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MULTIATTRIBUTE UTILITY MODELING OF CARDIAC HEALTH EFFECTS FROM CARBON MONOXIDE EXPOSURE

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Abstract

Methods for evaluating carbon monoxide standards are described and critiqued, with a focus on impacts on cardiac patients' health. Willingness to pay for health increments is evaluated as a source of information in cost-benefit analyses. A multiattribute utility model is presented for choosing among standards.

1. Introduction

The Environmental Protection Agency of the United States Government is responsible for setting standards regulating carbon monoxide levels in the ambient air. Carbon monoxide (CO) exposure leads to low blood oxygen levels since CO binds to oxygen-carrying sites on red blood cells. Low-oxygen conditions can result in adverse health effects in sensitive groups, such as heart patients with angina pectoris. Chest pain symptoms called "angina" are aggravated by chronic exposure to CO. We discuss approaches for evaluating CO standards on the basis of their effects on heart patients. Studies of the effects of CO exposure on coronary heart disease are described in Section 2.

In Section 3, we describe and critique means for assessing the relative severity of health effects from the individual patients' perspectives. We focus on the standard-setting problem at the societal level later in the paper. In cost-benefit analysis, individual-level information consists of actual monetary expenses, foregone income, and judgments of willingness to pay for increments in health. This information is aggregated over individuals to establish total costs and benefits for a specific alternative CO standard. The non-monetary effects experienced by a person upon exposure to CO could be evaluated in a more general decision analytic multiple attribute framework by eliciting tradeoffs between added adverse health effects and other factors, such as extra time spent on chores. However, as noted in Section 4, such decision-based or tradeoff methods may not be appropriate in the context of heart patients, since the chronic nature of the disease leads to routine behaviors which are no longer

seen as decisions. In Section 5, we suggest that a better way of incorporating the relative health impacts on individuals in setting CO standards may be to conduct longitudinal studies of patients from the onset of disease forward in time, monitoring altered behaviors and attitudes.

At the societal level, decision makers must evaluate alternative CO standards. Use of cost-benefit analysis techniques may be inappropriate in the context of heart disease since willingness-to-pay questions may not be eliciting valid judgments. In Section 6, we extend a multiattribute utility model suggested by Keeney and Ozernoy (1982) by adding attributes representing health and lifestyle effects experienced by heart patients. Finally, Section 7 contains a summary.

2. Carbon Monoxide Standards and Coronary Heart Disease

The Environmental Protection Agency sponsored a study by Keeney, Sarin, and Winkler (1984) to model the likely health effects from alternative national ambient air CO standards; see Keeney et al. (1982). A risk assessment model was developed based on medical researchers' judgments about the relation between CO levels in the blood and adverse health effects. The effects included additional angina, heart attacks, and deaths due to heart attacks; aggravation of angina, peripheral vascular disease, and chronic obstructive pulmonary disease; vigilance impairment; and incidence of premature births when mothers were exposed to CO. The model built upon previously completed studies relating CO standards to ambient CO levels, ambient air CO levels to human exposure and resulting levels of CO in the blood. This study did not address the standard evaluation problem, it focused only on modeling expert medical researchers' judgments of the health effects associated with different standards. Presumably expert judgments were based upon a compilation of the available scientific evidence, so this study should be continually reevaluated as additional scientific evidence becomes known about the assumptions underlying the model.

In on-going research projects (Colome and Keller, 1985, and Lambert, Colome, and Davidson, 1984), we seek more information about the cardiac health effects resulting from CO exposure than has previously been acquired from laboratory experiments, epidemiological studies, and surveys of medical researchers' judgments. Time/activity surveys and electronic instruments are being used to monitor personal CO exposures in the microenvironment, physiological effects, and activity

patterns experienced by heart disease patients who experience the pain of angina pectoris.

Such research provides valuable information in the evaluation of different standards. Equally important in the standard-setting process is determination of the relative severity of the different health effects using some valuation procedure. The rest of this paper is devoted to describing and critiquing possible valuation procedures.

3. Cost-Benefit Analysis with Willingness-To-Pay Information

Colome and Keller (1985) are evaluating the impact of the health effects on the cardiac patients' lives using cost-benefit analysis as the valuation procedure. Heart patients respond to telephone survey questions eliciting actual costs of their angina (e.g., hired household help or lost income) and willingness to pay for improved angina levels. The willingness-to-pay questions contain a hypothetical contingent market for treatments leading to improvements in angina.

