Methodological Review of WTP and QALY Frameworks for Valuing Environmental Health Risks to Children

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Paper prepared for the OECD Project on the "Valuation of Environment-Related Health Impacts, with a Particular Focus on Children" (VERHI).

Valuation of Environment-Related Health Impacts with a Particular Focus on Children

Background

The lack of empirical surveys and associated lack of data in this area is a barrier to the provision of sound policy advice. Indeed, existing values used for monetisation of environment-related health impacts focus on adult populations and use scenarios that often do not match well with environmental scenarios. As such, there is concern that the continued use of existing estimates from unrelated contexts that do not take these factors into account may result in a misguided benefit-cost analyses, and in a possible misallocation of resources, especially when environmental policies with significant implications for children are under consideration.

In this context, the OECD Environment Directorate implemented in 2006 a project on the valuation of environmental health impacts, with a particular focus on children: the VERHI Project.

Objectives

This three-year project (2006-2008) funded by the European Commission under the 6th Framework Programme of Research (contract number SSPE-CT-2005-006529) seeks to improve the incorporation of environment-related health impacts in policy-making. An original survey instrument will be applied in three OECD countries (United Kingdom, Italy and the Czech Republic) that have disparities in terms of important factors, such as social insurance systems, health care systems, social concern about the environment, etc.

This survey will be developed so as to obtain methodologically comparable values for adults and children for similar risks, and will also seek to cast light on the context of the risk reduction, and on latency issues. Finally, the project will explore the potential for benefits transfer across countries with different socioeconomic characteristics.

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For more information on the VERHI Project and to download documents, visit the website: http://www.oecd.org/env/social/envhealth/verhi

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1. Introduction

Environmental health risks can produce a variety of morbid and mortal effects, differing in severity, affected body parts, and duration. These effects can manifest in individuals that differ by age, pre-existing health, and other factors. Comparing the efficacy of measures to reduce environmental health risks with each other and with the opportunity costs of the resources consumed by these measures can be facilitated by a measure of human preferences for health. Several such measures have been developed and are often used in practice. The two that are most prominent are the "Willingness to Pay" (WTP) and "Quality Adjusted Life Year" (QALY) frameworks. WTP is widely used in evaluating environmental and transportation-related risks and QALYs are routinely used in other aspects of public health and medicine.

Although they have been developed in different application areas, the WTP and QALY frameworks share important similarities: both are justified as representing individuals' preferences, and both are summed across individuals to represent the social value of a change in health risk. However, the specific assumptions underlying the approaches differ in ways that produce systematic differences in the relative values of changes in risks. These differences can lead to different conclusions about whether a policy increases or decreases aggregate health risk.

This report reviews the theoretical foundations underlying the WTP and QALY approaches and examines the relationship between them, including the potential for translation using a constant value of WTP per QALY.

The report is organized as follows. Section 2 reviews the theoretical assumptions of the two approaches. Section 3 examines the implications for valuing mortality risk. Section 4 examines the potential for conversion between the approaches using a constant WTP per QALY. Section 5 discusses

[1] Information given in this report reflects the author's views only. The Community is not liable for any use that may be made of the information contained therein.

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some of the differences between children and adults that are relevant to valuing health risks to children. Section 6 concludes.[3]

2. Utility-theoretic foundations

This section describes the basic concepts of WTP and QALYs and the assumptions under which these measures can be interpreted as measures of individual preferences.

An individual experiences various "health states" over her lifetime. The time-path of health states experienced, ending in death, is a "health profile." Risks to health and/or longevity may be represented as lotteries (probability distributions) over alternative health profiles, and policies or other interventions that alter health risks alter the probabilities associated with experiencing different health profiles.[4]

A utility function is any function that summarizes an individual's preferences, in the sense that it assigns a higher number to a more preferred lottery. Both WTP and QALYs can represent an individual's utility function if his or her preferences satisfy certain conditions. QALYs assume that preferences over health and longevity depend only on health consequences and do not depend on other characteristics of the individual or the risk.[5] In contrast, WTP allows for the possibility that preferences over health outcomes depend on individual characteristics such as wealth, as well as on characteristics of the risk such as whether it is perceived to be uncontrollable, unfamiliar, and dreaded.

2.1 WTP

The WTP approach reflects conventional microeconomic principles. Anything over which an individual has preferences, including lotteries on health profiles, can be described as an "economic good." An individual's preference for one lottery over another can be represented in terms of a change in income or wealth which can be used to purchase other goods.

There are two alternative measures of an individual's willingness to trade money for an improvement in health: WTP and willingness to accept (WTA). Consider the value to an individual with wealth w_0 of moving from health profile H_0 to a preferred health profile H_1. Her utility is a function of the health profile and wealth, $u(H, w)$. The value of the improvement may be measured as:

1. WTP for improvement (compensating variation), the value of c_0 satisfying $u(H_0, w_0) = u(H_1, w_0 - c_0)$. The name implies that the loss of wealth c_0 *compensates* for the gain in health leaving the individual no better or worse off than without the health improvement.
2. WTA to forgo improvement (equivalent variation), the value of e_0 satisfying $u(H_0, w_0 + e_0) = u(H_1, w_0)$. The payment is *equivalent* to the health gain in that the individual is equally well off whether she obtains the payment or the health improvement.[6]

[3] Sections 2 and 3 draw heavily from Hammitt (2002b, 2006), Section 4 from Hammitt (2002a), and Section 5 from Hammitt (2006).

[4] Note that a health profile experienced with certainty can be represented as a degenerate lottery that assigns probability one to the certain health profile and probability zero to all other profiles.

