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"Valuing Non-fatal Health Risks: Monetary and Health-Utility Measures "

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Abstract

Metrics for valuing environmental, health, and safety policies should be consistent with both the preferences of affected individuals and social preferences for distribution of health risks in the population. Two classes of metrics are widely used: monetary measures (e.g., willingness to pay) and health-utility measures (e.g., quality-adjusted life years (QALYs), disability-adjusted life years (DALYs)), both of which are summed across the population. Health-utility measures impose more structure than monetary measures, with the result that individuals' preferences often appear inconsistent with these measures; for the same reason, health-utility measures help protect against cognitive errors and other sources of incoherence in valuation. This paper presents theoretical and empirical evidence comparing these metrics and examining how they co-vary.

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1. INTRODUCTION

Measures for summarizing individuals' preferences for changes in health risk are useful for evaluating a wide range of public and private decisions that affect, inter alia, environmental quality, product safety, and medical procedures. An objective of quantification is to help determine whether the net change in health risks associated with an intervention justifies the opportunity cost of the resources used to achieve it.

Interventions that affect health risk may reduce one risk while simultaneously increasing another. In some cases, an intervention can have both beneficial and adverse effects on the same individual; for example, encouraging people to substitute bicycles for automobiles may improve cardiovascular health by increasing exercise but reduce safety by increasing the risk of serious injury in a crash (Rabl and Nazelle [2013]). Interventions can also have beneficial health effects on some individuals and harmful effects on others; for example, pregnant and nursing women who reduce their consumption of fish may reduce the risk of adverse neurocognitive effects to their children by decreasing exposure to methylmercury but increase their own risk of heart attack by reducing exposure to omega-3 fatty acids (Cohen et al. [2005], Rheinberger and Hammitt [2012]).

There are two classes of methods that are widely used to value changes in health risk: monetary measures and health-adjusted life year measures. Monetary measures value a change in health risk by the amount of money the effected individual views as equivalent to that change: either the willingness to pay (WTP) for an improvement (or to prevent a harm) or the willingness to accept compensation (WTA) to forgo an improvement (or accept a harm). Monetary measures are extremely flexible and can, in principle, incorporate any aspects of the health risk that are relevant to an individual's preferences. As a result, estimates of monetary values can also be influenced by cognitive errors or other factors that can influence survey responses or other behavior but that do not reflect an individual's normative preferences.

Health-adjusted life year measures, of which the most common are quality-adjusted life years (QALYs) and disability-adjusted life years (DALYs), measure a health risk as the expected change in duration-weighted health, where health is measured by an index such as health-related quality of life (HRQL). Health-adjusted life year measures put more structure on individual preferences; hence they are less flexible in incorporating attributes of a health risk that may affect an individual's preferences but are also less susceptible to cognitive errors or other factors that may lead to a divergence between an estimate of the value of a health risk and the individual's normative preferences.

As described below, health-adjusted life year measures require only an estimate of the HRQL (or other appropriate index of health quality) associated with a health state and its duration. With these, one can immediately calculate the value of reducing the risk or duration of an adverse health effect. Moreover, HRQL can be estimated relatively easily, or can be approximated by comparing the health state in question with other health states for which HRQL has been estimated. In contrast, monetary measures impose little structure on preferences so it may be necessary to elicit the monetary value independently for each health state and duration. Moreover, the value may depend on other attributes of the illness. Because the set of health conditions that may be relevant to policy is virtually unlimited, direct elicitation of monetary measures is a formidable task. This suggests that it would be valuable to develop a method for estimating the monetary value of a change in health risk using as input an estimate of the corresponding change in health-adjusted life years.

When evaluating a method for valuing health risk, two criteria that merit attention are: (1) the extent to which the method corresponds with individuals' normative preferences for health risks they face, and (2) the extent to which the method corresponds with social judgments about aggregating changes in health risks across individuals. Monetary measures are likely to be superior on the first criterion, because they impose much weaker assumptions

on the structure of individual preferences. However, they may be inferior on the second criterion because they are more sensitive to individuals' wealth and other factors than may be consistent with social preferences. Excessive sensitivity to wealth or other factors can, in principle, be ameliorated by applying an appropriate social-welfare function or by weighting monetary values by a decreasing function of individual wealth (Adler [2012], Adler et al. [2014]).

An important concern is that individuals may be uncertain about their preferences for their own health risk. Beshears et al. [2008] distinguish between normative preferences, which "represent the agent's actual interests," and revealed preferences, which "rationalize an economic agent's observed actions." In the context of health risk, there are a number of reasons why individuals' behaviors (and responses to stated-preference surveys) may be inconsistent with their normative preferences. First, people have limited information about health states they have not experienced and may have imperfect information about states they have experienced. Second, they have limited information-processing capacity and may be excessively sensitive to some attributes of a risk and insufficiently sensitive to others. For example, people may evaluate probabilities using heuristics that yield predictable biases, may be excessively sensitive to the way a risk is described or "framed" or to qualitative aspects of the risk (e.g., whether it is caused by a natural or synthetic material), or may make intertemporally inconsistent decisions (Tversky and Kahneman [1974], Kahneman [2011], Beshears et al. [2008], Hammitt [2013b]).

In the following sections, I provide a description of the conceptual framework for the two classes of measures then analyze how they relate to each other in theory and empirically.

2. MONETARY MEASURES OF HEALTH RISK

The monetary value to an individual of a change in her portfolio of health risks can be defined using either of two conventional measures, compensating or equivalent variation. For a change viewed as beneficial, the value can be assessed by the individual's willingness to pay (WTP) for the improvement (compensating variation) or her willingness to accept compensation (WTA) to forgo the improvement (equivalent variation). Similarly, for a change viewed as adverse, the value can be assessed by the individual's WTA for the harm (compensating variation) or WTP to prevent the harm (equivalent variation). Under standard economic theory, the WTA measure of a change is anticipated to be larger than the corresponding WTP measure, but in many cases the two measures should be approximately equal. The difference between WTA and WTP can be large when the value of the change is large compared with the individual's budget constraint (e.g., income or wealth) or when the health risk has no close market substitutes (Hanemann [1991]). However, empirical estimates of the two measures, obtained by stated-preference or experimental methods, often differ by a factor of five or more and there is no consensus on the reasons that this disparity is so large (Horowitz and McConnell [2002], Tunçel and Hammitt [2014]).

