefer situation X. Theorem 9 says that by relating the policy alternative (Y-X) to the respondent's own endowment rather than some less familiar reference point X', the respondent invests more effort in thinking about his own real preferences.

Further work needs to be done along these lines on the life path scenarios on heavy symptoms reported in section 4.5. For example, certainty scenarios begin with a person of age 50 and present life path alternatives with later ages. Application of theorem 4-9 suggests that people who are younger or older than 50 do not have strong prior beliefs about their health values at age 50, and will not invest much effort in making accurate WTP statements about the alternatives. Investment in introspection would be increased if these scenarios were tailored to each respondent's actual situation.

The foregoing theorems assume that there are no memory limitations that reduce the effects of information gathering about preferences. Relaxing this assumption yields a theorem that says that the more limited is memory capacity the more numerous will be instances of preference reversals and intransitivities.

Theorems 4-10 and 4-11, of limited empirical usefulness when memory capacity is large, provide a method of measuring the extent to which memory endures during a period of reflecting about preferences.

A problem of importance in discovering the values of uncertain preferences is the presence of bias. The problem is for the individual to learn the size and direction of his biases and correct them in discovering his underlying preferences. Questions arise during reflection in which biases occur. Theorem 4-12 states that biases will be reduced by questions that focus on comparisons of alternatives in which the biases occur.

In conclusion, the framework we have built, although rudimentary, allows us to address several of the most vexing problems which arise in researchers' attempts to make use of data from risk surveys. It has been constructed as a series of nested generalizations starting from expected utility theory and gradually dropping or modifying assumptions that have been refuted in one or another examination of responses to survey questions.

Although the outlines of the model at every level are clear, there remains much to be done. In particular when the homogeneity assumptions are dropped there remain a great variety of unexplored possibilities. It will be most useful to tailor specifications of assumed structural relationships between the priors on various alternatives or the measurement errors of various acts of introspection to the specific description of the alternatives in any particular experiment. Once this is done we can begin to make useful inferences from watching individuals' behavior in the face of specific complicated offers, and learn which sorts of simplifications individuals actually make in estimating preferences.

Similarly, there is much work to be done in specifying particular biases to which we would wish to attach the priors. Here previous psychology studies will be most useful for providing insight as to the most reasonable specifications. Tendencies to overestimate small probabilities and to underestimate large quantities can be among those considerations we capture in the biased priors. In short, although the structure is now available, much work remains to be done in terms of specific applications.

4.4.15. References

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4.5. DESIGN OF CONTINGENT VALUATION APPROACHES TO SERIOUS ILLNESS

4.5.1. Special Problems of Contingent Valuation Encountered With Serious Illness

The valuation of serious illness entails a number of analytic problems that are fundamentally different from the valuation of minor illness and light symptoms experienced occasionally by everyone in relatively unpatterned ways throughout their lives. Thus the analysis of section 4 requires completely different analytic techniques from those employed in section 3, even though it builds on the survey research knowledge obtained there.

Two fundamental aspects of behavior, relatively unimportant to the study of light symptoms, are introduced in section 4. The first of these is risk. Serious illness, dreaded by people at some stage of their lives, is a prospect they face with varying degrees of probability. Because people have some control over the probability of serious illness, their behavior in the face of serious health risks is an important measure of the value they attach to good health prospects. Hence it is important to understand people's attitudes towards health risks.

The second fundamental aspects of health behavior is the way prospects vary over a person's lifetime. In younger persons, choice and consequence are often separated by many years. Over time one's health prospects change, and behavior tends to be modified accordingly. At the same time, life expectancy becomes a matter of conscious concern. How one responds to these interrelated matters depends in large measure on the social and economic circumstances of one's life, and on how one has cared for his health in the past. Thus the focus of section 4 research turns to an integrated view of serious illness and death in the context of a person's overall lifecycle experience.

Accordingly+ section 4.2 explicitly introduces the concept of health as a behavior-dependent condition of overall well being. Operationally, a narrower version is adopted--health is measured in terms of its absence, or in terms of the amount and types of the person's ill health. This narrower operational definition preserves the prespective of the broader, more satisfactory definition by being embedded in a life cycle model of quantity and quality of life, developed in section 4.3,

Section 4.4 addresses the difficult problem of eliciting expressions of people's behavior towards risks to health. Respondents will have thought about these matters to a greater or lesser extent and adjusted their behavior accordingly. The research challenge is to obtain quantitative equivalents to the sometimes nebulous attitudes that govern health behavior in the face of risks. The current state of utility theory leaves unanswered the question how best to obtain these quantitative equivalents in a form suitable for use in welfare analysis. Section 4.4 provides the inquiry required to guide the investigation along sound theoretical lines.

The empirical framework that resulted from this conceptual investigation is presented in section 4.5. This empirical framework takes the form of a four-module approach to the valuation of health-risk reduction. The first module, health experience, quantifies the respondent's health endowment according to the operational definition of health established in the conceptual work of section 4.2. Health costs and defensive measures, the second module, quantifies certain important money outlays and nonmarket behavioral costs incurred on behalf of health. The module on risk perception and risk behavior prepares respondents to think carefully about the kinds of probabilites involved in behavioral decisions about serious illness and longevity. This involves a prepartory session to impart an intuitive grasp of the elementary principles of probability. It also obtains information about respondents' behavioral responses to a variety of risky situations. The fourth module presents the contingent valuation questions used to obtain values related to longevity and reduction of risk of serious illness. The goal of these questions was *to* integrate prospects for serious illness and death into an integrated life cycle approach. The questions progress from simple life experience situations to more complicated life path situations involving various probabilities of serious illness and death.

The four-module approach requires about three hours to complete, including breaks for relaxation. Designing a survey of this complexity and duration is a novel research enterprise. Past economic survey experience suggests it to be too taxing of respondents' patience and stamina. In view of this experience the necessity of taking steps to avoid fatigue was apparent. Taking several breaks at intervals defined by the modules is the simpliest of these. Use of this Health Risk Appraisal also serves this purpose by providing an interactive computer program approach to obtaining information about the respondents' health endowments. Respondents are aware that the program output gives them information about their own health status, which is expected to sustain their interest and energy while at the same time providing information that will unable the contingent valuation questions to be tailored to their own life situations. Considerable thought has also been given to devising entertaining probability teaching devices that can accomplish their task with a minimum of effort. The contingent valuation questions themselves are designed to capture the interest of respondents. Path-of-life situations are presented with the assistance of such devices as a type of roulette wheel that respondents manipulate, and with various card-game analagies with which many are familiar. Lastly, the incorporation of in-depth marketing-research interview techniques will be employed in order to make the exercise as effective as possible.

Much work on morbidity has pertained to non life-threatening diseases, including section 3 of this report. At the other extreme, there have been many studies of mortality, as reflected in an extensive value of life literature. Serious illness has been relatively neglected. Only the health expenditure approach has given much attention to serious illness. As was brought out in section 2 of this report, which concerned comparative analysis of approaches to valuing health, the health expenditure approach suffers from crucial conceptual problems, and at best it gives lower bound estimates.

Serious illness involves valuation problems that combine pure morbidity effects and value of life and mortality effects

It might be thought that serious illness could involve only morbidity and not mortality., However there are two important reasons why the valuation of serious illness must be concerned with both morbidity and mortality. First, most serious illness is life threatening. Increased risk of death becomes a cost of the illness along with more usually recognized morbidity effects such as medical expenditures, lost work and discomfort. Second, serious illness affects the quality of life in an extreme way. The value of life is affected by the quality of life as well as its quantity. That is, the value of life depends on well being during life as well as the number of years lived. The traditional value of life literature may be interpreted as pertaining to duration, or number of years of life, assuming cause of death does not affect the quality of life.

In this regard the usual value of life approach to death from a disease like cancer, coming at the end of a lingering illness, understates the costs of cancer. Cancer reduces the number of years of life -- which is taken account of by the traditional value of life approach, and it also reduces the quality of life while living -- which is ignored in the traditional value of life approach.

Recognizing that serious illness involves both the quality and quantity of life leads to a reformulation where morbidity and mortality are considered in a common framework. One of the most important results of using this framework is to view values of serious illness in terms of tradeoffs between the quantity and quality of life. In this section we develop and apply this framework.

In addition to raising questions about the relationships between the quantity and quality of life, serious illness is more complicated than non-serious illness because risk is an important consideration. Perception of risk is a prerequisite to intelligent valuation of serious illness. Just as with death, the value attached to serious illness with certainty is different from the value attached to small changes in the probability of the illness, which in the aggregate mount up to the same number of deaths.

People's knowledge of risks and their abilities to verbalize their attitudes toward risks are notoriously difficult areas, which must be dealt with if the contingent valuation approach is to have hope of yielding reliable results. In addition to perception and knowledge about risks, issues arise concerning behavior in the face of risk. The degree of a person's risk aversion will influence how greatly he values a reduction of the probability of the problem of a serious illness.

The present section draws on the three previous sections in devising a contingent valuation approach to serious illness. Section 4.5.2 first states why in-depth interview techniques are needed in the valuation of serious illness. Then the basic structure of a four module interview approach is described. The four modules pertain to 1) health experience, 2) health costs including defensive measures, 3) risk and 4) contingent value questions. Sections 4.5.3 through 4.5.6 describe the four modules in detail. Finally section 4.5.7 draws implications from preliminary experimentation with the modules and makes recommendations 'for further work.

4.5.2. Rationale and Overview of Four Module Approach

Early focus group efforts indicated that respondents have great difficulty in a short interview in forming quantitative opinions on small risks and heavy health damages outside their everyday experience. An in-depth four module approach was therefore developed. The four module approach establishes the basis for intensive interviewing for the study of life threatening illness..

4.5.2.1. Health Experience

The first module, health experience, establishes the respondents' health endowment and health habits as part of the explanation of willingness to pay survey responses. It also helps respondents focus their attention on the subject of the survey and prepares them to give carefully thought-out answers.