[5] Technically, preferences over health quality and longevity must be "utility independent" (Keeney and Raiffa, 1976) of other characteristics of the individual and the risk.

[6] Note that WTA to forgo an improvement from H_0 to H_1 is different than willingness to accept compensation for a reduction in health from H_0 to some less desired health profile. One can also define WTP to prevent a reduction from H_1 to H_0 (an equivalent variation) and WTA to permit a reduction from H_1 to H_0 (a compensating variation).

Figure 1 illustrates WTP and WTA for changes in the risk of dying during the current period, holding the lottery on health and survival in future time periods constant. The figure illustrates two indifference curves for the probability of surviving a specified period (*e.g.*, the current year) and wealth available for spending on other goods. An indifference curve is defined as a set of points such that the individual judges all points along it to be equally desirable. Points above and to the right of the indifference curve, representing larger survival probability and/or greater wealth, are preferred. Under plausible assumptions (described in Section 3.1), the indifference curves relating survival probability and income are downward sloping and convex to the origin as illustrated.

The initial position with survival probability p_0 and wealth w_0 is labeled A. An increase in survival probability to p_1 would shift the individual to B, on a higher indifference curve. The individual's WTP for this increase in survival probability is given by the vertical distance between the two indifference curves at p_1, B – C. Alternatively, the individual could achieve the same increase in utility by moving to point D, which involves no change in her survival probability but an increase in her wealth. The individual's WTA compensation in lieu of the survival improvement is given by the vertical distance between the two indifference curves at p_0, D – A.

If the risk reduction $p_1 - p_0$ is small, the two indifference curves will be nearly parallel between p_0 and p_1 (indifference curves cannot intersect). In this case, WTP and WTA will be nearly identical. If the risk reduction is large relative to the curvature of the indifference curves, WTA and WTP may be substantially different, with WTA > WTP.[7] For large changes in mortality risk, an individual's WTA compensation in place of an increase in survival probability may be much larger than her WTP for the same survival gain (note that WTP is limited by ability to pay, but WTA is not).

In principle, the choice of whether WTP or WTA is the appropriate measure of a change in risk may depend on the "property right" in the situation. If the individual having wealth w_0 is entitled only to the inferior health profile H_0, then it may be appropriate to compare her WTP for the improvement to H_1 with the costs of providing the improvement. Alternatively, if the individual is entitled to H_1, then it may be appropriate to compare her WTA to forgo the improvement with the costs that can be saved by not providing H_1. At the social level, when the costs of reducing risk are born by the beneficiaries, this distinction breaks down. If starting at H_0, the question is whether the individuals' collective WTP for an improvement exceeds the cost of improvement and, if starting at H_1, whether their collective WTA compensation for an increase in risk is less than the costs saved by allowing the increase. The situation in which individuals are entitled to H_1 without paying for it is not logically available in this case (Mitchell and Carson, 1989).

2.2 QALYs

The QALY framework provides a method for measuring the value of a health profile in terms of the duration of an equally preferred health profile free of any health impairment. The number of QALYs in a specified health profile is calculated as the quality-weighted lifespan

[7] If the indifference curve is smooth (which is the case if there are no satiation levels or other thresholds in the individual's preferences for survival probability and wealth), then WTP and WTA for infinitesimal changes in risk are equal. Hanemann (1991) shows that indifference curves for a publicly provided good may be curved sharply when no private goods provide close substitutes. In this case, WTP and WTA may diverge substantially even for small changes in the quantity of the public good. The intuition is that the quantity of the publicly provided good (e.g., mortality risk from ambient air pollution) is not subject to the individual's choice. If some private good provides a close substitute, the individual can adjust for a suboptimal quantity of the public good by purchasing more or less of the private good. Thus, if health risk from indoor air quality at home is a close substitute for health risk from ambient air quality, the individual may be able to compensate for poor ambient air quality by investing in cleaner air at home (or for excessively clean ambient air by spending less on controlling indoor pollution).

$$QALYs = \sum_{i=1}^{M} q_i T_i \qquad (2.1)$$

In equation (2.1), lifespan is divided into M periods that are indexed by i. The periods are defined so that only one health state is experienced in each period. The duration of period i is T_i and the "health-related quality of life" (HRQL) associated with that period is characterized by a weight q_i.[8] The value of an intervention that affects health and/or longevity is measured as the difference in QALYs between the health profiles obtained with and without the intervention, as illustrated in Figure 2. It is standard practice to discount QALYs for the time lag until they will be achieved, yielding a present value of QALYs (Gold *et al*., 1996).

The HRQL is a number that represents the quality of health.[9] It is scaled so that a value of one corresponds to perfect or excellent health and a value of zero corresponds to health that is equivalent to dead[10] (*i.e.*, an individual would be indifferent between living in such a state and dying immediately). Typically, q is between one and zero but values of q less than zero can be used to represent states of health that are worse than dead.

The conditions under which QALYs represent a valid individual utility function were identified by Pliskin *et al*. (1980). These authors restrict their attention to the special case of chronic (constant) health states, for which equation (2.1) simplifies to

$$\text{QALYs} = q\ T \qquad (2.2)$$

where T is remaining lifespan and q is the HRQL for the constant health state in which the individual will live until death. In this case, QALYs represent a valid utility function for an individual if her preferences satisfy the following conditions:

1. *Mutual utility independence*. This condition has two parts: (a) preferences between lotteries on health states, holding length of life constant, do not depend on remaining lifespan; and (b) preferences between lotteries on lifespan, holding health state constant, do not depend on health state. An example of part (a) is that, if an individual is indifferent between living 40 years in "good" health and a 70-30 lottery between living 40 years in "excellent" health or in "fair" health, she is also indifferent between living 25 years in "good" health and a 70-30 lottery between living 25 years in "excellent" or "fair" health.[11] An example of part (b) is that, if an individual is indifferent between living 30 years and a 50-50 lottery between living 40 years and 25 years, with all years lived in "excellent" health, then she is also indifferent between living 30 years and a 50-50 lottery between living 40 years and 25 years, with all years lived in "fair" health. Mutual utility independence is necessary for utility to be represented as a product of separate health and longevity terms as in equation (2.2) (Keeney and Raiffa, 1976).