The standard model for the monetary value of a change in health risk was developed in the context of the risk of mortality (Drèze [1962], Jones-Lee [1974], Weinstein et al. [1980]). It assumes the individual seeks to maximize her expected state-dependent indirect utility of wealth,

$$EU = (1-p)u_a(w) + pu_d(w), \tag{1}$$

where p is the probability of dying during the current period, $u_a(w)$ is the utility of wealth conditional on surviving the period, and $u_d(w)$ is the utility of wealth conditional on dying during the period (i.e., the utility of a bequest). The marginal rate of substitution between wealth and mortality risk, conventionally described as the value per statistical life (VSL), is given by

$$VSL = \frac{dw}{dp} = \frac{u_a(w) - u_d(w)}{(1-p)u_a'(w) + pu_d'(w)} = \frac{\Delta u(w)}{Eu'(w)}. \quad (2)$$

As illustrated by the last expression in eqn. (2), VSL can be interpreted as the ratio of the gain in utility by decreasing p (the difference in utility between survival and death) to the expected opportunity cost of spending (the marginal utility of wealth weighted by the probabilities that spending diminishes wealth while living or as a bequest). It is conventional to assume that $u_a(w) > u_d(w)$ (survival is preferred to death), $u_a'(w) > u_d'(w) \geq 0$ (the marginal utility of wealth is non-negative and greater given survival than death), and $u_a''(w) \leq 0$, $u_d''(w) \leq 0$ (weak risk aversion with respect to wealth given survival and death). These conditions are sufficient to conclude that VSL is positive and increasing in wealth. The assumption that the marginal utility of wealth is larger given survival than death implies that VSL increases with initial risk p (the dead-anyway effect, Pratt and Zeckhauser [1996]). If actuarially fair insurance were available, an individual should transfer wealth from death to survival (e.g., by purchasing annuities) so the marginal utility of wealth is equal in the two states.

This model can be interpreted as applying to a non-fatal health condition by defining $u_a(w)$ to be the utility conditional on the absence of the specified health condition (e.g., on full health or health given pre-existing conditions). The interpretation of $u_d(w)$ depends on whether the impaired health state is chronic or transient. For a chronic health state, $u_d(w)$ may be interpreted as living the rest of one's life in the impaired health state (incorporating any reduction in life expectancy caused by the illness); for a transient health state, $u_d(w)$ may be interpreted as the utility conditional on becoming ill for the relevant period and then recovering.

For non-fatal health conditions, it is less clear that assuming the marginal utility of wealth increases with health is appropriate, especially if ill health creates medical expenses or reduces income. Defining wealth to be net of these effects (e.g., assuming that medical expenses and lost earnings are compensated by insurance), it seems plausible that the marginal utility of income is weakly increasing in health (because impaired health limits one's ability to produce utility through spending) and there is some empirical support for this assumption (Viscusi and Evans [1990], Sloan et al. [1998], Domeij and Johannesson [2006], Finkelstein et al. [2013]; for a contrary view see Lillard and Weiss [1997]). For an acute illness of short duration, it seems plausible that the marginal utility of wealth over a period significantly longer than the illness is not substantially affected, as one may defer consumption from the period while ill until later with little effect on total utility.

The effect of future health on the marginal rate of substitution between wealth and the probability of death or of illness is ambiguous. Improved health increases $u_a(w)$, and hence the utility gain from survival or avoiding illness (the numerator of eqn. (2)). However, if the marginal utility of wealth is increasing with health, improved health also increases $u_a'(w)$ and hence increases the denominator of eqn. (2). Similarly, the effect of life expectancy is also ambiguous. Greater life expectancy presumably increases the utility gain from avoiding illness or death in the current period (the numerator) but may increase the opportunity cost of spending (the denominator) if the increased in life expectancy does not provide a corresponding increase in wealth.

An implication of the VSL model is that WTP for a small reduction in p, Δp, is approximately proportional to Δp. Intuitively, as p decreases and w decreases to hold EU constant, VSL decreases because of the positive income elasticity and because of the dead-anyway effect. The proportional decrease in VSL because of the dead-anyway effect is smaller than $\Delta p/(1-p)$, so is negligible for small p. Empirically, the income elasticity is on the order of one, and so if WTP is a small fraction of the budget the proportional effect on VSL and hence on WTP is comparably small (see Alolayan et al. [2015] for details).

3. HEALTH-ADJUSTED LIFE YEAR MEASURES OF HEALTH RISK

Health-adjusted life year measures value a change in health risk as the expected value of the change in health-adjusted life years, which are periods of time weighted by an index of health. The two standard measures are quality-adjusted life years (QALYs) and disability-adjusted life years (DALYs). QALYs are typically used for cost-effectiveness analysis of health interventions (Gold et al. [1996]) and DALYs are typically used for quantifying the burden of health impairment in a population (Murray [1994]).

QALYs can be interpreted as the value of a health profile, i.e., a time path through various health states. In continuous time, QALYs in the period from the present (time zero) to some future date T can be represented by

$$Q = \int_0^T q\left[h(t)\right]e^{-rt}dt \tag{3}$$

where *h(t)* is the individual's health at time *t* and *q(h)* is the health-related quality of life (HRQL) associated with health h. It is conventional to discount future QALYs at some rate $r \geq 0$. The HRQL associated with a health state *q(h)* is an index of health scaled such that *q(h)* = 1 corresponds to full health and *q(h)* = 0 corresponds to a health state equivalent to death, in the sense that the individual is indifferent to living the rest of his life in that state or dying immediately. HRQL cannot exceed 1 (by definition) but can be less than 0 for health states judged to be worse than dead. Given a probability distribution of health states (including death) at each future time, *f[h(t)]*, an individual's expected future QALYs are given by

$$E(Q) = \int_{t=0}^{T}\int_{h=h^-}^{1} q\left[h(t)\right] f\left[h(t)\right]e^{-rt}dhdt \tag{4}$$

where T is some maximum possible longevity and h^- is some minimum possible HRQL.