4.5.2.2. Health Costs And Defensive Measures

The second module deals with the costs of maintaining health and treating illness. It considers defensive measures taken to promote health and avoid illness as well as expenditures to treat illness. Respondents are asked to recall the number of days of work and recreation that were lost because of illness, and also the number of such days that were partially impaired by illness. Defensive measures include all behavior intended to avert risks to health and life. They comprise actions identifiable by market expenditures and also behavior that is costly to the individual in a non-market sense. Non-market preventive measures include both abstinence and health producing activities that in part, at least, do not yield utility directly.

Measurement of these activities is part of the empirical framework for studying behavior towards risk. They are an important part of the behavior by which people reveal the values they place on improved life and health prospects.

4.5.2.3. Risk Perception And Risk Behavior

The third module, risk perception and risk behavior, gives the respondent an intuitive grasp of probability and discusses the importance of the concept in everyday life. Fundamentals of probability are discussed using everyday language supplemented by physical devices such as urns from which drawings illustrating randomness and chance are made. Following this grounding in probability, the respondent's attitudes towards risk and perceptions of the danger of various activities are explored. Respondents are asked how they attempt to keep risks downintheir life at present. They are asked what they would do if exposed to greater or less risks than at present.

4.5.2.4. Contingent Valuation Questions

The fourth module pertains to the construction of the contingent market. The contingent valuation (CV) exercise provides the basic valuation data that permits estimation of the benefits of health risk reduction. The CV module has been designed in segments.

The first segment concerns mortality, for which alternative approaches to presentation have been developed. The first is the excess deaths approach, which pertains to the increases in death rates in various age groups because of some particular cause of death such as cancer. The second is the life expectancy approach, which states the average age of death in the U. S. population, and establishes contingent market programs that would increase life expectancy. Bar charts that illustrate the probability of living beyond age 50 with and without the program are introduced. The third method is life shortening. This is similar to life expectancy, except that it can be presented without mention of probabilities. A bar chart illustrates the average remaining number of years at five-year age intervals beginning at age 50. Program effects can be shown by changing the height of the bars. The last two methods devised to present mortality are a lottery wheel and a card game. The lottery wheel has a spinning arm with a pointer that comes to rest in a zone of the board that corresponds to a given life experience. It is useful in conveying the probabilities of occurrence of many life-health situations. The card game involves the chance occurence of drawing a card indicating that a sickness such as a heart attack will occur. The respondent is asked about willingness to pay to reduce the number of sickness cards in the deck.

In the second segment of the CV module, questions about several kinds of illness of varying degrees of seriousness are asked. Two types of contingent markets are utilized. In the first, a disease specific approach is used in which disease is mentioned by name. In the second, a health attribute approach is used in which only the symptoms are mentioned.

In the next section of the CV module several specific and explicitly depicted comparative life paths are presented, with symptoms and illnesses of varying severities and different life expectancies. Respondents are asked first to rank alternative life paths according to their preferences. A hypothetical life path endowment is postulated, and willingness to pay and accept questions are asked, based on respondent rankings. The questions are constructed so as to reveal the strengths of preferences in choices involving severity of symptoms and length of life. These tradeoffs are offered in terms of certainty prospects.

The following section explores how health valuations are affected by the existence of risk. The respondent is offered one life path with certainty and pairs of alternative life paths -- one better and one worse -- with various probabilities. Respondents are asked about their willingness to pay for the scenarios.

Willingness to pay questions are asked based on the life path preferences. A base life path endowment is established and programs that would improve or prevent deterioration of the environment are offered. The program effects are linked to the life paths. Linkages are not established between dollar bids and probability statements. It would be possible, however, to apply this contingent valuation structure to obtain statements of willingness to pay for risk reduction in future work.

Based on the four module formulation and focus group experience, refinement and development of alternative approaches for each of the modules was undertaken. The approaches are illustrated in the next four subsections. They provide the basis for possible future field work.

4.5.3. First Module, Health Experience

The first module, health experience, develops the information and preference context of the questionnaire. It serves two research purposes. The first is to focus the respondents' attention and research their references on the subject of the survey and prepare them to give carefully thought-out answers. The second purpose is to establish the respondents' health endowment and health habits as part of the explanation of willingness to pay responses to survey questions. The questions encourage the respondents to link health status to the behavior and activities of daily living. Their perceptions about psychological well being and degree of control over personal health reinforce the connection between health and behavior, which will be important later in reflecting on the value of health preservation or improvement.

Obtaining detailed knowledge of respondents' experiences with specific kinds of life threatening illness is an important part of the health appraisal framework. Detailed information about specific health problems of interest in the survey supplement the more general health status information obtained earlier. The empirical framework integrates mortality into the study of behavior towards risks to health and life. Some recent theoretical contributions have recognized that death has important endogenous elements in life cycle choices, but the present study goes farther than others in empirically integrating mortality into the investigation of the value of risk reduction in a life cycle context. It accomplishes this by making the prospective life path of the respondent the basis for the contingent market good. The following abridged set of health status questions 'was developed to meet these ends.

Self-assessment of health status:

1. In your own opinion, which one of the following best describes your current health status:
   1 Excellent 2 Good 3 Fair 4 Poor

Belief concerning control over health:

2. Which one of the following best describes the control you have over your health?

   1 There is little I can do because it is beyond my control.
   2 I can do some things, but they have little effect.
   3 My actions have a moderate effect.
   4 My actions have a great effect.

Detailed questions on health status:

3. Are you unable to do certain kinds or amounts of work, housework, or schoolwork because of health?
   Yes _________ No ---------
   If "yes" then 4.

4. Have you been unable to do this work for more than three months? Yes _________ No ---------

5. Does health limit the kind of vigorous activities you can do, such as running, lifting heavy objects, or participating in strenous sports?
   Yes --------- No ---------
   If "yes" then 6.

6. Has health limited the kinds of vigorous activities you can do for more than three months?
   Yes ------a-- No ---------

Questions about sick days:

7. What conditions (such as specific illness and injuries) caused you to'stayinbed?

8. How many of the days that you lost from market work did you stay in bed all or most of the day?
-e---e--- days

9. During the last year, how many days did you cut down for as much as a day?
________ days

What condition caused you to cut down?

General questionsabouthealth perceptions:

10

	Definitely true	Mostly true	Don't know	Mostly false	Definitely false
According to the health professionals, my health is now excellent	5	4	3	2	1
I try to avoid letting illness interfere with my life	5	4	3		

Focus group experience indicated that respondents are willing to answer these questions. They served their intended purpose well, but consumed too much time in a conventional interview context. For use in a half-day, in-depth interview, however., their use is feasible and deserves further considera- tion.

4.5.4. Second Module-. Health Costs and Defensive Measures

.Much of the material in this module is very similar to the modules on health costs and defensive measures already presented in section 3. The earlier material will not be repeated here. In addition to the earlier material, defensive measures toward serious illnesses that have low probability risk are explored.

An illustration will be presented here of questions about willingness to undertake changes in lifestyle to reduce risk of serious illness. The illustration centers on diet.

Referring again to cancer probabilities, imagine you were told by your physicianthatthe cancer life path is what you had to look forward to --because of some condition he had just discovered. He offers you a program, however, which will give you a 50% chance of avoiding the cancer scenario and getting the health scenario instead. His terms are this:. stop smoking, stop drinking, and immediately adopt a Special diet (not shown Here). Would accept the doctor's program?

Yes __________ No __________.

If yes: Are you confident that you would be able to adhere to these terms for the restofyour life?

Very confident ----------------
Somewhat confident ----------------
Doubtful ---------------
Virtually no chance ________________

If no: Suppose the doctor told you that you could be <u>certain</u> of improving your prospects to thehealth scenario. Would you accept the doctor's program?

Yes --------e **No** ---------

If no: What is the most difficult part of the doctor's program for you?

Rank them 1, 2, 3.

Diet ________
Drinking ---------
Smoking ---------

If Diet: Would you accept the doctor's program if it only required the Special Diet?

Yes --------- No ---------

If no: Would you accept the doctor's program if there were no dietary restrictions at all?

If yes: Repeat above.

If no: [Eliminate second most difficult part of doctor's program and repeat.]

Building on this illustration, iteration on defensive measures could be used as part of the contingent valuation modules considered below in section 4.5.1.3. Hypothetical future life experiences would be ranked from worst to most desirable. The respondent wold then be endowed with the worst path and asked to bid for more desirable alternatives. Bidding would be in terms of defensive measures involving smoking, drinking, diet and exercise. Iteration would be used to determine how much averting behavior would be tolerated in order to improve life prospects by various amounts. Some experimentation with uncertainty could be introduced by setting the probability of payoff equal to 50 percent. The respondent would be asked how confident he is of being able to stay on the various programs, and which parts of the programs are the most difficult. The latter responses would be used in further iterations by eliminating the most difficult parts of a rejected program and asking if it would then be an acceptable price to pay for a preferred life path.

The rest of this iterate-on-defensive-measures approach entails eliciting willingness to pay (WTP) in dollars for the programs, based on their careful thought about sacrifices made for measures they are already taking.

4.5.5. Third Module-. Risk Perception and Risk Behavior

A major result of work with focus groups is recognition of the need to carefully educate respondents in the basic concepts of probability and risks. The procedures, whose principles are discussed in detail in section 4.4, are necessary if respondents are to be able to respond intelligently about low probability environmental threats to life and health.

It is furthermore important to delve into people's general risk perceptions because they underlie judgements and choices in particular risky situations. The risk percetions help to explain choices in contingent markets for health risk. Asking respondents to reflect on these attitudes brings them more clearly to mind, improving the quality of contingent valuation responses.

Examination of people's actions in various risky situations reveals attitudes towards risks, just as do their prior perceptions of risk. These risk attitudes, formed over long periods under innumerable influences, are important determinants of behavior towards health risks, and are therefore likely to be important to analysis. Responding to risk behavior questions also helps prepare the respondent give well considered contingent valuation answers.

It is thus apparent from the focus group experience that a major experimental effort is required to develop teaching devices that will permit the effective use of probabilistic contingent markets in health. Basic drills for teaching probability are not presented here. The defensive measures module contains some information on risk behavior which could be extended. Building on the present module, games have been devised using a lottery wheel and cards directly in contingent valuation questions as will be reported on in Section 4.5.6.

The presentation in the present section is limited to questions on risk perception, which are as follows.