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[8] QALYs can also be represented using a continuous-time representation $QALYs = \int_0^T q(t)dt$ where T is greater than or equal to a maximum longevity.

[9] Several terms, including health related quality of life, health status, and functional status, are used in the literature to designate a variety of single and multidimensional measures of health. I follow Gold *et al*. (1996) and Dolan (2000) in using the term HRQL to designate the one-dimensional utility value q_i.

[10] Note that it is the state of being dead rather than the event of death to which HRQL is anchored.

[11] As described below, health states are typically described in much greater detail. Simple descriptions such as "excellent, "good," and "fair" are used here for illustration. The notation "p-q lottery" denotes a lottery where the probability of the first outcome is p percent and the probability of the second outcome in q percent

2. *Constant proportional tradeoff of longevity for health*. The fraction of remaining lifespan the individual would be willing to sacrifice to improve her health from one state to another does not depend on her remaining lifespan. For example, if an individual is indifferent between living 40 years in "fair" health and 30 years in "excellent" health, she is also indifferent between living 20 years in "fair" health and 15 years in "excellent" health. This condition implies that the HRQL associated with a health state does not depend on the length of time spent in that state.

3. *Risk neutrality over lifespan*. Holding health state constant, the individual prefers whichever lottery on longevity provides the greatest life expectancy. For example, the individual would prefer to live 41 years to a 50-50 lottery between living 50 and 30 years, and she would prefer that lottery to living 39 years (where all years are lived in the same health state, *e.g.*, "excellent" health). A risk-adjusted form of QALY (which does not require risk neutrality) has also been developed (Pliskin *et al*., 1980) but is rarely used in practice. In the risk-adjusted case, the simple and ethically appealing calculation of changes in social utility as the population sum of individual changes in QALYs is inconsistent with individual preferences. This follows because the value of a health profile to an individual is a nonlinear function of duration, and so the individual's utility is not equal to the sum of her quality-weighted life years.

Bleichrodt *et al*. (1997) and Miyamoto *et al*. (1998) have proposed simpler conditions that imply an individual's preferences over lotteries on chronic health profiles can be represented by QALYs. One condition is that the individual is indifferent among all health states when her lifespan is zero (the so-called "zero condition"). If, in addition, she is risk neutral over lifespan for each health state (which implies that longevity is utility independent of health state), then her preferences can be described by equation (2.2) (Bleichrodt *et al*., 1997). Alternatively, if her preferences for lotteries on lifespan holding health constant do not depend on the health state (*i.e.*, lifespan is utility independent of health), then her preferences can be represented as a form of risk-adjusted QALY (Miyamoto *et al*., 1998).[12]

For the more general case in which health can vary over the lifespan (equation (2.1)), an additional condition is required:

4. *Additive independence across periods*. The individual's preferences for lotteries on health in any subset of the periods do not depend on health in other periods (Dolan, 2000). For example, if the individual is indifferent between (a) spending 10 years in "good" health and (b) spending 5 years in "good" health followed by a 70-30 lottery between 5 years in "excellent" health and 5 years in "poor" health, then she is also indifferent between (c) spending 5 years in "excellent" health followed by 5 years in "good" health and (d) spending 5 years in "excellent" health followed by a 70-30 lottery between 5 years in "excellent" health and 5 years in "poor" health.[13] Additive independence also implies that the individual is indifferent between health profiles offering the same total time spent in each health state, regardless of the sequence in which the health states are experienced (*e.g.*, the individual is assumed to be indifferent between (e) spending 8 years in excellent health followed by 2 years in poor health and (f) spending 2 years in poor health followed by 8 years in excellent health). This condition is necessary for QALYs to be calculated as the sum of HRQL-weighted time spent in each health state.

[12] The form of risk-adjusted QALY consistent with the Pliskin *et al*. (1980) assumptions is more restrictive than the form consistent with the Miyamoto *et al*. (1998) assumptions. The Pliskin *et al*. assumptions require that risk posture with respect to longevity, holding health constant, satisfy constant relative risk aversion (or constant relative risk proneness). The Miyamoto *et al*. assumptions impose no constraint on risk posture with respect to longevity (one can be risk averse for some range of lifespan and risk seeking for another), and do not even require that an individual always prefers a longer lifespan.

[13] The alternatives (c) and (d) can be obtained from alternatives (a) and (b) by changing the health state for the first 5 years from "good" to "excellent."

When QALYs are added across individuals (to evaluate social policies) it is generally considered appropriate to discount future QALYs at the same rate at which future monetary costs are discounted (Gold *et al*., 1996). Discounting QALYs is justified as treating individuals equally when resources are allocated using cost-effectiveness ratios: if the costs of an intervention are discounted but the effects (measured as additional QALYs) are not, then an intervention can be made to appear more favorable simply by postponing its implementation (Keeler and Cretin, 1983). Discounting future QALYs conflicts with the utility-theoretic justification, although the conflict could be remedied by substituting the present value of duration (using the appropriate discount rate) in conditions 2 and 3 above (Johannesson *et al*., 1994).