QALYs are a function of health and duration. They are (usually implicitly) assumed to be independent of other factors that may affect well-being, such as wealth or consumption. Alternative sets of conditions under which QALYs represent an individual's preferences for health have been derived by Pliskin et al. [1980] and by Bleichrodt et al. [1997]. Essentially, two conditions are necessary: (1) the HRQL associated with a health state is a function of the health state alone; it is independent of the duration of the health state, any preceding or succeeding health states, and of other factors such as wealth; and (2) preferences for longevity risk (for a constant health state) are consistent with some specific restrictions, the nature of which differs between authors. Bleichrodt et al. [1997] assume individuals are risk neutral toward longevity, which implies the discount rate $r = 0$. Johannesson et al. [1994] note that non-zero discount rates, as typically applied in practice, are consistent with the assumption that individuals are risk neutral with respect to the present value of longevity discounted at rate r. The use of a constant discount rate, as in eqn. (4), implies individuals exhibit constant absolute risk aversion with respect to longevity (including risk-seeking preferences for $r < 0$ and risk neutrality for $r = 0$). Miyamoto et al. [1998] consider a more general case in which preferences toward longevity risks are independent of the health state. Pliskin et al. [1980] analyze the case in which an individual is willing to trade the same fraction of longevity for improvement from one specified chronic health state to another (constant proportional tradeoff). This requires that preferences toward longevity risk are consistent with constant relative risk aversion (i.e., hyperbolic discounting), which implies, for constant health h,

$$Q = \int_0^T q(h)t^{-\gamma}dt = q(h)\frac{T^{1-\gamma}}{1-\gamma} \tag{5}$$

where γ is the coefficient of relative risk aversion (for $\gamma = 1$, the last expression = *q(h) ln(T)*). Doctor et al. [2004] extend the QALY model to cases in which individuals evaluate risks not by expected utility but by rank-dependent utility or prospect theory.

Empirically, most of the evidence suggests that individual preferences are not consistent with QALYs. However, there is much heterogeneity and population-average preferences may be more consistent with QALYs than most individuals' preferences. Consider the evidence with respect to risk posture and HRQL.

Risk posture with respect to longevity seems to vary substantially among individuals. Pliskin et al. [1980] asked members of a Harvard faculty group working on health preferences to state the number of years of life for which each was indifferent to a lottery with equal chances of living 5 or 15 years; of the ten members, four were risk-neutral, four were risk-seeking, and two were risk-averse. More recently, Nielsen et al. [2010] and Hammitt and Tunçel [2015] asked survey respondents to make pairwise choices between three time patterns of mortality-risk reduction yielding the same increase in life expectancy. Nielsen et al. surveyed 129 Newcastle (UK) area residents aged 40-50 years in-person; Hammitt and Tunçel surveyed more than 1000 French residents aged 20-69 years over the internet. In both studies, most respondents (85 to 90 percent) made choices that are consistent with a transitive ordering over the three scenarios. A small fraction are consistent with risk neutrality toward longevity while the other respondents are divided between global risk aversion, global risk seekingness, and other patterns that are not consistent with any global risk posture toward longevity.

The HRQL associated with a health state is not independent of the health state's duration or the states that precede or follow. McNeil et al. [1981] surveyed 37 individuals in-person to elicit their preferences toward longevity and HRQL associated with loss of normal speech (as a side-effect of treatment for laryngeal cancer). They found a variety of preferences, but in general individuals' HRQL associated with the impaired health state was highly sensitive to duration, with a value near 1 when longevity was short (5 years or less) but declining substantially (to about 0.6) for longevity of 25 years. (In addition, McNeil et al. found their respondents were typically risk-averse with respect to longevity.) Bleichrodt and Filko [2008] tested whether preferences over health risk satisfy a condition that implies preferences depend on the marginal probabilities of experiencing different health states rather than the joint probabilities (i.e., are independent of preceding and succeeding health states). With a sample of 60 university students, they found that this marginality condition was satisfied on average, though it was rejected for a large number of respondents. Tsuchiya and Dolan (2005) reviewed the literature on whether HRQL is independent of the duration of a health state and of the states that precede or follow; they found strong evidence that these assumptions were violated at the individual level but concluded the assumptions were reasonable approximations for evaluating aggregated preferences.

4. INTEGRATING MONETARY AND HEALTH-ADJUSTED LIFE YEAR MEASURES

QALYs and other health-adjusted life year measures of the value of changes in health risk attempt to represent preferences for health and longevity; they provide no information about preferences for tradeoffs of disposable income, environmental quality, or other goods and services for reductions in risks to health and longevity. However, developing a catalog of monetary values for changes in health risks through direct measurement is challenging (Cameron [2014]). The number of health states and health profiles (time paths through health states) is potentially limitless. Moreover, the potential for using revealed-preference methods is limited by the paucity of situations in which individuals confront tradeoffs between non-fatal health risks and monetary consequences, which implies most estimates will need to come from stated-preference methods. Cameron and DeShazo [2013] describe an innovative stated-preference survey in which they characterize health profiles by the latency period before a health impairment begins, the duration and severity of the impaired-health state, the

duration of any post-recovery period, and the time of death, and estimate individuals' WTP to reduce risks as a function of these and other characteristics.