Risk perception, relative to past:

1. Relative to your parents' experience, the risks to health and safety you are faced with are:

   1 Much less
   2 Somewhat less
   3 About the same
   4 Somewhat greater
   5 Much greater

General awareness and concern:

2. Risks to health and safety come from a variety of activities, substances and technologies. Which causes the greatest, second greatest and third greatest concern to you? (Put appropriate number in each box.)

1 Crime	8 Power lawn mowers
2 Swimming pools	9 Smoking
3 Nuclear power	10 Motor vehicles
4 Alcoholic beverages	11 Food preservatives
5 Pesticides and herbicides	12 Asbestos
	13 Water pollution
6 Home gas furnaces	14 Job risks
7 Air pollution	15 Other (specify) _____

   [ ] Greatest concern
   [ ] Second greatest concern
   [ ] Third greatest concern

Ranking questions about causes of concern about risks and also about household production of health and safety:

3. Much has been said about various risks to health and safety. Using a scale of 1 to 10 going from least risky to most risky, enter the number you feel best describes the risk.

Crime	Swimming Pools	Nuclear Power	Alcoholic Beverages	Pesticides and Herbicides	Home Gas Furnace	Air Pollution
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Power Lawn Mowers	**Smoking**	**Motor Vehicles**	**Food Preser-vatives**	**Asbestos**	**Water Pollution**	**Job Risks**
[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

4. To what extent are the risks knownbypeople exposed to the risk? Use the following scale.

   risk level known precisely   1 2 3 4 5   risk level not known at all

   Knowledge [ ] (Enter the number 1,2,3,4 or 5)

5. To what extent through your own actions can you control exposure to the risk? Use the following scale.

   exposure. can't be controlled at all by individuals   1 2 3 4 5   exposure can be completely controlled by individual

   Exposure control [ ] (Enter the number 1,2,3,4 or 5)

6. To what extent can you by personal efforts and use of available resources control the outcome if you are exposed to risk? Use the following scale.

   outcome can't be controlled at all by individuals   1 2 3 4 5   outcome can be completely controlled by individual

   Consequence Control [ ] (Enter the number 1,2,3,4 or 5)

This set of questions, while effective when used in a focus group session, would be too long for a door to door survey. Use of these questions in a half-day, in-depth interview settfng would be effective, however.

4.5.6. Fourth Module. Contingent Valuation Questions

4.5.6.1. Mortality

Several methods of presenting mortality risks were developed and tested in focus groups. Five methods are-reported on here: excess deaths, life expectancy, life shortening, use of a lottery wheel, and use of a card game.

Excess Deaths

The following sample illustrates the excess deaths approach -- possibly the most easily understood idea of mortality risk:

> We have all used the term "epidemic" to describe the outbreak of a disease. An **epidemic** is said to exist when more people develop an illness -- measles, flu, for example -- than is expected under normal conditions. Similarly, the term "excess deaths" can be used when more people die from a certain illness or condition than is normally the case.
>
> For example, suppose that on average, 1000 people die every year in fires in the United States. If 5000 people were to die this year in fires, those additional 4000 deaths could be thought of as "excess," that is, more than could normally be expected to occur. Some scientists warn that pollution of the air and water cause excess deaths in the population today.

Q. How much would you be willing to pay to eliminate one excess death due to air pollution?

Life Expectancy

Various approaches were tested to present the idea of life expectancy, changes in life expectancy, and people's willingness to pay to get improvement or avoid decline. One type of life expectancy question offered a rather elaborate contingent market to the respondent. The following example contains explanatory narrative that relates life expectancy to cancer, and illustrates a life path for a person of age 50 by means of the bar charts.

> Of all the possible consequences to human health arising from pollution problems, the threat of cancer may be the greatest source of concern. It is the only major cause of death which has continued to rise since 1900. It is difficult to determine how great a role

pollution plays in causing cancer. People differ in **age**, place of residence, occupation, health status, diet and lifestyle, and all of these factors together influence the probability of developing cancer.

Please look the first set of bars (see figure 4-7). These bars illustrate the overall probability of a person surviving from the age of 50 to the ages shown. For example, the likelihood of living to age 80 is about **48%**, to age 85 about 308, and so on. (Of course, it is impossible to predict how and when a person will die; many factors will influence that event. The probabilities shown here are national averages)

Now look at the second set of bars. They show the probabilities of surviving to advanced age, but also the changes in the percentages if cancer were eliminated as a cause of death. Without cancer, the chances of living to be 80 or 85 would increase to 55% and **37%**, respectively.

Suppose that it were possible to devise programs that would eliminate all cancer.

Q. How much would you be willing to pay for the programs?

Maureen Cropper comments that asking a person to value changes in life expectancy is somewhat ambiguous and does not necessarily measure what one wants to measure. Suppose Dj represents conditional probability of death at age j and $q_{j,t}$ represents the probability of surviving to the beginning of the j^{it} year given that one is alive at age t. It follows that

(4-43) $q_{j,t} = (1-D_{t+1}) \ldots (1-D_{j-1})$, j > or = t.

Furthermore, life expectancy at age t can be shown to be

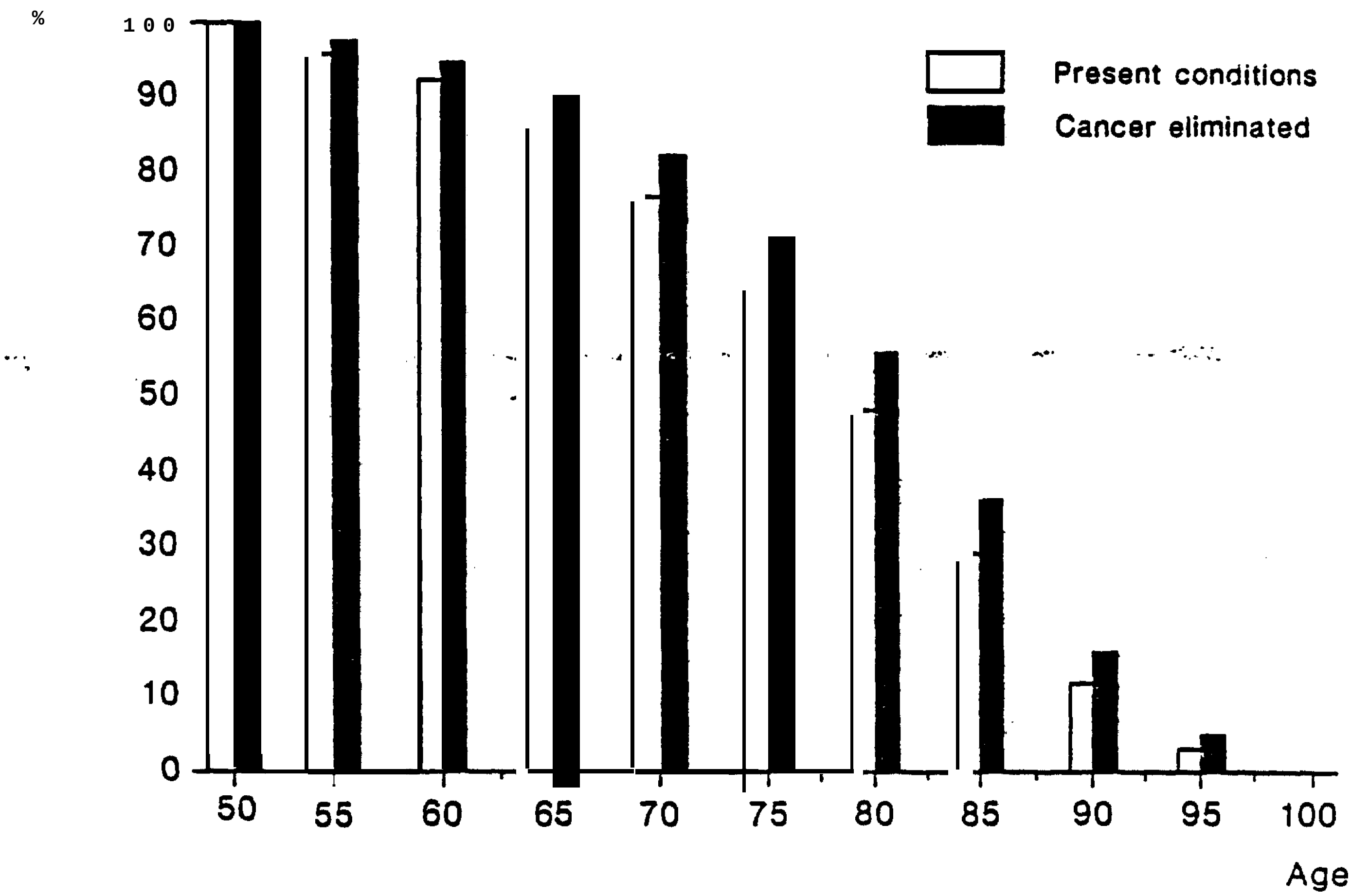
(4-44) Summation of q_{jt} **from** $j = t+1$ to T.

Equation (4-44) indicates that a change in life expectancy is ambiguous in the sense that there are many sets of changes in **the** $q_{j,t}$**'s** consistent with a given change in life expectancy. **Furthermore** it seems that what one wants to value is the D_j**'s**. She suggests that it might be better to ask people to value a change in the conditional probability of death at various ages.

Life Shortening

The life shortening method of presenting mortality risks to respondents is similar to life expectancy except that it does not require a discussion of probabilities.

Figure 4-7
PROBABILITY OF SURVIVAL WITH AND WITHOUT THREAT OF CANCER (FOR LIFE EXPECTANCY QUESTION)



The absence of probability from the discussion makes this approach easier to understand than the life expectancy approach. Also it is possible to use one chart to illustrate remaining life for people in every age group. This makes it easy to tailor the question to the endowment of each individual respondent. The remoteness of the contingent market product for many respondents remains a problem, however.

An example of the life shortening approach is as follows.

> Consider how many more years you can expect to live once live once you reach the age of 50. Of course, you would hope to live as healthy and as long a life as is possible. Please look now at Figure 4-8, which depicts in graphic form the national averages for remaining lifetime, expressed in years. Note for example that a 50 year old can look forward to 16 more years, etc.