Empirical research suggests that individual preferences for health and longevity often violate the conditions under which QALYs provide a valid utility function for individual health (Johannesson *et al*., 1994; McNeil *et al*., 1981; Miyamoto *et al*., 1985; Loomes and McKenzie, 1989; Maas and Wakker, 1994; Stiggelbout *et al*., 1994; Verhoef *et al*., 1994; Bleichrodt, and Johannesson, 1996; Stalmeier *et al*., 1996). These violations are often small and idiosyncratic, and QALYs are considered by many to provide a reasonable starting point for representing preferences (Gold *et al*., 1996; Dolan, 2000).

3. Valuing mortality risk

For many environmental-health risks, the effect of greatest concern is fatality. The effects on the value of reducing mortality risk of both individual characteristics (*e.g.*, age, health, competing mortality risk, income) and risk characteristics (*e.g.*, dread, voluntariness, controllability) differ systematically between QALY and WTP approaches. In this section, the effects of these characteristics on the value of reducing a specific current risk (defined as a probability of dying within the current period from a specified cause) are examined under each framework.

3.1 WTP

Under the WTP approach, the value of reducing mortality risk is measured as the “value of a statistical life” (VSL). VSL is an individual-specific value defined as the marginal rate of substitution between mortality risk and wealth or income, *i.e.*, the individual’s WTP for a small reduction in mortality risk divided by the risk change, which is equivalent to the WTA for a small increase in mortality risk divided by the risk change and to the slope of the indifference curve illustrated in Figure 1 at the individual’s wealth and risk level.

VSL depends on wealth, current mortality risk, and the lottery over future health profiles the individual faces. The standard model (Drèze, 1962; Jones-Lee, 1974; Weinstein *et al*., 1980) assumes the individual maximizes her expected utility

$$EU(p, w) = (1 - p)\, u_a(w) + p\, u_d(w) \qquad (3.1)$$

where p is the individual’s chance of dying during the current period and $u_a(w)$ and $u_d(w)$ represent her utility as a function of wealth conditional on surviving and not surviving the period, respectively. The function $u_d(\bullet)$ incorporates the individual’s preferences for bequests and can incorporate any financial consequences of dying (such as medical bills or life-insurance benefits). In this single-period model, wealth and income are treated as equivalent. In multi-period models, the difference between wealth and income and the opportunities for future earnings can be important.

The individual’s VSL is derived by differentiating equation (3.1), holding utility constant, to obtain

$$VSL = \left.\frac{dw}{dp}\right|_{EU=k} = \frac{u_a(w) - u_d(w)}{(1-p)u_a'(w) + pu_d'(w)} = \frac{\Delta U}{EU'} \qquad (3.2)$$

where prime indicates first derivative.

The numerator in equation (3.2) is the difference in utility between surviving and dying in the current period. The denominator is the expected marginal utility of wealth, that is, the incremental utility associated with additional wealth conditional on surviving and dying in the current period, weighted by their respective probabilities. Assuming that survival is preferred to death (*i.e.*, $u_a(w) > u_d(w)$) and that greater wealth is preferred to less (*i.e.*, $u'_a(w) > 0$, $u'_d(w) \geq 0$), both numerator and denominator are positive and so VSL is positive and the indifference curves in Figure 1 slope downward.

Under the WTP approach, the value of reducing a specific mortality risk in the current period depends on life expectancy, competing mortality risk, the individual's health if she survives the specific risk, baseline risk and on income or wealth. The value of reducing a latent mortality risk depends on the duration of the latency.

First, consider the effect of baseline (total) risk on VSL. It is standard to assume that $u'_a(w) > u'_d(w)$, that is, the increased utility provided by greater wealth is larger if the individual survives and has the opportunity to spend it. With this assumption, an increase in the baseline risk p decreases the expected utility-cost of spending (the denominator in equation (3.2)). The incremental utility associated with survival (the numerator in equation (3.2)) is unaffected by baseline risk, so the individual would be willing to spend more to reduce her mortality risk. This "dead-anyway" effect (Pratt and Zeckhauser, 1996) is small for small changes in risk. The proportional effect on VSL of a change in baseline risk is less than the proportional change in the survival probability (1 - p).

The value of reducing the specific mortality risk is smaller if the individual also faces a competing mortality risk. The existence of a competing mortality risk reduces the magnitudes of both the numerator and the denominator in equation (3.2). The numerator decreases because the total probability of survival is smaller, and the denominator decreases because of the dead-anyway effect. The effect in the numerator dominates, and so competing mortality risk reduces WTP to reduce the specific mortality risk (Eeckhoudt and Hammitt, 2001).

VSL may depend on the individual's future health if she survives the specific mortality risk, but the sign of the effect is ambiguous. Survival in good health rather than poor increases the value of the numerator in equation (3.2). However, if the marginal utility of wealth is higher in good health than in poor health, the value of the denominator is larger and the effect on the ratio is indeterminate. As noted above, limited empirical evidence suggests that the marginal utility of income is smaller in a state of chronic health impairment (Sloan *et al*., 1998; Viscusi and Evans, 1990) and some empirical studies suggest that VSL is larger for people with cancer (Krupnick *et al*., 2001; Smith *et al*., 2002) or angina (Smith *et al*., 2002) than for people without those impairments.