This approach has been used previously in the context of valuing cardiac health effects. Acton (1973) used the willingness-to-pay approach in a seminal study evaluating different ambulance/coronary care unit plans, based upon citizens' answers to a survey. An assumption underlying this approach is that public expenditures for health programs should be based on community members' aggregated willingness to pay for programs.

Randall et al. (1983) call for research investigating the behavior of subjects when faced with contingent market valuation questions. A problem encountered with applying the willingness-to-pay approach to valuing health is that people are often unwilling to put a monetary value on their suffering, since they feel that "fate" has given them their disease and that the discomfort and altered lifestyle are unalterable. If no monetary amount is attached to suffering, an essential concept of cost-benefit analysis--the possibility for a redistribution of costs and benefits among the society members --will be unsupported. Even if the economy as a whole experiences a favorable cost-benefit tradeoff due to the implementation of a specific standard, it is impossible to distribute the benefits fairly, since heart patients do not feel that money can compensate them for their suffering. One solution to this problem is to provide an increment in a non-monetary attribute (e.g., another health dimension), rather than added money. For example, the Environmental Protection Agency might relax CO standards, and provide each heart patient with

free air filtering devices for their homes and cars. On the other hand, even if patients are willing to provide a monetary value, their aggregated willingness to pay will likely understate their suffering since people with long illnesses tend to have reduced incomes.

Fischer (1979) adopted a psychological perspective in a critique of the willingness-to-pay principle in the context of cost-benefit analyses of health and safety programs. Since decisions involving tradeoffs between health status and other forms of material consumption have complex structures and since psychological research has shown that people are not adept at dealing with decisions of such complexity, Fischer concluded that willingness-to-pay judgments are not likely to be valid representations of preferences.

Changes in Health Status

It is useful to distinguish between willingness to pay for health status changes and willingness to pay for changes in health status transition probabilities. Fischer noted that willingness-to-pay questions about health status transitions are appropriate if the patients could be guaranteed to be in specific health states during specific periods. However, the nature of health problems is that they are uncertain; the patient has subjective beliefs about probabilities of being in different states. This subjectivity confounds willingness-to-pay measures when patients respond to questions. The Colome and Keller study elicits willingness to pay for hypothetical treatments which patients "purchase" and then experience altered health states (in terms of number of angina attacks). In this procedure patients must model the increased likelihood of a heart attack and death due to increased angina attacks. Thus, the probabilities of a heart attack and death in addition to the discomfort from anginal pain are considered when responding to a willingness-to-pay question of the form: "How much would you pay for a treatment to avoid two angina attacks per week?"

Thompson et al. (1984) evaluated willingness-to-pay measures in chronic arthritis. Questions were of the form: "What percentage of your income would you pay to get rid of your arthritis and all its symptoms?" In such a case, the patient must consider the implications of the seemingly simple question: Will I really be cured, i.e., have no chance of relapse in a few years? Will I contract another, worse disease, soon and need the money I have given up? Will the deformities I now have remain, or will I be fully able to participate in sports? A characteristic of this situation is the

uncertain quality of the "cure". The patient must consider different possible scenarios of future health states and weigh these scenarios intuitively before giving a summary response to the stated question.

Ease of imagining health symptoms raised the perceived likelihood of diseases in a study by Sherman et al. (1985). Thus, because a person's recent health status is easily imaginable, it might be overweighted. Further, McNeil et al. (1982) found that expressed preferences of both patients and physicians are affected by the framing of outcomes in terms of probability of living or probability of dying. Bishop et al. (1983) discovered large differences in the implied value of hunting permits when elicited via questions about willingness to pay for permits and willingness to accept compensation to give up permits. Gregory (1986) explained the difference between willingness to pay and compensation demanded from the perspective of psychological framing of one scenario as a gain and the other as a loss. Richer modeling of the hypothetical decision problem faced by the patient may help avoid biases in the elicited judgments. However, as Bishop et al. (1983) warn, more detailed questions may cause subjects to base responses primarily on the interview context, and not on the economic factors relevant for cost-benefit analysis.