Q. How much would you be willing to pay for a program that would extend your life by two years?

Lottery Wheel

The lottery wheel is the most graphic portrait of mortality experience developed so far. It is a device that involves the respondent in an activity that builds up an idea of a person's risk of death under varying conditions.

The prototype wheel is two feet in diameter and consists of a wooden arm spinning on a skate boardwheelbearing affixed to a sheet of plywood. Nails, equally spaced at the periphery, divide the circle into 90 segments. A piece of flexible plastic at the end of the arm provides Las Vegas-type noise and forces the arm to stop within a single segment (between two nails). Paper overlays depict a wide variety of pie charts that show age of death and health-disease distributions. The pie charts depict different size segments that correspond to different likelihoods of being in good health, having heart disease, etc., at various ages. The pie charts are constructed to reflect the probability distribution, the population within five year intervals beginning at each decade of life. A sample is shown in Figure 4-9.

Contingent market goods were constructed for testing in focus groups by depicting the mortality expectation of a 50 year old person with and without cancer risk. This is done by showing the actual expectations of the person in one ring of a pie chart, and the calculated expectations of death with cancer removed in another ring. Repeated spinning of the "wheel of death" gives the participant a sense of improved prospects in the absence of cancer. When the participant is adequately prepared, willingness to pay questions to get the without-cancer lottery are asked.

Testing of the lottery wheel in focus groups indicated that it has a great deal of promise for future use in both mortality and morbidity contingent-valuation work.

Card Game

As probabilities become smaller, the probabilities generally become more difficlt for resopndents to interpret. Some people however have acquired a sense of small probabilities in connection with work or leisure or activities. People who play cards are examples of such people.

An example making a link between card games and probabilities encountered in health risks follows. Unexpected painless mortality from heart malfunction is a health risk that carries quantifiable probabilities for persons of given age, general health and personal characteristics. A contingent market can be established by proposing a card game to persons in various risk categories, with hands dealt from a deck in which the probability of heart malfunction corresponds to the propbability for people of their category. Respondents are then asked how much they would pay to reduce the number of heart malfunction cards in the deck.

4.5.6.2. Morbidity

Several different approaches were developed for posing contingent valuation questions on serious morbidilty. The approaches are discussed in this section.

Specific Disease 'Approach

In the specific disease approach, diseases are named, allowing for the possibility for semantic effects in the valuation of risk reduction. A bronchitis question is illustrated in the following question.

> Chronic bronchitis is an illness affecting about 3 percent of all adults in the United States. Bronchitis is an upper respiratory disease which causes coughing andchest pain. In addition to physical discomfort, many people with chronic bronchitis become discouraged and depressed about this illness. In addition to to cigarette smoking, air pollution is acause of chronicbronchitis and it also aggravates the condition. Treatment of chronic bronchitis with medicinesis helpful but tends to create side effects.

Figure 4-8
REMAINING YEARS OF LIFE AT VARIOUS AGES
(FOR LIFE SHORTENING QUESTION)

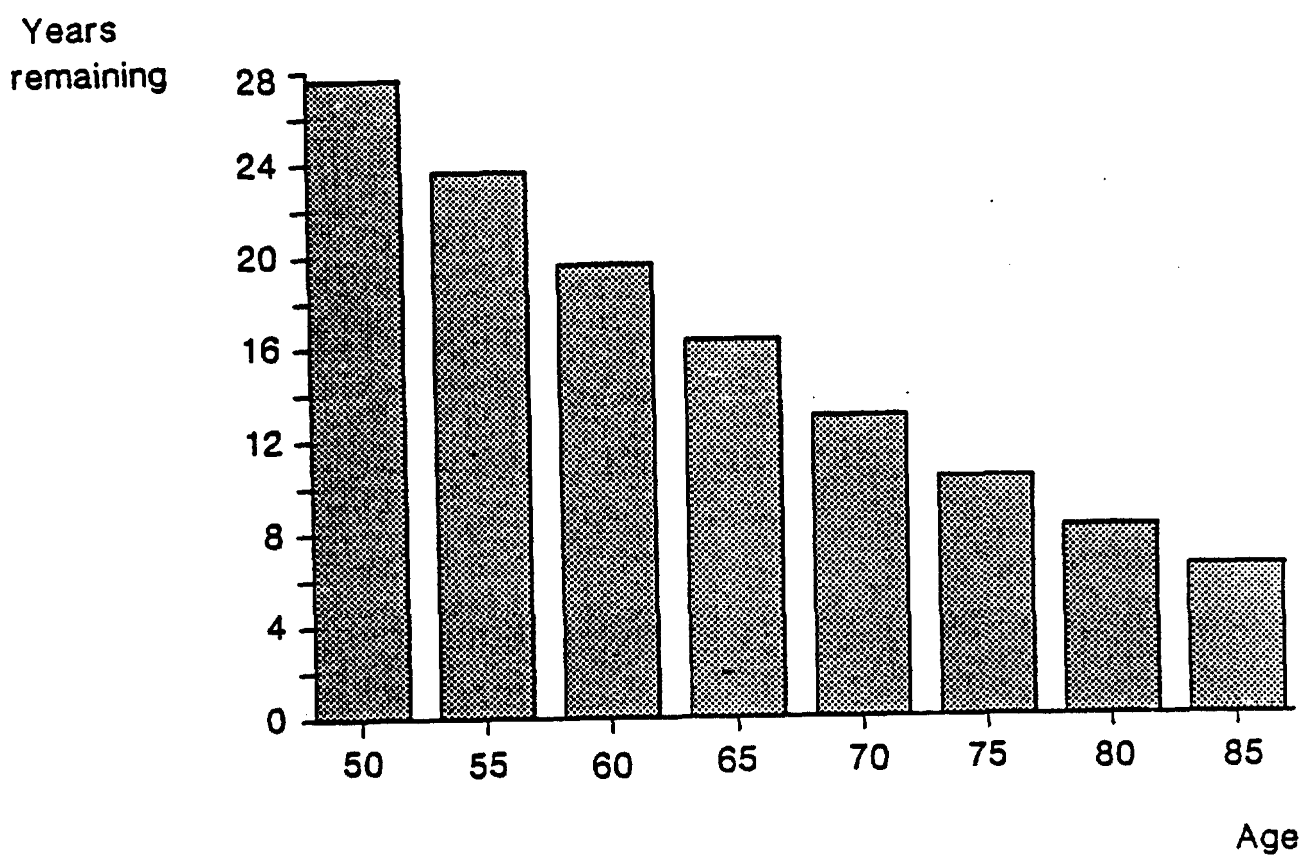
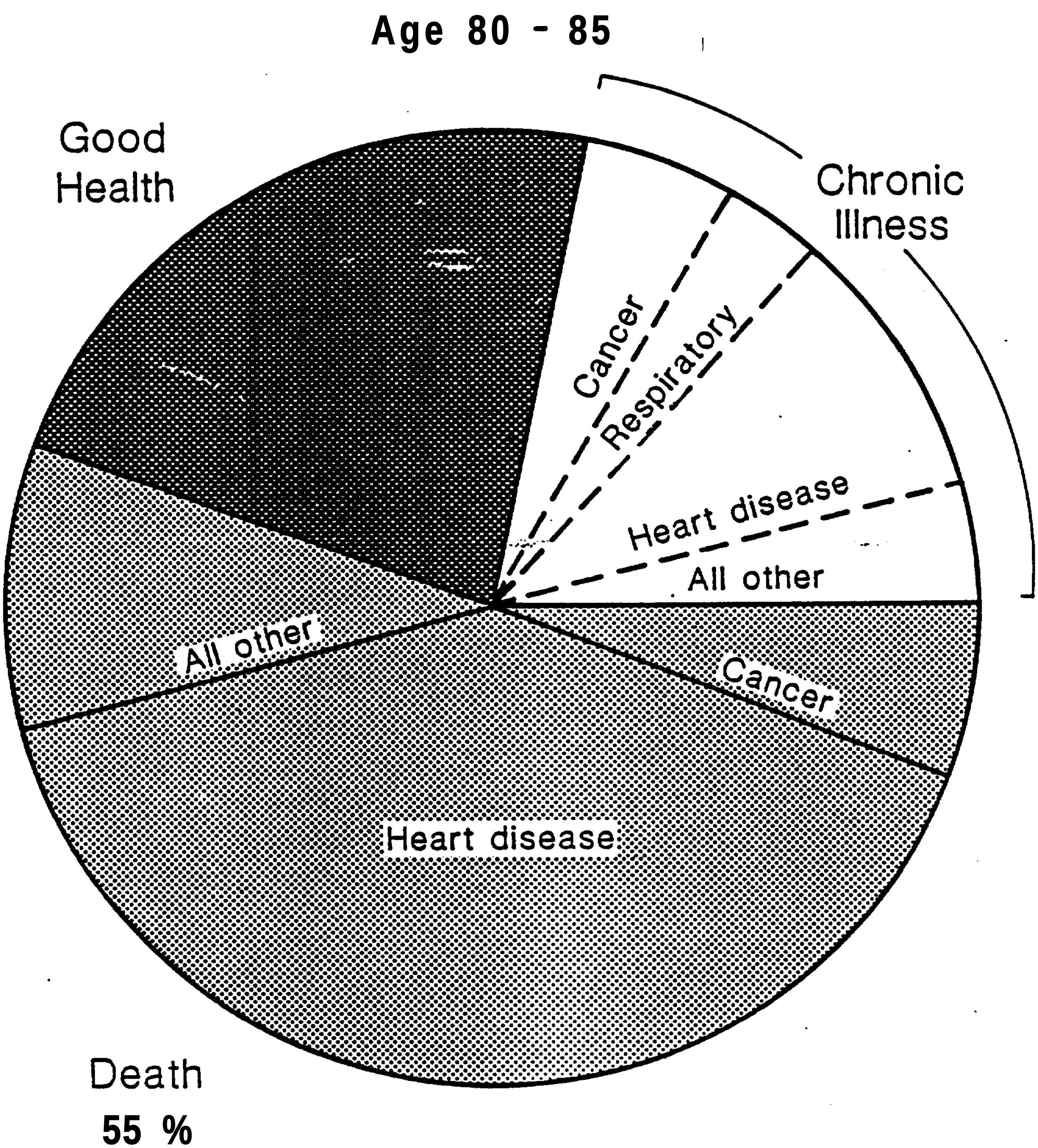


Figure 4-9
PIE CHART FOR MORTALITY LOTTERY WHEEL



How much would you be willing to pay per month in to eliminate the risk of bronchitis?