An alternative approach to estimating monetary values for changes in both non-fatal and fatal health risks is to develop a function to estimate the monetary value to an individual of an expected change in QALYs. This would be valid if preferences for health and longevity, conditional on wealth and perhaps other factors, were consistent with QALYs. Restricting attention to the case of constant health, Hammitt [2013a] shows that if utility for health and longevity are conditionally independent of wealth then utility for health h, longevity t, and wealth w must be a positive affine transformation of the corresponding QALYs $Q(h,t)$, i.e.,

$$U(h,t,w) = Q(h,t)a(w) + b(w), \tag{6}$$

where $a(w) > 0$ for all h,t such that life is preferred to death. Note that in the event of death $Q(0,0) = 0$ and hence $U(0,0,w) = b(w)$, so $b(w)$ is equivalent to the bequest function $u_d(w)$, and for h,t such that $Q(h,t) > 0$, $U(h,t,w)$ is equivalent to the utility function conditional on survival $u_a(w)$ introduced in eqn. (1). Adopting the standard assumptions from the VSL literature that the marginal utility of wealth is non-negative and greater given survival than death implies $a'(w) > 0$ and $b'(w) \geq 0$. Weak risk aversion with respect to wealth is satisfied if $a''(w) \leq 0$ and $b''(w) \leq 0$.

From eqn. (6), the marginal rate of substitution between wealth and QALYs v is given by

$$v = -\frac{dw}{dQ(h,t)}U(h,t,w) = \frac{a(w)}{Q(h,t)a'(w) + b'(w)}. \tag{7}$$

Under the assumptions in the previous paragraph, v is positive and decreasing in $Q(h,t)$. A constant marginal rate of substitution of wealth for QALYs seems implausible, as it requires $a'(w) = 0$, which implies the marginal utility of wealth is no greater given survival than death. While this condition is consistent with optimal life insurance when insurance is actuarially fair, it is not realistic with costly insurance.

The average rate of substitution between wealth and QALYs for a discrete increase of magnitude Δ, conditional on baseline QALYs $Q(h,t)$, is given by

$$v_{avg} = \frac{WTP}{\Delta} = \frac{a(w)}{Q(h,t)a'(w - y_1) + \Delta a'(w - y_2) + b'(w - y_3)} \tag{8}$$

where WTP is the individual's WTP for the gain of Δ and y_1, y_2, and y_3 are some amounts bounded by $0 < y_1, y_2, y_3 < WTP$. Similar to the marginal rate of substitution, the average rate of substitution is decreasing in both baseline QALYs and the magnitude of the increase. However, the average rate of substitution of wealth for QALYs for gains of different magnitude, Δ_1 and Δ_2, will be similar if both gains are small fractions of baseline QALYs.

A common approach to estimating WTP to reduce the risk of illness is to assume that WTP to reduce any health risk is proportional to the expected change in QALYs, and hence WTP per QALY is a constant that can be inferred from estimates of VSL (e.g., Mauskopf and French [1991], Hirth et al. [2000], Minor et al. [2015]). Formally, the assumption is that

$$WTP = \omega \cdot \Delta p \cdot \Delta Q \tag{9}$$

where ω is the constant rate of substitution between money and QALYs, Δp is the reduction in probability of an adverse health state, and ΔQ is the loss of QALYs conditional on suffering the adverse state. Solving for ω yields

$$\omega = \frac{WTP/\Delta p}{\Delta Q}. \tag{10}$$

In the case of current-period mortality risk, the numerator of eqn. (10) is VSL; hence the assumed constant WTP per QALY can be estimated by dividing an estimate of VSL by an estimate of expected future QALYs conditional on surviving the current period.

The assumption that WTP per QALY is constant is inconsistent with theory (e.g., eqn. (7)) and with evidence that age-specific VSL does not necessarily decrease with age and reduced life expectancy (Hammitt [2007], Aldy and Viscusi [2007], [2008], Krupnick [2007], Cameron et al. [2010]). Nevertheless, this approach provides a pragmatic method for estimating WTP to reduce a wide range of health risks.

5. EMPIRICAL ESTIMATES OF WTP PER QALY

To estimate the relationship between individual WTP and QALY measures of a change in health risk, consider the results of two stated-preference studies (Haninger and Hammitt [2011], Hammitt and Haninger [2016]). Both studies elicited individuals' WTP to reduce the probability of suffering a specified illness and were conducted by administering a survey to an internet panel. The panel, maintained by GfK (formerly Knowledge Networks) is a representative sample of the US general public; members are recruited by random-digit dial and other methods to guard against selection effects and results from the panel have been shown to be consistent with those of other methods of surveying the general public (Yeager et al. [2011]).

The first study (Haninger and Hammitt [2011]) concerns acute illness (of one to seven days duration) and the second (Hammitt and Haninger [2016]) concerns chronic illness (lasting one month, one year, or the rest of one's lifetime). In both studies, the duration and severity of illness and the reduction in probability of illness are randomly varied across respondents. WTP is elicited using a standard double-bounded dichotomous-choice format (Hanemann et al. [1991]).

In the first study, the risk is described as illness caused by microbial contaminants on a food the individual might eat (chicken, ground beef or packaged deli meat, randomly assigned). The probability of illness is stated to be 2/10,000 or 4/10,000 per meal. The individual can reduce this risk to 1/10,000 per meal (i.e., by 1/10,000 or 3/10,000) by purchasing an alternative version of the food produced using a "superior safety system" that reduces risk of illness-producing contamination through additional inspection and cleaning stages prior to final sale. The illness is described by its duration (1, 3, or 7 days) and symptoms. Symptom descriptions are presented in Table 1; they range from mild (upset stomach that does not prevent one from conducting normal activities) to severe (hospitalization with intravenous feeding tube).