There are additional problems with willingness-to-pay measures due to the specific cardiac health problems we investigate. For example, consider the valuation of reductions in angina attacks. First, an angina attack may be perceived as an early warning to stop exertion before a heart attack occurs. Though patients dislike the anginal pain, they may value this warning, and discount any monetary amount they'd state to reduce angina. Second, it is often possible to avoid or control angina attacks by altering activities. Thus patients "pay" to avoid attacks by avoiding exertion, rather than expending money. Third, reducing the number of angina attacks may not significantly reduce the psychological and behavioral effects of having angina pectoris, including dread of an attack, worry by family, and behavior adjustments (such as not being employed).

Health Status Transition Probabilities

A theoretically appropriate willingness-to-pay question, according to Fischer, asks about the value of changes in health status transition probabilities, since the transition probabilities, not health status, are likely to be altered when new programs or treatments are instituted. Questions are of the form: "What is the most that you are willing to pay to achieve a .001 reduction in your prob-

ability of dying from a heart attack next year?" Patients are not forced to model the probabilities and outcomes which result from a specific program. Rather, these are explicitly modeled for them. Acton used this approach in his community survey of willingness to pay for reductions in a neighbor's chances of death. But community members may not have fully developed opinions about the worth of a probability reduction, since they are generally not heart patients. Fischer critically evaluates Acton's results and concludes that though the study was done very carefully, the patterns of responses were inconsistent with basic principles required of the judgments (i.e., a person should not pay more for a small reduction in mortality than for a large one).

Fischer called for a decision analytic approach to willingness-to-pay questions and proposed a multiperiod utility model over health level and consumption level. In such an approach, subjects are not required to specify their problem structure and probabilities at the same time values are stated.

Decision analysis has been employed effectively as an aid in decision making in many complex problem situations. Decision analytic aids which have been developed within the medical arena in the context of health care policy evaluation and clinical care decisions are summarized by Krischer (1980). For example, Pauker (1976) used decision analysis to evaluate the decision to have coronary by-pass surgery.

4. Why Decision-Based Valuation Questions May Not Work for Angina

Angina pectoris is a chronic, painful disease that leads to altered behavior patterns in at least two fashions. First, some major life changes, such as giving up full-time work or undergoing coronary artery bypass surgery, are approached as decisions. However, a great deal of a person's behavior results from many small decisions or changes that become habits. This habituation process occurs over time, so that long-term sufferers who can identify their day-to-day habits via time-activity studies may find it difficult to describe tradeoffs they made in acquiring their habits. Thus, hypothetical decision questions are framed with a context and a response mode which does not match the patient's perspective.

Some special features of the habituation process lead to problems interpreting judgments elicited via a decision framework. As time passes, a person's perceptions and values may change to reduce cognitive dissonance. For example, those who can no longer work or par-

ticipate in contact sports may indicate that they don't want to engage in these activities. Based on preliminary results of the Colome and Keller (1985) study, patients seem to fall into at least two groups: those who give very low values for willingness to pay to avoid extra angina because they feel that they should bear the burden of the disease themselves and not bother others with it; and those who give very high values for willingness to pay to avoid extra angina because they feel that they deserve to devote whatever resources are available to easing their burden. Although there may be alternative explanations, these responses are similar to those found by Ramshaw and Stanley (1984). They found that angina patients who underwent coronary artery surgery could be divided into two distinct groups. Those who had coped well with previous stressful situations and had scored low on a neuroticism scale tended to rate themselves "well off" one year after their operation. In contrast, those who had not coped well with stress and who scored high on neuroticism did not rate themselves as well off as the other group.

Finally, even if a decision framework is valid, patients may believe that their angina can't improve because their doctors have done everything possible for them already, so no better treatment options could exist. Further, patients may believe that angina and risk of heart attack are biologically linked, so that hypothetical questions which attempt to isolate only angina effects may not be realistic.

5. Another Approach to Valuation of Angina Health Effects

Since decision-based valuation questions may not work for long-term angina sufferers, a modified valuation approach is needed. Longitudinal studies of angina patients' activities, psychological states, and decision behavior should be conducted. At the onset of a disease, a person is likely to be in a decision mode. At this time, many values and behaviors must be critically examined in light of added probabilistic information on future health states. Willingness-to-pay or decision analytic models may only be appropriate at this stage. As time passes, behavior and attitudes change. Special attention should be placed on the influences of the disease in changing behavior and attitudes. Such studies would provide rich data on the effects of a disease on a person's lifestyle as information to be used by societal decision makers in models for evaluating standards.