Aside from the semantic effect of mentioning a specific disease, a problem in this question is the precise amount of risk that is being eliminated in the contingent market.

The following question, concerning cancer, combined illness with substantial risk of death. The death risk was presented implicitly to the respondent by revealing the overall experience in the U.S. population.

> Chemicals in the environment, in the air, in water, and in some foods are believed to be significant cause of cnacer in the United States. These cancers include cancers of the lung, kidney and liver. Today about half of all cancer patients die of the disease and about half survive. A great many cancer patients, both those who die and thosewho survive, have to undergo- radiation, chemotherapy, or surgery, often in combination, which formany is a highly uncomfortable and emotionally trying experience.
>
> How much per month would you be willing to pay to eliminate the risk of getting cancer of the lung, kidney, or liver or some other organ?

General references to the experiences of the entire U.S. population are limited by the fact that they do not give respondents the kind of graphic description of illness that assists them in judging the value of removing or lowering the risks they face. This health attribute and life path approaches, which follow, add the desired element of realism to the contingent market product.

Health Attribute Apporach

The health attribute approach focuses entirely on the effects of diseases and avoids naming the underlying causes. Semantic effects can be tested by listing the symptoms caused by a disease in one survey and actually naming the disease in another, comparable survey. An example of the health atrribute approach follows.

> Physical discomfort effects of illnesses include coughing, pain with each breath, and other effects. I

will ask about each effect separately. Each of these effects would continue for many years, unless the question says that is it for several months.

a. Frequent, persistent coughing $--m--e-- per month

b. Chronic throat irritation $-e--v--- per month

c. Gripping pain with each breath $a------- per month

d. Itching and smarting of eyes $-------- per month

e. Frequent nausea, feeling of need to vomit for several days each week for several months $-------- per month

f. Whole body discomfort, feeling rotten all over for several days each week for several months $-------- per month

It was discovered in focus group experiments that numerous questions in quick succession are not conducive to carefully considered answers. Instead, answers may become rather -mechanical unless broken up with intervening discussion and preparatory thinking on the part of the respondent. This consideration limits the number of bids that can accurately be obtained.

4.5.6.3. Life Path Approaches Combining Morbidity and Mortality

Life path approaches represent a progression towards the creation of a realistic setting in which respondents can relate to health problems that are either current, possible in the next few years, or in the distant future. The approach is to construct several parallel life paths with a number of common elements and ask contingent valuation questions on each. Respondents who might not be able to value an isolated event such as dying two years earlier in 40 years may well be able to express a preference for one life path over another and assign dollar values to the preference.

Both morbidity and mortality considerations are embodied in the life path scenarios. Consideration was given to measuring interactions between them and valufng tradeoffs. Scenarios were developed in terms of certain alternatives and in terms of uncertainty, as will be described in this section.

Certainty Scenarios

Table 4-2 shows three alternative life paths, characterized by either cancer, emphysema or heart attack. They differ substantially in the overall quality and length of life that is

Table 4-2. LIFE PATH SCENARIOS

Age	Cancer Scenario	Emphysema Scenario
50	Good Health	Good health
55		Symptoms (which probably began. earlier) become apparent: Loss of energy (e.g., climbing stairs tires you out; shortness of breath, difficulty in breathing. Breathing difficulties result in increasing work absences.
60	Relative good health but Symptoms become noticeably reduced from that at 50.	Symptoms become increasingly severe. Health deteriorates to the extent that early retirement is necessary.
65	Health reductions continue both with no serious illnesses. You continue able to do a full day's work, but you retire at age 65.	Lung deterioration reaches point where you intermittently must use a portable bottled oxygen supply to reduce breathing difficulties while walking.
70	Cancer symptoms become apparent, and chemotherapy is initiated. Side effects include nausea. You feel the need to vomit several days each week. There are periods of improved well being, but on other occasions you feel rotten for days at a time.	You become bedridden and require continuous bottled oxygen to reduce breathing difficulties.
74	Chemotherapy and side effects continue, but otherwise you lead a normal life.	Death due to heart failure.
76	Cancer spreads throughout your body and death occurs.	
78		

(Third scenario presented on next page)

Table 4-2 (continued)

Age	Heart Attack Scenario
50	Good health
55	
60	Relative good health but noticeably reduced from that at age 50.
65	Health reductions continue but with no serious illnesses. You continue able to do a full day's work, but retire at age 65.
70	Still no serious illnesses
74	
76	
78	Sudden and painless death occurs due to heart failure.

(End of Table 4-2)

offered. The example illustrates the certainty approach to life path analysis.

Respondents are asked to rank the life paths in order of desirability and express a willingness to pay to avoid the less preferred life paths. Focus group experience indicates that this is a promising method of obtaining values. It imparts reality to the contingent market alternatives that are offered.

Possibilities exist to tailor the scenarios for special purposes. Distinct symptom modules 'form the life path building blocks. A set of life paths can be built from the symptom sets and combined with different ages at death. The life paths can be ranked and values expressed relative to a base case path. The results could be used in policy analyses that detail the disease effects of illness by symptom and age of death more completely than at present, but they would also be **useable** in present state of the art policy evaluations.

Uncertainty Scenarios

The following survey segment substituted probabilities of obtaining the life paths for the certain alternatives of the previous questionnaire. A simple probability display device was used to convey the idea of risks and help the respondent make probabilistic choices.

The example below illustrates the questionnaire approach.

> Each of us faces an uncertain future concerning our health and length of life. Knowledge about health is increasing, however, and we are learning more about how we can influence our own prospects. Public health officials, are learning more about what of government policies can improve the health and life expectancy of the general population.
>
> We are very interested in your views about the value of health improvements. I would like to ask you some questions about a matter of importance to people- -how you feel about the uncertainties and risks to your future health.

The life path scenarios presented above in Table 4-2 would then be combined with a probability analysis to see how much people wold be willing to pay to reduce the risk of the more undesirable scenarios.

4.5.7. Implications

The proposal for the in-depth four module approach that has been developed in this section grew out of findings from focus group experiments. For example, early focus group work indirected respondents had difficulty grappling with life threatening illness in a short interview. It became apparent that a major experimental effort would be required to devise effective probabilistic contingent markets in health. Several experimental games were tested that may develop into useful approaches in future work.

Equally difficult was the task of getting respondents to think seriously about contingent payoffs defined far into the future. Younger respondents in particular found it was difficult to place any value in an extra year of life or health at age 70 or 75. Because certain benefits of environmental improvement are likely to be of this type, it will be particularly important to address the problem of deferred benefits in future work.

The role of the participant's own health endowment became the subject of thought during this early period. Two objectives became apparent. One was to have a standard, well defined contingent product for which all respondents would bid. The second was to make the contingent market as realistic as possible by relating it to the respondent's own experience. This eliminates the need for the respondents to try to imagine having a hypothetical endowment and then imagine hypothetical departures from that endowment.

The first module of the four module approach, health status, developed the methods required to establish the respondent's endowment, to tailor contingent market goods to the individual's own circumstances, and to start the respondent to think about health preferences that have usually not received much attention. The second module, defensive measures, investigates and records the activities that people take to avert illness or threats to life and health. These activities include health practices, changes in life style and also expenditures on market goods that contribute to health. Risk perception and risk behavior in the third module. Its purpose is to convey an understanding of probability that is adequate to understand and respond to questions that elicit the value of health improvements that are plausible results of environmental policy. The work of the first three modules is brought together in the fourth module, contingent valuation. Contingent market health products, realistically tailored to each respondent's health endowment, are formulated. Respondents are assited in thinking carefully about the value that these health products would have in their lives, and to express their willingness to pay for them. Program effects are presented in terms of alternatives that can be obtained with certainty, and also as alternatives that will occur only with various stated probabilities.

Risk age, life shortening, life expectancy, and lottery of life approaches are used in constructing life path scenarios. Further research is necessary before the most effective approaches can be identified.

In life path scenarios, which are needed and promising, methods and information for relating to environmental effects needed to be developed. The visual approach is one effect on death rates. Even apart from the latency problem, a person with increased.exposure to pollutants faces a stream of altered life path prospects from different points in the future depending on when the disease is contracted. The problem exists when the probability of contraction of disease is independent between time periods and it also exists when there is a latency period, which merely complicates slightly the estimation of probabilities of when the disease will be contracted.

Future research needs to address two closely related concepts, as follows.

Level of Discrimination

Intuitively one would expect that individuals could value some risk reductions more meaningfully than others. For example the probability or risk of death could increase from almost zero to 1/6 (if one should choose to play Russian Roulette) or it could increase from 1.1/1,000,000 to 1.8/1,000,000 (odds perhaps associated with an increase in an environmental trace concentration of some toxic substance). Somewhere between these extremes, an average respondent likely would lose the ability to discriminate between one risk level and another. Future research would attempt to approximate this discrimination treshold.

Level of Complexity

There are other complexities in addition to discrimination which make it difficult to distinguish between and ultimately value one risk versus another. Pertinent information is helpful in this regard. Increased information beyond, some point, however, has less value and eventually is counterproductive.

Pertinent variables include:

Age specificity
(present age and age of death)

Disease specificity

Cause of death

Cause of the cause of death
(risk factors such as alcohol, obesity, air pollution)

Level of health or morbidity
(physical status, level of disability)

Thus, at one extreme, a respondent might be given virtually no information prior to being asked to value a change in health or death risk. At the other end very explicit life paths, tailored to the individual, could be provided. Future research should identify minimum information levels needed to obtain meaningful contingent valuations.

4.6 SUMMARY AND CONCLUSIONS ON SERIOUS ILLNESS

In section 4 attention has been directed towards serious illness, including risks to life. The work builds on the investigation of the valuation of light symptom reduction, reported in section 3.