Following presentation of the illness, the respondent's HRQL for that state is elicited using the Health Utilities Index Mark 3 (HUI). The HUI is a generic health-state classification and valuation system in which each health state is described by seven attributes, each of which has four or five levels (the attributes are vision, hearing, speech, ambulation, dexterity, emotion, cognition, and pain). Given the illness description, the respondent assigns the level of each attribute; from these, the HRQL is calculated using a scoring function that was developed by eliciting HRQL for illnesses with specified attribute profiles in a previous study (Feeney et al. [2002]). The respondent's HRQL for current health is also elicited using the HUI and the decrement associated with illness is calculated as the difference between the HRQL for current health and the HRQL for the described illness. Mean HRQL for current health and for the three symptom descriptions are reported in Table 1. On average, current health is about 0.8. HRQL for the three illnesses are much smaller: about 0.5 for the mild symptoms, 0.3 for moderate, and 0.1 for the severe case.

WTP for a reduction in the probability of becoming ill is elicited by asking the respondent to choose between the conventional version of a specified food and the safer version, which offers a smaller probability of illness and higher price. For two thirds of the sample, the risk and price difference are for a single meal; for the remainder of the sample, the risk and price are for one month's consumption of the specified food (calculated by

multiplying the risk reduction and price increment per meal by the respondent's reported average monthly consumption of the food).

The survey included questions about WTP to reduce risk to the respondent and to a child or other adult living in the household (if any). I consider here only the results pertaining to the respondent's WTP to reduce her own risk, and restrict the sample to respondents whose first valuation question was about risk to self (rather than risk to another person). This yields 2,858 respondents of whom 1,993 answered a second valuation question about risk to themselves (the others answered questions about risk to other household members). Haninger and Hammitt [2011] found no significant difference between the responses to the first and second valuation questions and hence pool them, yielding a total of 4,851 responses.

The empirical model is motivated by the hypothesis that WTP is proportional to the expected change in QALYs, i.e.,

$$WTP \propto \Delta p^{\delta} \Delta q^{\alpha} t^{\beta} \tag{11}$$

where Δp is the reduction in probability of illness, Δq is the difference in HRQL between current health and health if ill, and t is the duration of the illness. Under the null hypothesis that WTP is proportional to the change in expected QALYs, the elasticities of WTP with respect to Δp, Δq, and t (δ, α, and β, respectively) are all equal to one. Taking logarithms yields the linear regression equation

$$\log(WTP) = \delta \log(\Delta p) + \alpha \log(\Delta q) + \beta \log(t) + X\gamma + \varepsilon \tag{12}$$

where X is a vector of respondent characteristics and an intercept, γ is a vector of coefficients, and ε is random error.

The second study is similar in structure and implementation, with the following differences. First, it is concerned with chronic illness with durations of one month, one year, or the remainder of the individual's lifetime. The illness is said to be caused by exposure to environmental contaminants and can be reduced by participating in a US government environmental-health-protection program that includes an annual screening test and preventive medicine. The baseline risk is 3 or 4 per 10,000 per year and participation in the program reduces it by either 1 or 2 per 10,000 per year. The cost of participating in the program is described as an annual payment that is not covered by insurance or other sources (in addition to the time and inconvenience associated with the annual screening and medicines).

The illness was described by the EQ-5D health-state classification and valuation system (EuroQol Group [1990]). The EQ-5D is similar to the HUI described above, but includes only five attributes each of which can take any of three levels (the attributes are mobility, self-care, ability to conduct usual activities, pain/discomfort, and anxiety/depression). For half the respondents, the illness was described only by its duration and EQ-5D profile (i.e., the level on each of the five attributes); for the other half, this information was supplemented by the name of the disease (disease names included bronchitis, heart disease, hepatitis, influenza, liver cancer, liver disease, lung cancer, migraine headache, Parkinson's disease, respiratory infection, and skin cancer). EQ-5D profiles were representative of the profiles reported by individuals suffering these conditions who were surveyed through the US Medical Expenditure Panel Survey (MEPS). The survey included 22 combinations of EQ-5D profile and duration and 38 combinations of EQ-5D profile, duration, and disease name (implausible disease-name/duration pairs were excluded).

The HRQL if ill was calculated from the EQ-5D profile using the scoring function estimated for the US population (Shaw et al. [2005]). Respondents also characterized their usual health using the EQ-5D and the loss in HRQL if ill is calculated as the difference from usual health.

WTP was elicited for the choice between participating and not participating in the screening and preventive-medicine program. The reduction in probability of illness and monetary cost were described as annual amounts. I include only the response to a single

question valuing a reduction in risk to the respondent, yielding 2,339 respondents who each provide one valuation.

5.1. Regression estimates

Regression results are presented in Table 2. Columns (1) and (2) are for the acute-illness study; columns (3) and (4) are for the chronic-illness study. For each study, the table presents a simple regression model including the primary variables *log Δp*, *log Δq*, *log t*, and a few others, and a second model including selected respondent characteristics.

For both studies, the hypothesis that WTP is proportional to the expected change in QALYs is rejected. Consider first the estimated elasticity of WTP with respect to risk reduction δ. As described above, under conventional theory δ should be approximately one, as WTP should be nearly proportional to the reduction in probability of illness (assuming WTP is small enough relative to income that the income effect is small). In both studies, the estimate of δ is significantly different from zero. This implies that respondents were sensitive to the size of the risk reduction, even though these are small (on the order of 1/10,000 per meal or per year). For the chronic study, the estimated value of δ is approximately one and the hypothesis that it is equal to one cannot be rejected ($p > 0.9$). For the acute study, it is slightly larger than one-half and is significantly different from one.