As with most goods, WTP for reduction in mortality risk depends on ability to pay and increases with wealth. The assumption that additional wealth is more valuable in life than as a bequest (*i.e.*, $u'_a(w) > u'_d(w)$) implies that the numerator of equation (3.2) increases with wealth. Individuals are generally averse to financial risk. If so, the denominator declines with wealth (the second derivatives of $u_a(w)$ and $u_d(w)$ are negative), and VSL increases. If the individual is indifferent to financial risk, the denominator is constant and again VSL increases with wealth. Only in the implausible case in which the individual prefers to bear greater financial risk (for the same expected return) can the denominator increase with wealth, making the effect on VSL indeterminate.[14]

The effect of life expectancy on VSL is influenced by two competing factors. A greater life expectancy increases the utility of surviving the current period (the numerator in equation (3.2)), since one has more future years to enjoy. Greater life expectancy may also increase the denominator, because of the desire to save wealth for consumption in future periods, or because the opportunity cost of current spending to reduce mortality risk is larger for individuals with longer investment horizons. In the extreme case where the individual must support him or herself from accumulated savings, the opportunity cost of current spending clearly increases with life expectancy. The effect of life expectancy also depends on whether the individual is able to borrow against future income and on any difference between the rate at which she discounts future utility and the rate of return to savings.

A number of investigators have developed theoretical models to examine how VSL varies over an individual's life cycle. These models extend the one-period model described in equation (3.1) by assuming the individual seeks to maximize the expected discounted value of the utility of consumption

$$EU = \sum_{t=0}^{\infty} p_t \delta^t u(c_t) \qquad (3.3)$$

where p_t is the probability of surviving to at least age t, c_t is consumption at age t, and δ is the individual's discount factor (*i.e.*, $\delta = 1/(1+r)$ where r is the rate at which the individual discounts future utility).

Shepard and Zeckhauser (1984) assume individuals discount future utility at the market interest rate. If individuals can borrow against future earnings, VSL declines monotonically with age. Under this assumption, Shepard and Zeckhauser (1984) calculate that VSL for a typical American worker falls by a factor of three from age 25 to age 75. If individuals can save but not borrow, VSL rises in early years as the individual's savings (and earnings) increase before it ultimately declines. In this case, Shepard and Zeckhauser calculate that VSL peaks near age 40 and is less than half as large at ages 20 and 65.

Ng (1992) suggests that individuals may discount their future utility at a rate smaller than the rate of return to financial assets. If so, individuals should save more when they are young and consume more when old. Under these conditions, VSL may not peak until age 60 or so (Ng, 1992). Even if they discount future utility at the market interest rate, prudent (Kimball, 1990) individuals might be anticipated to save more and spend less on reducing mortality risk when they are young, because of the greater range of financial contingencies they face.

The effect of latency on WTP to reduce mortality risk combines two effects: the change in WTP to reduce current risk with time and age, and discounting for the delay (Cropper and Sussman, 1990; Cropper and Portney, 1990; Johannesson *et al.*, 1997; Hammitt and Liu, 2004). Since WTP is a monetary measure of value, WTP at different points in time should be related exactly as any other monetary values at those dates. Hence WTP now to reduce a mortality risk whose effects will manifest at a specific future date should be the present value of WTP then to reduce the risk at that future date, *i.e.*,

$$WTP_0 = \left(\frac{1}{1+r}\right)^t WTP_t \approx \left(\frac{1}{1+r}\right)^t VSL_t \Delta_t , \qquad (3.4)$$

[14] Positive effects of baseline risk and wealth on VSL are sufficient conditions for the convexity of the indifference curves in Fig. 2.

where WTP_0 and WTP_t are respectively WTP now and WTP at date t to reduce mortality risk at date t by Δ_t, VSL_t is the individual's VSL at date t, and r is the rate at which she discounts future monetary values, *e.g.*, the rate at which she can save or borrow. (Current WTP may also depend on the probability of surviving to date t, depending on the marginal utility of a bequest and whether her estate benefits from and is liable for investments and loans.)

Future WTP to reduce the then-current mortality risk may differ from current WTP for a similar reduction in current mortality risk for a variety of reasons. At the future date, the individual will be older and presumably have a shorter remaining life expectancy. His or her anticipated future health is likely to differ from its current value (in general, health declines with age). The individual may face unanticipated changes in competing mortality risks and income (anticipated changes in these and other factors should also affect current WTP for current risk). The net effect of these factors is ambiguous and it is possible that WTP to reduce a latent risk may exceed WTP to reduce a current risk. Hammitt and Liu (2004) provide an example in which utility in the near term is very small but will be larger in the future (perhaps because the individual is suffering from a severe but temporary illness). The primary benefit of reducing current mortality risk is to increase the chance of living during the future, high-utility period. If the latent risk reduction increases this probability by more than the current risk reduction does, the individual may prefer and have higher WTP for the latent benefit. Typically, however, it is likely that current WTP to reduce a latent mortality risk is a decreasing function of the latency period.

For evaluating social programs, it is possible to ignore the effects of individual differences in wealth or other factors that are considered ethically inappropriate by replacing individual VSLs with a value that is obtained by averaging over the objectionable characteristics. This approach is often taken in practice, where differences in wealth and health quality are generally ignored. An alternative approach is to consider how individuals might choose to incorporate differences in wealth and other factors in allocation of social resources if they were to make the decision behind a Rawlsian veil of ignorance, before they knew their own characteristics. Pratt and Zeckhauser (1996) use this approach to argue that the appropriate VSL for use in social policy choices increases with income, although at a smaller rate than empirical studies estimate. They also argue that differences in VSL due to differences in baseline risk (the dead-anyway effect) should not be incorporated.

3.2 QALYs

The value of a change in a specific current mortality risk under the QALY approach is the change in the expected number of QALYs. It depends on life expectancy, expected future health state, and latency, but not (with limited exceptions described below) on income or other individual or risk characteristics.