Section 4.2 addressed the problem of health measurement. It contained a discussion of different approaches to health measurement. The importance of recognizing that health is a state of mental as well as physical well being was emphasized. Self assessed health status was found to be the most widely used health status measurement technique. While this approach has limitations, it was seen to have an important role to play in health risk reduction benefit research. Its importance stems primarily from the role that self-assessment plays in the perception of benefits from improvements in health prospects.

Because health is a multi-dimensional condition, it is necessary to supplement self-assessment with other measures of health status. Further refinements in health status measurment are needed, including the possible use of the health risk assessment as an interactive health measurement tool.

It is in the valuation of serious illness and mortality that the fragmentary nature of much of the existing literature related to health values becomes most apparent. Progress has been made in valuing aspects of these experiences that are often more important than those that can be measured in terms of market transactions. An important research result reported in section 4 is the integration of serious illness and death as a single life experience. This integration is achieved by placing the experience in a life cycle setting.

Section 4.3 modelled the basic context in which people make decisions regarding serious threats to health. A person's position in his own life cycle is seen to be the relevant decision making context. People are seen to make decisions about health over their lifetimes, and life is viewed as a stream of experiences involving widely varying degrees of healthiness and sickness and uncertainty concerning length of life. The major challenge that arose out of this approach was to construct contingent markets that preserved the preference-formation and value-determining context. Isolating small parts of the context in the interest of simplicity was seen to be theoretically problematic and led to emphasis on life path scenarios.

Section 4.4 is another source of theoretical guidance to the development of the approach of this study. This section brings utility theory to bear on the problem of valuing small changes in events that are thought of only infrequently and involve low probabilities of occurrence. The model developed in this section unfolds in a series of theorems. Several theorems address the problem of stimulating respondents to think carefully about their preferences. One theorem states that the closer the sum of money is to the (unknown) value of the program benefit, the harder the respondent will think about the choice. Iterative bidding begins with a rather arbitrary starting point. In subsequent bidding, however, the theorem is applied by taking account of previous completed bids on related programs. The starting point is made identical or close to the final bid on the similar previous program to encourage careful thinking from the beginning.

An important objective is to realistically rel'ate the contingent market good to the respondent's own circumstances. This means tailoring the good to the respondents's endowment. An implication of the theorems is that introspection about preferences is much more effective when this is accomplished, Much progress has been made in tailoring contingent market goods to individual endowments. Nevertheless, more research is required in this area.

Based on the results of the preceding sections, an intensive interview approach to contingent valuation work, reported in section 4.5, proposed a four module interview scheme. The interview is designed to be conducted with from six to ten people and to last about four hours including breaks. The intensive encounter is necessary because of the great difficulty of achieving its central task--obtaining values of events that entail small changes in small probabilities.

The health status module is the first module. It establishes health endowments of respondents and begins the process of careful scrutinizing of preferences. Self-assessment was judged to be an appropriate method. Its brevity is a virtue in survey work, and subjective perception of health is an important determinant of willingness to pay. Detailed knowledge of respondents' symptoms or chronic ailments appropriate to the CV framework were judged to be essential. These health status questions served as explanatory variables as discussed in the health status literature, but they had other functions as well. The questions established the respondents' health endowments, permitting tailoring of the contingent market product to the circumstances of the respondent and, as explained in section 4.4, stimulating maximum reflection of the respondent on his preferences.

The second or defensive measures module examines averting behavior to preserve health. Averting behavior includes expenditures and also activities not measured by market transactions. Efforts people are willing to make to achieve better health prospects are probed, with a view to placing a monetary value on them.

The third or risk perception and risk behavior module begins by teaching respondents basic notions of probability as related to their everyday experiences. It then obtains information about their perceptions of and attitudes towards risk in a variety of situations. Next it conveys an idea of the kinds of probabilities that are involved in matters that concern their health.

The fourth or contingent valuation module establishes contingent markets in health. Hypothetical life experiences involve both quality and length of life that people are asked to evaluate in comparison with their own prospects. Excess deaths, life expectancy, life shortening, a lottery wheel and card games were among the devices developed to present alternatives on which to bid. The module features evaluation of alternative life path scenarios values in a certainty and then in an uncertainty context.

It is believed that the survey **aproach** developed in section 4, and the extensive preparation for obtaining expressions of willingness to pay described in the four proposed modules, constitute an advance in survey research on the value of heatlh improvements, and that further empirical applications are needed.

APPENDIX. MANIPULATION OF LIFE TABLES: CANCER ILLUSTRATION

Numerous studies have estimated the effects of environmental and behvforal stressors or interventions on life expectancy. Limited results of uncertain epidemiological and other studies are described in following sections. Results based on assumed elimination of a specific reported disease or other reported cause of death are more illustrative. The following discussion describes results of mathematically changing the level of death-causing cancer while allowing other competing health risks to proceed at the same rates for each age interval. The results indicate that total removal of cancer would increase the percentage of the population reaching age 80 from 44.5 percent to 52.9 percent, or increase life expectancy by 2.7 years. This conclusion avoids all controversies regarding causes of cancer.

Further, this illustration utilizes available data for female deaths in 1964. The approach could be applied as readily to more recent results for another population category.

Table A-l presents the mortality experience of an imaginary sample of 100,000 females subject to the death rates which prevailed in 1964. Column 1 lists.five-year age intervals, minus the first five years of life. Columns 2 through 4 report deaths for several of the major causes (neoplasms, cardiovasacular diseases, motor vehicle accidents, and other violence). In column 5 all other deaths are reported and total deaths appear in-column 6. The final column contains the number of persons of an age period who survive to enter the next age group. Thus, of 100,000 born, a total of 2,107 do not survive the entire first year; the forces of mortality then act on the remaining 97,893 one-year olds, of whom 340 additional females do not survive the fifth birthday.

In Table A-2 the numbers of deaths (from Table A-l) are expressed as fractions of the total numbers of survivors who entered the age interval. Out of 100,000 newborns, 7 die of some neoplasm before the end of year one, for a probability of dying of 0.00007. The probabilities of death for the causes shown are then summed in column 7. The number entering the interval for the 1.0-4.9 age bracket is then

$$100,000 - (100,000 \times 0.02107) = 97,893.$$

Another way of portraying the life experience is to focus on the chances of surviving from one age to another, rather than on the prospects of dying. Table A-3 contains the probabilities of surviving from one age (x) to another age (y) for selected ages. To determine the chances of a 20-year old surviving to age 55, for example, first look at column 1, the goal age, then read across the table to the appropriate base age of 20. The probability is shown to be 0.9137. This is calculated by dividing the number of survivors to age 55 by the number of living 20-year olds: 88,583 by 96,954. By this formula, the likelihood that a lo-year old will live to age 85 is 0.2792.

At this point it is possible to demonstrate the effect of removal of a specific cause of death on survival probabilities, while holding constant the death rates due to other causes. In table A-4, when the probability of dying of cancer is reduced to zero, the numbers of people surviving to an older age increases. This is calculated in the same manner as in table A-2; i.e., the number entering the 1.0-4.9 age interval is:

100,000 - (100,000 x 0.02100) = 97,900.

Compare this figure to the corresponding number in table A-2; it represents an increase in survivors of 7 per 100,000. A comparison of the number of survivors to age 75 reveals an increase of 67,195 - 59,237 = 7,958.

Note that in the absence of information on disease interaction, the technique used in these calculations probably results in an incorrect estimate of the expected survivorship. As Preston, Keyfitz and Schoen (1972) point out, pneumonia, for example, may develop as a complication resulting from another illness, and increase the probability of death from the original illness. Eliminating pneumonia might result in 'an incorrect decrease of deaths from other causes.

In table A-5, the new probabilities of survival, cancer threat removed, are listed. In a comparison with table A-3, a 20-year old's chances of surviving to age 55 are increased from 0.9137 to 0.9402. In other words, the fraction of the population surviving from age 20 to age 55 with the eliminationofcancer is 94 percent. In addition, the fraction of the population surviving to age 80 increases from 44.5 percent to 52.9 percent. Interpolation of these results indicates an increase in life expectancy of 2.7 years.

In table A-6, the new probabilities of survival are converted back to the numbers of deaths that would occur at each age interval, as in table A-l.

In tables A-7 to A-9, a scenario of altered mortality resulting from halving the cancer death rate is presented tables A-10 to A-12 portray the "life experience" with a doubling of the probability of dying of cancer. All six of these tables employ the same mathematical technique used to represent total elimination of cancer.

Table A-l. NUMBER OF PERSONS DYING (OUT OF 100,000 AT BIRTH) FROM ALL CAUSES U.S. FEMALES, 1964

Age	Causes: Neoplasms	Causes: Cardio-vascular	Causes: Motor Veh. + Other Viol.	Causes: All Other + Unknown	Total	Number Entering Interval
0 - .9	7	12	79	2009	2107	100000
1 - 4.9	33	9	109	189	340	97843
5 - 9.9	33	7	67	75	182	97553
10 - 14.9	28	11	51	60	150	97371
15 - 19.9	33	19	130	85	267	97931
20 - 24.9	42	42	150	114	348	96954
2s - 29.9	67	65	140	151	423	96606
30 - 34.9.	133	110	152	210	607	96183
35 - 39.9	245	200	163	277	885	95576
40 - 44.9	426	350	166	354	1296	94691
45 - 49.9	640	595	177	471	1933	93395
50 - 54.9	1017	1067	178	617	2879	91462
55 - 59.9	1291	1736	197	786	3990	88583
60 - 64.9	1577	2967	204	1027	5775	84593
65 - 69.9	1935	4834	237	1353	8359	78818
70 - 74.9	2050	7175	278	1719	11222	70459
73 - 79.9	2063	10173	355	2044	14690	59237
80 - 84.9	1854	12734	47s	2301	17364	44547
85 - 89.9	1086	12573	580	2071	16310	27103
90 - 94.9	543	6287	290	1035	8155	10873
95 - 99.9	181	2095	97	345	2718	2718
					100000	