Consider the specific case of silent ischemia (low oxygen stress on the heart muscle without the anginal pain). A study of those at risk of silent ischemia would allow examination of valuation of de-

creases in risk of heart attacks to be considered separately from changes in angina. As mentioned above, these two health effects are likely to be perceived as biologically linked whenever angina patients respond to valuation questions. Studies of the silent ischemia high risk group (males 35 to 50 years old, overweight, with high blood pressure) would provide valuable comparisons with results from angina patients. First, the group at risk is likely to be still working, so income levels wouldn't be deflated. This could lead to higher values for willingness to pay to avoid extra risks of heart attacks. Second, this group would not yet have had values and behavior altered by disease. This might lead to different assessments of the value of various behaviors, such as working or participating in sports.

6. Multiattribute Utility Modeling of CO Standard Setting Decision

Keeney and Ozernoy (1982) outlined the use of multiattribute utility theory (Keeney and Raiffa, 1976) for evaluating CO standards. Their purpose was to demonstrate a framework for analyzing different standards; it was not to create a model for decision purposes. Though input for the modeling process was not made by actual decision makers, Environmental Protection Agency staff members did provide judgments required to develop the illustrative model. Four attributes were used in the model, number of persons with: heart attacks (x_1), angina attacks (x_2), peripheral vascular attacks (x_3), and vigilance impairment (x_4). An additive multiattribute utility function $u_H(x_1,x_2,x_3,x_4)$ over the health effects was found to have the form $k_1u_1(x_1) + k_2u_2(x_2) + k_3u_3(x_3) + k_4u_4(x_4)$. The assessment of the component utility functions led to linear functional forms, $u_i(x_i) = -x_i$, with utility decreasing as each x_i increased (the attributes represent numbers of persons having added adverse health effects). Finally, the scaling factors were assessed by asking questions such as "How many angina attacks are equally as bad as one heart attack?" After deliberation, 1000 angina attacks were determined to be as bad as 1 heart attack. Thus the heart attack scaling factor was set at $k_1 = 1$ and the angina scaling factor was set at 1/1000th of this, or $k_2 = 0.001$. Similarly, the added scaling factors were found to be $k_3 = 0.0002$ and $k_4 = 0.00002$. This utility function over health effects was then combined with a cost attribute x_5 reflecting the costs of implementing standards: $u(x_1,x_2,x_3,x_4,x_5) = u_H(x_1,x_2,x_3,x_4) + (1/k_c)u_c(c)$, where k_c is the scaling factor representing the relative undesirability of additional costs versus additional heart attacks.

If k_c= 0.1, the interpretation is that we would be willing to pay \$100,000 to avoid each heart attack. Assuming the utility function for cost is linear, $u_c(c) = -c$, the different standards were evaluated, as an illustration of the analysis technique.

The framework suggested by Keeney and Ozernoy can be extended through detailed modeling of the effects experienced by angina sufferers. First, longitudinal time/activity/attitude studies would identify the distribution of angina patients in different health status categories and the base-line transition probabilities for moving between states, due to progress of the disease and to CO exposure. Next, within each health status category, a prototypical patient profile could be described with attributes such as: angina severity, risk of heart attack, forced modification of behavior (working, activities), financial effects (health care, purchase of labor-saving devices), effects on others (worry by family/friends, effects on children), and psychological effects on patient. The preference tradeoffs for representative patients in each category could be determined via a combination of decision-based assessments and longitudinal attitude surveys. Then these results would be aggregated over the different categories, weighted by the probabilities associated with different CO standards. Finally, standards could then be ranked in order of overall utility.

7. Summary

Decision-based methods for eliciting individuals' valuations of health effects, such as willingness-to-pay judgments in cost-benefit analysis, may be inappropriate for angina patients since the chronic nature of the disease leads to habitual behavior patterns which are not perceived as sequences of decisions. Longitudinal studies of alterations in behavior and attitudes of heart patients as their disease progresses may provide better information for valuing health effects. A multiattribute utility approach for modeling the societal decision maker's problem of evaluating carbon monoxide standards is described.

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