The estimated coefficients of the log loss in HRQL if ill (*log Δq*) and the log duration of illness (*log t*) allow one to reject the hypothesis that WTP is proportional to the QALYs at stake. Despite the different contexts, the estimated coefficients are similar between the two studies: the coefficients of log duration are slightly larger than 0.1 in both studies and are significantly different from both zero and one. The coefficient on log loss of HRQL is approximately 0.2 in the acute study and 0.3 in the chronic study. These estimates are not significantly different from each other but again one can reject the hypotheses that the coefficient equals zero or one. The implication is that WTP to reduce the risk of illness increases with both the duration and severity of the illness (measured by the loss in HRQL) but the increase is much less than proportionate. Estimated WTP is a strongly concave function of both the duration and severity of the illness, and hence of their product (the loss in QALYs if ill). Cameron and DeShazo [2013] also find evidence that WTP is a concave function of the duration of illness and other health states: they find that a regression model including the logarithm of time in each health state fits their data much better than a model that is linear in time.

The estimated effects of respondent characteristics show some similarities and some differences between the studies. In both samples, estimated WTP is increasing with age, substantially smaller for male than for female respondents, and the relationship to household income is modest (the estimated coefficient is positive in both studies but not significantly different from zero in the acute study). The estimated relationships with education and marriage differ: WTP decreases with education (measured by completing university) and marriage in the acute study but increases with years of education and is not related to marriage in the chronic study.

Table 2 also reports some effects that are estimated in one study but not the other. In the acute study, the risk of illness and cost of the risk reduction were presented per meal for about two thirds of respondents and per month for the other third (using respondent-reported frequency of eating the specified food, which averages 5.6 meals per month). Estimated effects of the main variables of interest (representing the expected change in QALYs) are similar in the two subsamples so they are pooled. However, the mean rate of substitution between money and health risk is substantially larger in the sample presented with the per-month rather than the per-meal framing. This result suggests that respondents perceived a monthly increase in expenditure as less burdensome than the equivalent increase per meal or that the risks expressed per meal may be small enough that some respondents treated them as

negligible. However, respondents presented with the per-meal framing were sensitive to the risk reduction; the coefficients on $\log \Delta p$ are approximately the same when the regression models are estimated separately on the two subsamples, which suggests that the per-meal framing did not lead respondents to treat the risks as negligible.

For the chronic study, WTP is not significantly related to the initial risk (3 or 4 per 10,000). This result is consistent with the standard model, under which the larger baseline risk should increase the marginal rate of substitution by a factor of no more than $(1 - 0.0003) / (1 - 0.0004)$ (by the dead-anyway effect). Estimated WTP is significantly and substantially smaller when the disease is named. This suggests that the EQ-5D profile is not a sufficient description of the disease for valuation; i.e., the additional information associated with the disease name affects WTP. This further suggests that WTP is not a function of the expected change in QALYs alone; characteristics of the illness that are not captured in the HRQL and duration affect elicited valuation (and possibly normative preferences). Finally, WTP is significantly negatively related to the respondent's own health; for a fixed loss in HRQL, better baseline health decreases WTP. This is consistent with the standard model described above. For a fixed loss in HRQL, the numerator in eqn. (2) is constant but increasing marginal utility of wealth with health implies the marginal opportunity cost of spending (the denominator) increases with baseline health.

5.2. WTP per QALY

Table 3 presents the predicted WTP to reduce risk, the value per statistical case, and the average value per QALY for several illustrative combinations of the loss in HRQL and duration of illness. Values are calculated using the results in columns (1) and (3) of Table 2 for the acute- and chronic-illness studies, respectively. In all cases, the risk reduction Δp is equal to the mean for the corresponding study and covariates other than the characteristics of the illness Δq and t are set equal to zero, except that baseline HRQL in the chronic-illness study is set equal to 0.9, which is representative of the typical healthy American and slightly larger than the mean HRQL of respondents to the acute-illness study (Table 1) (Hanmer et al. [2006] report that mean HRQL estimated using the EQ-5D declines from 0.92 for ages 20-29 to 0.75 for ages 80-89).

WTP is the predicted median over the error term, i.e., the exponential of the predicted log WTP obtained from the regression equation. The value per statistical case is WTP divided by the risk reduction and the average value per QALY is WTP divided by the expected gain in QALYs (calculated as $\Delta p \cdot \Delta q \cdot t$, with no discounting).

The illness severities and durations presented in Table 3 correspond to extreme cases from the two studies; the duration ranges between one and seven days for the acute study and between one month and the rest of one's lifetime for the chronic study (taken here as 40 years, corresponding to a mean respondent age of about 45 years). The illness severity Δq = 0.1 or 0.9, corresponding to a very small loss or a loss from assumed baseline health that yields a health state indifferent to dead.

Predicted median WTP to reduce the risk of illness ranges between $1.36 and $2.57 per meal (acute illness) and between $79 and $360 per year (chronic illness). These amounts are clearly within individuals' budget constraints for a single meal or year, as average household income is about $50,000. If the amounts from the acute-illness study are aggregated over many meals in a year, however, the annual WTP is comparable to, or larger than, the annual WTP estimated in the chronic-illness study, which is on the order of 100 times larger. This suggests respondents may have perceived the questions as pertaining to a specific (or occasional) meal, and not as a rate at which they would pay to reduce risk of illness for all meals.

The values per statistical case of illness are on the order of $10,000 for the acute illnesses and $1 million for the chronic illnesses. For a comparable illness, the results of the

chronic study imply a larger WTP than those of the acute study; for example, the value per statistical case for a one month illness with $\Delta q = 0.1$ or 0.9 is about 60 to 90 times larger than the value per statistical case for a one week illness of the same severity, much greater than the four-fold difference in duration. (The difference in valuation is even larger than this difference in elicited WTP, because the chronic-study respondents also incur non-monetary costs associated with the annual tests and preventive medicine.)

Reflecting the small estimated elasticities of WTP with respect to duration and severity of illness, the WTP and hence the values per statistical case differ by much smaller factors than the duration and severity of the illnesses. For the acute study, WTP varies by a factor of about two although duration varies by a factor of seven and severity by a factor of nine. In the chronic study, WTP varies by a factor of less than five although duration varies by a factor of almost 500 and severity by a factor of nine. As a result, the average values per QALY vary substantially across illnesses, between about $70,000 and $60 million for the chronic study, and between about $700,000 and $20 million for the acute study. If future QALYs are discounted in accordance with conventional practice, the average value per discounted QALY calculated for the 40 year duration is increased (discounting has little effect on the shorter duration cases). For example, discounting at an annual rate of 3 percent per year increases the value per discounted QALY by a factor of about 1.7 (to $470,000 for an HRQL loss of 0.1 and to $110,000 for an HRQL loss of 0.9).