TABLE A-2. PROBABILITY OF DYING FROM SELECTED CAUSES

Age Interval	Number Entering Interval	Neoplasms	Cardio vascular	Motor Veh. + Other Violence	All Other + Unknown	Total
0-.9	100000	0.00007	0.00012	0.00079	0.02009	0.02107
l-4.9	97893	0.00034	0.00009	0.00111	0.00193	0.00347
5-9.9	97553	0.00034	0.00007	0.00069	0.00077	0.00187
10-14.9	97371	0.00029	0.00011	0.00052	0.00062	0.00154
15-19.9	97221	0.00034	0.00020	0.00134	0.00087	[illegible]
20-24.9	96954	'0.00043	0.00043	0.04155	0.00118	0.00359
25-29.9	9 6 6 0 6	0.00069	0.00067	0.00145	0.00156	0.00438
m--34,9-	96183	0.00140	0.00114	0.00158	0.00218	0.00631
35.39.9	95576	0.00256	0.00209	0.00171	0.00290	0.00926
40-44.9	94691	0:00450	0. 00370	0.0017s	0.00374	0.01369
45-49.9	93395	0.00739	0.00637	0.00190	0.00504	0.02070
SO-34.9	91462	0.01112	0.01167	0.00195	0.00675	0.03148
55-59.9	88583	0.01457	0.01937	0.00222	0.00887	0.04504
60-64.9	84593	0.01864	0.03307	0.00241	0.01214	0.06827
65-69.9	78818	0.02455	0.06133	0.00301	0.01717	0.10605
70-74.9	70459	0.02909	0.10183	0.00395	0.02440	0.15927
75-79.9	59237	0.03483	0.17173	0.00599	0.03543	0.24799
80-84.9	44547	0.04162	0.28586	0.01066	0.05165	0.38979
85-89.9	27183	0.03995	0.46253	0.02134	0.07619	0.60001
90-94.9	10873	0.04994	0.57822	0.02667	0.09519	0.75002
95-99.9	2718	0.06659	0.71079	0.03569	0.12693	1.00000

TABLE A-3. PROBABILITY OF SURVIVAL FROM ONE AGE (x) TO ANOTHER AGE (y)

Goal Age (y)	Number Entering Interval	Age (x)									
			10	20	so	40	so	60	70	80	90
0	100000	1.0000									
1	97893	0.9789									
5	97553	0.9755									
10	97371	0.9737	1.0000								
15	97221	0.9722	0.9985								
20	96954	0.9695	0.9957	1.0000							
25	96606	0.9661	0.9921	0.9964							
30	96183	0.9618	0.9878	0.9920	1.0000						
35	95576	0.9558	0.9816	0.9858	0.9937						
40	94491	0.9469	0.972s	0.9767	0.9845	1.0000					
45	93395	0.9340	0.9592	0.9633	0.9710	0.9863					
50	91462	0.9146	0.93%	0.9434	0.9509	0.9659	1.0000				
55	88583	0.8858	0.9097	0.9137	0.9210	0.9355	0.9685				
60	84593	0.8459	0.8688	0.8725	0.4795	0.8934	0.9249	1.0000			
65	78818	0.7842	0.8095	0.8129	0.8195	0.8324	0.8618	0.9317			
70	70459	0.7046	0.7236	0.7267	0.7326	0.7441	0.7704	0.8329	1.0000		
75	59237	0.5924	0.6084	0.6110	0.6159	0.6256	0.6477	0.7003	0.8447		
80	44347	0.4453	0.4575	0.4595	0.4631	0.4704	0.4871	0.4266	0.6322	1.0000	
as	27183	0.2718	0.2792	0.2804	0.2426	0.2871	0.2972	0.3213	0.3858	0.6102	
90	10873	0.1087	0.1117	0.1121	0.1130	0.1148	0.1189	0.1285	0.1543	0.2441	1.0000
9s	2718	0.0272	0.0270	0.0200	0.0243	0.0247	0.0297	0.0321	0.0386	0.0610	0.2500
100	0	0.0000	0. 0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

TABLE A-4. PROBABILITY OF DEATH WITH NEOPLASMS ELIMINATED

Age Interval	Number Entering Interval	Neoplasms	Cardio-vascular	Motor Veh. + Other Violence	All other + Unknown	New Total
0-.9	100000	0.00000	0.00012	0.00979	0.02009	0.02100
1-4.9	97900	0.00000	0.00009	0.00111	0.00193	0.00314
5-9.9	97593	0.00000	0.00007	0.00069	0.00077	0.00153
10-14.9	97444	0.00000	0.00011	0.00052	0.00062	0.00125
15-19.9	97322	0.00000	0.09020	0.00134	0.00087	0.00241
20-24.9	97088	0.00000	0.00043	0.00155	0.00118	0.00316
25-29.9	96781	0.00000	0.00067	0.00145	0.00156	0.00369
30-34.9	96425	0.00000	0.00114	0.00158	0.00218	0.00491
35-39.9	95951	0.00000	0.00209	0.00171	0.00290	0.00670
40-44.9	95309	0.00000	0.00370	0.00175	0.00374	0.00919
45-49.9	94433	0.00000	0.00637	0.00190	0.00504	0.01331
50-54.9	93176	0.00000	0.01167	0.00195	0.00675	0.02036
55-59.9	91279	0.00000	0.01951	0.00222	0.00887	0.03047
60-64.9	88498	0.00000	0.03507	0.00241	0.01214	0.04963
65-69.9	84106	0.00000	0.06133	0.00301	0.01717	0.08150
70-74.9	77251	0.00000	0.10183	0.00395	0.02440	0.13017
75-79.9	67195	0.00000	0.17173	0.00599	0.03543	0.21326
80-84.9	52872	0.00000	0.28586	0.01066	0.05165	0.34817
85-89.9	34463	0.00000	0.46253	0.02134	0.07619	0.56006
90-94.9	15162	0.00000	0.57822	0.02667	0.09519	0.70008
95-99.9	4547	0.00009	0.82578	0.03823	0.13599	1.00000

TABLE A-5. PROBABILITY OF SURVIVAL FROM ONE AGE (x) TO ANOTHER AGE (y) WITH NEOPLASMS ELIMINATED

Goal Age (y)	New Number Entering Interval	Age (x) 0	10	20	30	40	SO	60	70	80	90
0	100000	1.0000									
1	97900	0.9790									
5	97593	0.9759									
10	97444	0.9744	1.0008								
15	97322	0.9732	0.9987								
20	97088	0.9709	0.9963	1.0000							
25	96781	0.9678	0.9932	0.9968							
so	96425	0.9642	0.9895	0.9932	1.0000						
35	95951	0.9595	0.9847	0.9883	0.9951						
40	95309	0.9531	0.9781	0.9817	0.9884	1.0000					
45	94433	0.9443	0.9691	0.9727	0.97%	0.9908					
50	93176	0.9318	0.9562	0.9597	0.9663	0.9776	1.0000				
55	91279	0.9128	0.9367	0.9402	0.9466	0.9577	0.9796				
60	88498	0.483	0.9082	0.9115	0.9178	0.9285	0.9498	1.0000			
65	84106	0.4411	0.8631	0.8663	0.4723	0.8825	0.9027	0.9504			
70	77251	0.7725	0.7928	0.7937	0.8012	0.8105	0.8291	0.8729	1.0000		
75	67195	0.6720	0.6896	0.6921	0.6969	0.7050	0.7212	0.7593	0.8698		
80	52872	0.5287	0.5426	0.5446	0.5483	0.5547	0.5674	0.5974	0.6844	1.0000	
85	34463	0.3446	0.3537	0.3550	0.3574	0.3616	0.1699	0.194	0.4461	0.6518	
90	15162	0.1516	0.1556	0.1562	0.1572	0.1591	0.1627	0.1713	0.1963	0.2868	1.0000
95	4547	0.0455	0.0467	0.0468	0.0472	0.0477	0.0448	0.0514	0.0589	0.0860	0.2399
100	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

TABLE A-6. NUMBER OF PERSONS DYING (OUT OF 100,000 AT BIRTH) FROM ALL CAUSES WITH NEOPLASMS ELIMINATED

Age	Causes: Neoplasms	Causes: Cardio-vascular	Causes: Other Motor Veh.+ Viol.	Causes: All Other + Unknown	Total	Number Entering Interval
0 - .9	0	12	79	2009	2100	100000
1 - 4.9	0	9	109	189	307	97900
5 - 9.9	0	7	67	75	149	97593
10 - 14.9	0	11	51	60	122	97444
15 - 19.9	0	19	130	85	234	97322
20 - 24.9	0	42	150	114	306	97088
25 - 29.9	0	65	140	151	357	96781
30 - 34.9	0	110	152	211	473	96425
35 - 39.9	0	201	164	278	643	95951
40 - 44.9	0	352	167	356	876	95309
45 - 49.9	0	602	179	476	1257	94433
50 - 54.9	0	1087	181	629	1897	93376
55 - 59.9	0	1768	203	810	2781	91279
60 - 64.9	0	3104	213	1074	4592	88498
65 - 69.9	0	5158	253	1444	6855	84106
70 - 74.9	0	7067	305	1885	10056	77251
75 - 79.9	0	11540	403	2381	14323	67195
80 - 84.9	0	15114	564	2731	18408	52972
85 - 89.9	0	15940	735	2626	19301	34463
90 - 94.9	0	8767	404	1443	10615	15162
95 - 99.9	0	3755	174	618	4547	4547