If the probability of dying from a specific cause in the current period is p, the individual faces a lottery with a p chance of dying in the current period and a complementary chance of surviving the specific risk and facing the lottery over health profiles that is determined by all the other health risks she faces in the current and future periods. Assuming the current period is one year, the health profile if the individual dies from the specific risk provides approximately one-half QALY (assuming she is equally likely to die at any time during the year and that her HRQL until then is nearly one). The value of a small reduction in the specific fatality risk is

$$W = \Delta p \, E(QALY) - \Delta p/2 \qquad (3.4)$$

where Δp is the change in the specific risk and E(QALY) is the expected number of QALYs if she survives the specific risk. Assuming the expected future QALYs are large compared with 1/2, the second term in equation (3.4) can be neglected, yielding

$$W \approx \Delta p \, E(QALY) \qquad (3.5)$$

As shown by equation (3.5), the value of reducing a specific mortality risk depends on the health lottery the individual faces if she survives that risk. Indeed, it is nearly proportional to the expected number of QALYs the individual will live if she survives. This implies that the value of reducing the specific mortality risk is directly related to the individual's life expectancy conditional on surviving the specific risk and to her expected future health state. For an individual who is likely to survive in very good health ($q \approx 1$), the value of reducing the specific mortality risk is proportional to life expectancy. For example, the conditional life expectancy of US residents is about 58 years at age 20 and 18 years at age 65, and so the value of reducing a near-term mortality risk to a 20 year old is approximately 3.2 (= 58/18) times as large as the value of a comparable risk reduction to a 65 year old. If future QALYs are discounted, the effect of life expectancy is attenuated. Using a recommended discount rate of 3 percent per annum (Gold *et al*., 1996) the relative value of reducing risk to a 20 year old would be about twice as large as the value of reducing risk to a 65 year old.

The effect of a competing mortality risk is to reduce the value of mitigating the specific mortality risk in direct proportion to the magnitude of the competing risk. This follows because the competing risk reduces the expected QALYs conditional on surviving the specific risk. For example, it has been suggested that the individuals who are at greatest risk of dying because of particulate air pollution face very large competing risks because of their age and cardio-pulmonary impairments (McMichael *et al*., 1998). The associated competing mortality risk may approach one per year, consistent with a life expectancy of less than one year.[15] Under the QALY approach, the value of reducing the risk that such people will die from air pollution is relatively small, because their life expectancy conditional on surviving the air pollution is small.

The value of reducing a specific mortality risk is also proportional to the individual's expected future health. Hence, the QALY approach implies it is more valuable to reduce a current mortality risk for someone whose survival would be in very good health than for someone whose survival would be in impaired health**.** For example, the HRQL for life after a myocardial infarction has been estimated as about 0.9 (Salkeld *et al*., 1997). Under the QALY approach, the value of reducing current mortality risk to someone who has survived a myocardial infarction is about 90 percent as large as the value of an identical risk reduction to someone who will survive with the same life expectancy but with no significant health impairment. Similarly, if people at risk of death from air pollution have low HRQL because of pre-existing illness, the QALY value of reducing mortality risk from air pollution may be lower than the value of reducing risks to healthier people.

The effect of latency is also straightforward. Because the individual's life expectancy at the time the latent risk may manifest differs from his or her current life expectancy (typically, it is smaller), fewer life years are at risk and so the expected change in QALYs is changed accordingly.

The relative value of reducing mortality risks to different individuals under the QALY approach is generally considered to be independent of individual economic circumstances, because life years (adjusted for health status) are counted equally regardless of personal characteristics. However, this claim must be qualified since HRQL, which represents the rate of substitution between longevity and health quality, may depend on wealth and other economic factors.

First, HRQL may depend on individual characteristics and circumstances. For example, the utility consequence of health impairment may depend on the individual's ability to mitigate the impairment, which may depend on economic circumstances. If the effects of an adverse health condition on individual

[15] Life expectancy of people who die from air pollution is estimated to be on the order of months to years (Schwartz, 2001), although for those with chronic obstructive pulmonary disease, the mortality displacement may be on the order of weeks to months (Schwartz, 2000).

well-being can be substantially offset using market goods (*e.g.*, personnel or mechanical devices), an individual's well-being in that state may be positively related to her wealth or income. However, since HRQL measures utility in the impaired health state relative to utility in perfect health, the effect of wealth on HRQL will depend on the relative degree to which it improves well-being in the two states. Under the assumption that QALYs are a utility function for health and longevity, the incremental effect of wealth on welfare is positively associated with health and longevity, except in the unusual case in which incremental wealth is more valuable as a bequest than in life (see Section 4). Limited empirical evidence also suggests that the marginal utility of wealth is smaller in impaired health states than in full health.[16]

Second, under the approach recommended by an expert panel (Gold *et al*., 1996), the effects of health status on earnings capability and income are incorporated in HRQL.[17] The effect of health impairment on income is likely to depend on the individual's job. Individuals whose income is more sensitive to health status may have a smaller HRQL for the same health impairment (*e.g.*, a physical disability might cause a greater income loss to a construction worker than to a writer). To the extent that jobs for which performance is more closely related to health offer lower wages, lower income people are likely to suffer greater income losses from health impairment, and hence potential larger decreases in HRQL.

For evaluating the social value of changes in health risk, the effects of income or other individual characteristics on HRQL can be eliminated by valuing all changes using population-average values of HRQL. Indeed, this is the recommended practice (Gold *et al*., 1996). However, if HRQL depends on income, this approach does not aggregate individual changes in welfare and so may lead to ranking health interventions in an order different than the affected individuals would rank them.