The last four columns of Table 3 show the implications of assuming that WTP to reduce any health risk equals a constant WTP per QALY ω multiplied by the expected change in QALYs (eqn. (9)). The values of ω are calculated from eqn. (10) using VSL = $9.3 million (consistent with current practice of the US Environmental Protection Agency and Department of Transportation; Robinson and Hammitt [2015]), age = 40 years (consistent with the studies underlying the VSL estimate), the total US population survival curve from Arias ([2014], Table 1), and HRQL by age (averaging over gender) from Hanmer et al. ([2006], Table 3, EQ-5D US). For discount rate $r = 0$, the implied ω = $280,000; for $r = 3$ percent per year, ω = $480,000.

By construction, the implied WTP and value per statistical case vary in proportion to Δq and, for $r = 0$, in proportion to t. Discounting at $r = 3$ percent per year increases ω and hence the implied WTP and value per statistical case for the acute illnesses and the one-month chronic illness, but has negligible effect on WTP and the value per statistical case for the 40 year illnesses (because discounting decreases the present value of future QALYs for these illnesses, exactly offsetting the increase in ω).

The implied WTP varies much more among illnesses than the elicited values: from a few cents to a dollar or more for the acute illnesses and from less than a dollar to $1,500 for the chronic ones. For the chronic illness with $t = 40$ years and $\Delta q = 0.1$, the implied WTP ($168) and value per statistical case ($1.1 million) are virtually identical to the values elicited by the stated-preference study. In contrast, the implied WTP and value per statistical case for the acute illnesses and the chronic illnesses of one month duration are much smaller than the elicited values. For the mild cases with $\Delta q = 0.1$ and $t = 1$ day or 1 month the difference is two orders of magnitude, but it is only about a factor of two for the most severe acute illness ($\Delta q = 0.9$ and $t = 7$ days). The only case for which the implied WTP and value per statistical case exceed the elicited values is the most severe chronic illness ($\Delta q = 0.9$ and $t = 40$ years), for which the implied values are about four times larger than the elicited values.

6. CONCLUSIONS

Two prominent methods for evaluating the benefits of reductions in health risk, monetary measures (WTP or compensating variation for the risk reduction) and health-utility measures (QALYs) provide sharply different perspectives on the relative value of reducing risks of illnesses that differ in severity and duration. QALYs assume that the value of a

reduction in the risk of suffering an illness is proportional to the decrease in probability times the loss in QALYs if the illness occurs. The QALY loss conditional on illness is proportional to its duration (or in some formulations, to a function of duration that reflects some degree of discounting or risk aversion over longevity). QALYs also assume the utility loss is strictly proportional to the reduction in health quality, measured as the difference in HRQL between the without- and with-illness health states. In contrast, WTP makes much weaker assumptions; under the standard expected-utility model, WTP is nearly proportional to the reduction in the probability of harm (for cases where WTP is small relative to the budget constraint) and is increasing in wealth, but it is not necessarily increasing in the severity of illness or duration.

Direct elicitation of individuals' WTP to reduce their own risks of specified illnesses shows that WTP is much less sensitive to the duration and severity of the illness than the proportionality assumed by QALYs. However, WTP is sensitive to the change in probability of illness, and in one of the two studies described is proportional to the change, as implied by standard theory. As a result, the average WTP per QALY varies substantially, with much larger values for shorter and milder illnesses and much smaller values for longer and more severe illnesses (Table 3). The average WTP per QALY for lengthy illnesses (i.e., 40 years) is comparable to the value obtained by dividing conventional estimates of VSL by the expected QALYs that would be lost in the event of death. Alternative estimates of WTP derived by assuming WTP is proportional to the expected change in QALYs and that infer the average value per QALY from estimates of VSL are, by construction, proportional to and hence much more sensitive to differences in severity and duration of illness. These implied estimates of WTP are much smaller than the elicited values for the acute illnesses, virtually equal for the 40 year mild illness ($\Delta q = 0.1$), and much larger for the 40 year severe illness ($\Delta q = 0.9$).

Which of these measures provides a more accurate representation of individuals' normative preferences is unclear. The estimated elasticities of elicited WTP with respect to duration and severity of illness seem implausibly small: a two-fold difference in valuation between a one-day illness that does not prevent one from conducting his normal activities and a week-long illness that entails significant pain and hospitalization does not seem credible. Nor does the less than five-fold difference in valuation between a mild one-month illness and a severe 40 year illness.

The hypothesis that the very modest sensitivity of elicited WTP to illness characteristics reflects the well-known problems of lack of scope sensitivity in stated-preference studies is plausible, but is not consistent with the strong sensitivity to small changes in probability (on the order of 1/10,000). Even if respondents do not understand HRQL very well, they clearly understand durations of days, weeks, months, and years and the differences in symptoms presented in the acute-illness study. Explaining these results in terms of insensitivity to scope requires explaining why respondents are insensitive to attributes they do understand (duration and severity) yet sensitive to an attribute they probably do not understand well (small probabilities).