TABLE A-7. PROBABILITIES OF DEATH WITH NEOPLASMS REDUCED BY 50%

Age Interval	Number Entering Interval	Neoplasms	Cardio-vasculer	Motor Veh. + Other Violence	All Other + Unknown	New Total
0-.9	100000	0.00004	0.00012	0.00079	0.02009	0.02104
14.9	97897	0.00017	0.00009	0.00111	0.00193	0.00330
s-9.9	97373	0.00017	0.00007	0.0006'9	0.00077	0.00170
10-14.9	97407	0.00014	0.00011	0.00052	0.00062	0.00149
15-19.9	97271	0.00017	0.00020	0.00134	0.00087	0.00258
20-24.9	97021	0.00022	0.00043	0.00155	0.00118	0.00337
25-29.9	96694	0.0003s	0.00067	0.00145	0.00156	0.00403
30-34.9	96304	0.00070	0.00114	0.00158	0.00218	0.00561
35.39.9	95764	0.00128	0.00209	0.00171	0.00290	0.00798
4044.b	95000	0.00225	0.00370	0.0017s	0.00374	0.01144
45-49.9	93913	0.00369	0.00637	0.00190	0.00504	0.01700
50-54.9	92316	0.00556	0.01167	0.0019s	0.00673	0.02592
55-59.9	89924	0.00729	0.01937	0.00222	0.00887	0.03776
60-64.9	86528	0.00932	0.05507	0.00241	0.01214	0.05895
65-69.9	81428	0.01228	0.06133	0.00301	0.01717	0.09378
70-74.9	73792	0.014535	0.10183	0.60395	0.02449	0.14472
75-79.9	63112	0.01741	0.17273	0.00599	0.03543	0.23057
80-84.9	48560	0.02081	0.28586	0.01066	0.05163	0.36898
85-89.9	30642	0.01998	0.46253	0.02134	0.07619	0.58003
90-94.9	12869	0.02497	0.57822	0.02667	0.09519	0.72505
95-99.9	3538	0.03330	0.77079	0.03569	0.16023	1.00000

TABLE A-8. PROBABILITY OF SURVIVAL FROM ONE AGE (x) TO ANOTHER AGE (y) WITH NEOPLASMS REDUCED BY 50%

Goal Age m	New Number Entering (y)	Interval	Age (x) 0	10	20	30	40	50	60	70	80	90
0	100000	1.0000										
1	97897	0.9790										
5	97573	0.9757										
10	97407	0.9741	1.0000									
15	97271	0.7727	0.9986									
20	97021	0.9102	0.990	1.0000								
25	96694	0.9669	0.9927	0.9966								
30	96304	0.9630	0.9887	0.9926	1.0000							
35	95764	0.9576	0.9832	0.9870	0.9944							
40	95000	0.9500	0.9753	0.9792	0.9865	1.0000						
45	93913	0.9392	0.9641	0.9600	0.9752	0.9886						
50	92316	0.9232	0.9477	0.9515	0.9586	0.9718	1.0000					
55	89924	0.8-m	0.9232	0.9268	0.9337	0.9466	0.9741					
60	86528	0.8653	0.8883	0.8929	0.8985	0.9108	0.9373	1.0000				
65	81428	0.3243	0.8360	0.8393	0.8455	0.8571	0.8821	0.0412				
70	73792	0.7379	0.7576	0.7606	0.7662	0.7768	0.7993	0.8528	1.0000			
75	63112	0.6312	0.6479	0.6505	0.6553	0.6643	0.6837	0.7294	0.8553			
80	48560	0.4856	0.4985	0.5005	0.5042	0.5112	0.5260	0.5612	0.6581	1.0000		
as	30642	0.3064	0.3146	0.3158	0.3102	0.3226	0.3319	0.3541	0.4153	0.6310		
90	12869	0.1287	0.1321	0.1326	0.1336	0.1355	0.1394	0.1487	0.1744	0.2650	1.0000	
95	3538	0.0354	0.0363	0.0365	0.0367	0.0372	0.0383	0.0409	0.0479	0.0729	0.2749	
100	0	0.0000	0.0000	0. 0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.5000	

TABLE A-9. NUMBER OF PERSONS DYING (OUT OF 100,000 AT BIRTH) FROM ALL CAUSES WITH NEOPLASMS REDUCED BY 50%

Age	Causes					Number
	Neoplasms	Cardio- vascular	Motor Veh.+ Other Viol.	All Other + Unknown	Total	Number Entering Interval
0 - .9	4	12	79	2009	2104	100000
1 - 4.9	17	9	109	189	324	97897
5 - 9.9	17	7	67	7s	166	97573
to - 14.9	14	11	51	60	136	97407
1s - 19.9	1 7	19	130	8s	251	97271
20 - 24.9	21	42	150	114	327	97021
25 - 23.9	34	65	140	151	390	96694
30 - 34.9	68	110	152	210	540	96304
35 - 39.9	123	200	163	278	764	95764
40 - 44.9	214	351	167	355	1087	95000
4s - 49.5'	347	598	178	474	1597	93913
so - 54.9	513	1077	180	623	2393	92316
55 - 59.9	655	1742	200	738	3395	89924
60 - 64.9	807	3035	209	1050	5101	86528
65 - 69.9	1000	4994	245	1398	7636	81428
70 - 74.9	1073	7514	291	1800	10679	73792
75 - 79.9	1099	10839	378	2236	14552	63112
80 - 84.9	1011	13881	518	2508	17918	48560
85 - 89.9	612	14173	654	2335	17774	30642
90 - 94.9	321	7441	343	1225	9331	12969
95 - 99.9	118	2727	126	567	3538	3538

TABLE A-10. PROBABILITIES OF DEATH WITH NEOPLASMS INCREASED BY 100%

Age Interval	Number Entering Interval	Neoplasms	Cardio-vascular	Motor Veh. + Other Violence	All Other + Unknown	New Total
0-.9	100000	0.40014	0.00012	0.00079	0.02009	0.02114
l-4.9	97886	0.00067	0.0000~	0.00111	0.00195	0.09381
s-9.9	97513	0.00068	0.00047	0.00069	0.00077	0.00220
10-14.9	97298	0.00058	0.00011	0.00052	0.00062	0.00183
15-19.9	97120	0.00068	0.00020	0.00134	0.00087	0.00309
20-24.9	96821	0.00087	0.00043	0.00155	0.00118	0.00402
25-29.9	96431	0.00133	0.00067	0.0014s	0.00156	0.00507
30-34.9	95942	0.00281	0.00114	0.00158	0.00218	0.00771
35.39.9	95202	0.00513	0.00209	0.00171	0.00290	0.01182
40-44.9	94076	0.00900	0.00370	0.00175	0.00374	0.01819
45-49.9	92365	0.01478	0.006~7	0.00190	0.00504	0.02909
50-54.9	89771	o-02224	0.01167	0.0019s	0.00675	0.04260
55-59.9	85947	0.02915	0.01937	0.00222	0.00887	0.05962
60-64.9	80824	0.03728	0.03507	0.00241	0.01214	0.08691
65-69.9	73799	0.04910	0.06133	0.00301	0.01717	0.13060
70-74.9	64161	0.05819	0.10183	0.00395	0.02430	0.18826
75-79.9	52075	0.06965	0.17173	0.00599	0.03543	0.28281
80-84.9	37348	0.08324	0.28586	0.01066	0.05165	0.43141
85-89.9	21235	0.07990	0.46253	0.02134	0.07619	0.63996
90-94.9	7646	0.09988	0.57822	0.02667	0.09519	0.79996
95-99.9	2529	0.13319	0.77079	0.03569	0.06034	1.00000

TABLE A-11. PROBABILITY OF SURVIVAL FROM ONE AGE (x) TO ANOTHER AGE (y) WITH NEOPLASMS INCREASED BY 100%

Goal Age (y)	New Number Entering Interval	Age (x) 0	10	20	30	40	50	60	70	80	90
0	100000	1.0000									
1	97886	0.9789									
5	97513	0.9751									
10	97298	0.9730	1.0000								
15	97120	0.9712	0.9982								
20	96821	0.9682	0.9951	1.0000							
25	96431	0.964s	0.9911	0.9960							
30	95942	0.9594	0.9861	0.9909	1.0000						
35	95202	0.9520	0.9785	0.9833	0.9923						
40	94076	0.9408	0.9669	0.9717	0.9806	1.0000					
45	92365	0.9237	0.9493	0.9540	0.9627	0.9818					
50	89771	0.8977	0.9226	0.9272	0.9357	0.9542	2.0000				
55	85947	0.8595	0.8833	0.8877	0.8958	0.915)	0.9574				
60	80824	0.8082	0.8307	0.3348	0.8424	0.8591	0.9003	1.0000			
65	73799	0.7300	0.7585	0.7622	0.7692	0.7845	0.8221	0.913;			
70	64161	0.6416	0.6594	0.6627	0.6687	0.6820	0.7147	0.7938	1.0000		
75	52075	0.5207	0.5352	0.5379	0.5428	0.5535	0.5801	0.6443	0.8116		
80	37348	0.3735	0.3838	0.3857	0.3893	0.3970	0.4160	0.4621	0.5821	1.0000	
as	21235	0.2124	0.2183	0.2193	0.2213	0.2257	0.2366	0.2627	0.5310	0.5686	
90	7646	0.0765	0.0786	0.0790	0.0797	0.0813	0.0852	0.0944	0.1192	0.2047	1.0000
95	1529	0.0153	0.0157	0.0158	0.0159	0.0163	0.0170	0.0189	0.0238	0.0410	0.2000
100	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

TABLE A-12. NUMBER OF PERSONS DYING (OUT OF 100,000 AT BIRTH) FROM ALL CAUSES WITH NEOPLASMS INCREASED BY 100%

Age	Causes					Number
	Neoplrsms	Cardio-vascul • r	Motor Veh. + Other Viol.	All Other + Unknown	Total	Entering Interval
0 - .9	14	12	79	2009	2114	100000
1 - 4.9	66	9	109	189	373	97886
5 - 9.9	66	7	67	75	215	97513
10 - 14.9	56	11	51	60	178	97298
15 - 19.9	66	19	130	85	300	97120
20 - 24.9	84	42	150	114	389	96821
25 - 29.9	134	65	140	151	489	96431
30 - 34.9	269	110	152	209	-740	95942
35 - 39.9	488	199	162	276	1126	95202
40 - 44.9	846	348	165	352	1711	94076
45 - 49.9	1365	588	175	466	2594	92365
50 - 54.9	1996	1047	175	606	3824	89771
55 - 59.9	2505	1665	191	763	5124	85947
60 - 64.9	3013	2835	19s	981	7024	80824
65 - 69.9	5624	4526	222	1267	9639	73799
70 - 74.9	3733	6534	253	1565	12086	64161
75 - 79.9	3627	8943	312	1845	14727	52075
80 - 84.9	3109	10676	398	1329	16112..	37348
85 - 89.9	1697	9822	453	1618	13590	21235
90 - 44.9	764	4421	204	728	6116	7656
95 - 99.9	204	1179	55	92	1529	1529