3.3 Effects of risk attributes

A large literature suggests that individual's concerns about environmental and other health risks are sensitive to characteristics of the risk other than probability and health effects, such as dread, voluntariness, and controllability (*e.g.*, Slovic, 2000). In principal, WTP can incorporate any effects of these characteristics on individuals' rates of tradeoff between money and health risk. In contrast, QALYs by definition depend only on the health states that an individual experiences (and their duration).

Empirical research on the extent to which WTP to reduce mortal or other health risks depends on risk characteristics is limited, and many of the studies that address this topic do not appear to estimate individuals' rates of substitution between their own money and risk reductions. Several studies have estimated individuals' WTP to reduce risks to a population, but these may include substantial amounts of altruistic WTP to reduce risk to others in addition to, or as an alternative to, WTP to reduce risk to oneself (*e.g.*, Jones-Lee *et al*., 1985; Mendeloff and Kaplan, 1989; McDaniels *et al*., 1992). Others have estimated preferences for social programs to reduce various population risks that differ in controllability, dread, and other characteristics using risk-tradeoff methods in which respondents' rates of substitution between deaths averted from different risks are elicited (*e.g.*, Jones-Lee and Loomes, 1995; Subramanian and Cropper, 2000; Chilton *et al*., 2002; Itaoka *et al*., 2006). Cookson (2000) used both willingness to pay and risk-tradeoff methods to estimate relative preferences for programs to save lives from six risks expected to differ on these attributes (air pollution, birth control pills, food poisoning, medical radiation, automobile and rail crashes). Savage (1993) asked survey respondents to allocate a hypothetical $100 contribution to

[16] Sloan *et al*. (1998) estimate that having multiple sclerosis (MS) reduces the marginal utility of income by a factor of 0.67 (estimated for people with MS) or by a factor of 0.08 (estimated for people without MS). Similarly, Viscusi and Evans (1990) estimate that a workplace accident (which might be fatal or nonfatal) reduces the marginal utility of income by a factor of 0.78 or 0.93 (using alternative functional forms).

[17] Brouwer *et al*. (1997) criticize the Gold *et al*. (1996) recommendation and argue that HRQL should be defined to measure preferences for health alone, holding income constant.

research intended to reduce fatal health risks from stomach cancer, household fires, commercial-airplane accidents, and automobile crashes. As the value of research on methods to reduce risk depends on the probability that the research will identify practical interventions, the efficacy and cost of the interventions, it is difficult to know how to translate results of this study to values of reducing alternative risks.

Several studies do provide information on how individual tradeoffs depend on risk characteristics. Magat *et al*. (1996) used a risk-risk survey to elicit preferences for reductions in the risk of fatal automobile accidents and three chronic diseases: terminal lymph cancer, curable lymph cancer, and non-fatal nerve disease. The median respondent was indifferent between equal reductions in the probability of terminal lymph cancer and of fatal automobile crashes, suggesting that there is no difference in WTP to reduce risks of automobile-crash and lymph-cancer fatalities (or that any difference is offset by the presumably longer but unspecified latency for lymph cancer). Hammitt and Liu (2004) elicited WTP to reduce the risk that the respondent and other members of his or her household would develop a chronic fatal disease and estimated that WTP to reduce the risk of developing lung disease due to industrial air pollution is twice as large as WTP to reduce the risk of liver disease due to contaminated drinking water. Vassanadumrongdee and Matsuoka (2005) elicited WTP to reduce mortality risk from air pollution and traffic injuries. They found that although the air pollution risk is viewed as less subject to individual control and more dreaded, WTP to reduce the two risks is equal. Tsuge *et al*. (2005) found that WTP to reduce the risk of a fatal cancer is larger than WTP to reduce risks of fatal heart disease or accident, although the WTP per unit risk reduction (and hence VSL) is the same for all three risks.

In contrast to WTP, QALYs incorporate information only about the health states that are experienced and their durations. In principal, health states could be defined to include the cause of the impairment (*e.g.*, lung cancer caused by smoking cigarettes and lung cancer caused by exposure to industrial emissions could be treated as different health states) and separate values of the HRQL could be elicited for identical physiological conditions. This approach has rarely if ever been attempted. It contrasts with the movement toward using generic health utility instruments to assign a consistent set of HRQL values to health states (Gold *et al*., 1996), as the existing generic instruments (*e.g.*, HUI, EQ-5D) define health independent of the cause of impairment.

A concern when incorporating information about risk characteristics is that individuals may give too much attention to the risk characteristics and too little to other aspects of the health risk, such as the severity of any morbidity and the probability of suffering the effect.[18] WTP is a more flexible approach in that it can readily incorporate preferences over risk characteristics, but QALYs have the potential advantage that they should not be influenced by any excess salience of these characteristics.

4. Potential conversion using WTP per QALY

If WTP per expected QALY were constant across health risks and individuals, then benefit-cost analysis (BCA) using WTP to measure benefits and cost-effectiveness analysis (CEA) using QALYs to measure effects would produce equivalent results (Johannesson, 1995; Garber and Phelps, 1997).[19] The assumption that WTP per QALY is independent of wealth or income seems implausible, yet if WTP per QALY were constant at the individual level, then BCA and CEA as conducted at the population level (*e.g.*, using average WTP) could be equivalent. Moreover, this situation would allow an easy conversion

[18] This overweighting of qualitative factors may explain the Tsuge *et al*. (2005) finding that WTP to reduce risk of cancer is larger than to reduce heart-disease and accident risks, but WTP per unit risk reduction is the same across risks.