An alternative hypothesis is that the results reflect systematic differences between utility assessed before, during, and after an experience. Kahneman and colleagues have shown that remembered utility and experienced utility often differ; in particular, remembered utility is more sensitive to the peak and final utility levels and less sensitive to duration than experienced utility. Decision utility (the utility anticipated before an event) may be more strongly correlated with the utility that would be remembered than with the utility that would be experienced (e.g., Kahneman [2011], Kahneman et al. [1993], Redelmeier et al. [2003]). In addition, people may be strongly averse to loss of health (Kahneman and Tversky [1979]), though they often adapt to impaired health and other changes so that utility reported by individuals suffering health impairment is better than utility judged by people who have not experienced the condition (Dolan and Kahneman [2008]). These findings suggest that

decision utility, assessed by WTP, may be much less sensitive to duration than is experienced utility. The implications for severity are less clear, however: loss aversion and neglect of adaptation to health impairment could lead to an increase in WTP but do not appear to explain the strongly concave relationship between WTP and severity as measured by the decrement in HRQL.

The values derived from the assumption that WTP is proportional to the expected change in QALYs vary much more with severity and duration, by construction. However, the assumption of a constant WTP per QALY is inconsistent with theory and with evidence that VSL does not systematically decrease with increasing age and decreasing life expectancy. Moreover, the estimates of VSL from which the constant WTP per QALY is inferred necessarily reflect decision, not experienced, utility. However, the empirical literature on valuing mortality risk is stronger than that valuing risk of non-fatal conditions; it is much larger, richer, and is not restricted to stated-preference studies.

In sum, the strongly nonlinear relationship between elicited monetary and health-utility measures of the value of reducing health risk points to questions about the extent to which values elicited from the public should be viewed as the relevant measure for welfare evaluation. The standard economic model assumes individuals are the best judges of their own interests given adequate information and reflection but if these conditions are not satisfied for various health risks, is it better to impose more structure on values, even if that structure seems inconsistent with many peoples' preferences?

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Table 1. HRQL for illness descriptions and current health

	HRQL	
Health state	Mean	Std. Dev.
Current Health	0.801	0.205
Mild Symptoms You will have an upset stomach and will feel tired, but these symptoms will not prevent you from going to work or from doing most of your regular activities.	0.506	0.269
Moderate Symptoms You will have an upset stomach, fever, and will need to lie down most of the time. You will be tired and will not feel like eating or drinking much. Occasionally, you will have painful cramps in your stomach. In addition, you will have some diarrhea and will need to stay close to a bathroom. While you are sick, you will not be able to go to work or do most of your regular activities.	0.258	0.305
Severe Symptoms You will have to be admitted to a hospital. You will have painful cramps in your stomach, fever, and will need to spend most of your time lying in bed. You will need to vomit and will have severe diarrhea that will leave you seriously dehydrated. Because you will be unable to eat or drink much, you will need to have intravenous tubes put in your arm to provide nourishment.	0.116	0.310

Note: Adapted from Haninger and Hammitt ([2011], Table III).

Table 2. Regression results

	Acute		Chronic	
Variable	(1)	(2)	(3)	(4)
Intercept	5.156***	4.894***	15.804***	13.056***
	(0.419)	(0.669)	(2.095)	(2.279)
Log Δp (δ)	0.516***	0.583***	1.007***	0.967***
	(0.047)	(0.049)	(0.228)	(0.227)
Log Δq (α)	0.197***	0.196***	0.344***	0.339***
	(0.046)	(0.045)	(0.093)	(0.092)
Log t (β)	0.105**	0.105**	0.127***	0.137***
	(0.046)	(0.044)	(0.033)	(0.033)
Age		0.011***		0.020**
		(0.002)		(0.006)
Male		-0.289***		-0.580***
		(0.076)		(0.159)
Log household income		0.047		0.187*
		(0.043)		(0.108)
Education (college; years education)		-0.259***		0.063*
		(0.083)		(0.033)
Married		-0.317***		-0.325
		(0.093)		(0.222)
Monthly version	1.124***	1.270***		
	(0.100)	(0.233)		
Baseline risk = 4/10,000			0.112	0.108
			(0.158)	(0.156)
Illness named			-0.652***	-0.701***
			(0.164)	(0.164)
Current HRQL			-1.650***	-1.718***
			(0.531)	(0.557)
Residual standard deviation	2.110	1.981	3.156	3.128
	(0.045)	(0.042)	(0.102)	(0.101)
Sample Size	4,851	4,851	2,343	2,343
Log likelihood	-5,481.8	-5,224.3	-2,651.1	-2,630.5

Note: Standard errors are in parentheses. ***, **, and * denote statistical significance at 1, 5, and 10 percent, respectively, based on likelihood-ratio tests. Columns (1) and (2) adapted from Haninger and Hammitt ([2011], Table IV); Columns (3) and (4) adapted from Hammitt and Haninger ([2015], Tables 3 and 5). Columns (2), (3) and (4) include additional variables in the original sources.

Table 3. Estimated WTP and average value per QALY

		WTP estimated from Table 2			Value per QALY derived from VSL			
					r = 0, ω = $280,000		r = 3%, ω = $480,000	
Δq	t	WTP ($)	Value per statistical case ($)	Average value per QALY ($)	Implied WTP ($)	Implied value per statistical case ($)	Implied WTP ($)	Implied value per statistical case ($)
Acute (WTP per meal)								
0.1	1 day	1.36	6,800	24,800,000	0.02	77	0.03	132
0.9	1 day	2.10	10,500	4,250,000	0.14	690	0.24	1,180
0.1	7 days	1.67	8,300	4,350,000	0.11	537	0.18	921
0.9	7 days	2.57	12,900	745,000	0.97	4,830	1.66	8,290
Chronic (WTP per year)								
0.1	1 month	77	514,000	61,700,000	0.35	2,330	0.60	4,000
0.9	1 month	164	1,100,000	14,600,000	3.15	21,000	5.40	36,000
0.1	40 years	169	1,130,000	281,000	168	1,120,000	168	1,118,000
0.9	40 years	360	2,400,000	66,600	1,510	10,080,000	1,510	10,060,000

Notes: WTP estimated as median from columns (1) and (3) of Table 2 assuming mean Δp (2/10,000 for acute, 1.5/10,000 for chronic), baseline HRQL = 0.9 (chronic), and all other covariates = 0.