[19] Johannesson (1995: 485) writes “the difference between cost-benefit analysis and cost-effectiveness analysis is that in cost-effectiveness analysis the willingness to pay per QALY gained is assumed to be the same for all individuals under all circumstances and for all sizes of the change in QALYs.”

between WTP and QALY measures of value, which would be useful in permitting estimates of either WTP or QALYs for some intervention to be obtained from studies that estimated the value of that intervention using the alternative approach. For example, Tolley *et al*. (1994) estimated WTP for alleviation of a wide range of health conditions by assuming it is proportional to QALYs gained and the US Food and Drug Administration often uses this approach to estimate WTP for incorporation in regulatory assessments (Robinson, 2004).

The following subsections review the empirical evidence and economic theory concerning WTP per QALY. The conclusion is that WTP per QALY is unlikely to be constant, even at the individual level.

4.1 Empirical evidence

Several studies have examined the relationship between estimates of WTP and QALYs associated with various health risks. For example, Johnson *et al*. (1997) and Van Houtven *et al*. (2003) conduct meta-analyses in which they estimate how WTP to reduce the risk of suffering acute health impairment depends on the HRQL and duration of illness. They find that WTP increases less than in proportion to the duration of illness and bears a nonlinear relationship to the decrement in HRQL. Using stated-preference surveys, Johnson *et al*. (2000) find that WTP increases less than proportionally with the duration of illness averted, Gyrd-Hansen (2003) finds that WTP to improve health is not proportional to HRQL, and Haninger and Hammitt (2006) find that WTP increases less than proportionally to both duration and HRQL decrement. Similarly, Jones-Lee *et al*. (1995) find that WTP to reduce the risk of automobile-crash injuries varies less than proportionally to standard gamble probabilities (which can be interpreted as measures of HRQL) for the corresponding injury.

From a theoretical perspective, these empirical results are not surprising. Although WTP per QALY could be constant at the individual level in theory if certain assumptions were satisfied, these assumptions are very strong and it would not be surprising if they were violated. The following section describes the assumptions on individual preferences that must be satisfied if WTP per QALY is constant.

4.2 Theoretical model of utility for health, longevity and wealth

Let lifetime utility u(h, L, w) depend on health h, longevity L, and wealth w. The value of h may be assumed constant over the lifetime, or may represent an average or other representative lifetime value. Assume that preferences over health and longevity are such that, holding wealth constant at any value w', the individual prefers more QALYs to fewer. Although the standard form of QALY ubiquitous in the literature assumes risk neutrality over longevity, Pliskin *et al*. (1980) propose a more general form of QALY which includes other risk postures. Under these assumptions, the conditional utility function for health and longevity holding wealth constant at some value w' can be represented as

$$\begin{aligned} u(h, L \mid w') &= [q(h)\, L]^r & r > 0 \quad & (4.1a) \\ &= \log[q(h)\, L] & r = 0 \quad & (4.1b) \\ &= -[q(h)\, L]^r & r < 0 \quad & (4.1c) \end{aligned}$$

where q(h) is the HRQL associated with health h.

The utility function (4.1a–4.1c) exhibits constant relative risk posture with measure $1 - r$. If $r = 1$, the individual is risk neutral over longevity; if $r < 1$, he is risk averse; and if $r > 1$, he is risk seeking.

The literature on QALYs is virtually silent on the extent to which HRQL depends on wealth, income, or consumption. In practice, HRQL is usually elicited with no attention to income or wealth and so it is assumed (at least implicitly) to be independent of wealth, an assumption that is adopted here.

If preferences for health and longevity are consistent with the QALY formulation (4.a–41c) and q(h) is independent of wealth, then conditional preferences for lotteries on health and longevity holding w fixed do not depend on the level at which w is fixed. Hence the conditional utility functions {u(h, L | w)} for any value of w must be strategically equivalent (*i.e.*, represent the same preferences over [h, L]), and so these conditional utility functions must be related as positive affine transformations (Keeney and Raiffa, 1976). This implies that the utility function for health, longevity, and wealth can be written as

$$u(h, L, w) = u(h, L \mid w)\, a(w) + b(w) \qquad (4.2)$$

where a(w) > 0 (so more QALYs are preferred to fewer). If there is a subsistence wealth level w_s below which the individual prefers death to survival, a(w) may be less than or equal to zero for $w \le w_s$. Substituting equations (4.1a–4.1c) into equation (4.2) yields:

$$\begin{aligned} u(h, L, w) &= [q(h)\, L]^r\, a(w) + b(w) && r > 0 \quad (4.3a) \\ &= \log[q(h)\, L]\, a(w) + b(w) && r = 0 \quad (4.3b) \\ &= -\,[q(h)\, L]^r\, a(w) + b(w) && r < 0 \quad (4.3c) \end{aligned}$$

Equations (4.3a–4.3c) describe the utility functions for health, longevity, and wealth that are admissible under the assumptions that preferences for health and longevity can be represented using risk-adjusted QALYs and that q(h) is independent of wealth. The literature on WTP to reduce mortality risk assumes that the marginal utility of wealth in the event of survival is greater than the marginal utility in the event of death, which is non-negative (*i.e.*, $u_a'(w) > u_d'(w) \ge 0$; see Section 3.1). In equations (4.3a–4.3c), death implies q(h) = L = 0, and so the standard assumptions on the marginal utility of wealth imply a'(w) > 0 and b'(w) ≥ 0 for all relevant wealth levels.

In the following section, the implications of these admissible utility functions for WTP per QALY are examined. For simplicity, consider only the utility function (4.3a). This form includes all three risk postures for longevity (risk averse, risk neutral, and risk seeking). Analogous results can be obtained for equations (4.3b) and (4.3c), both of which require risk aversion for longevity. For notational simplicity, let Q = q(h) L so that equation (4.3a) may be written as

$$u(h, L, w) = Q^r\, a(w) + b(w). \qquad (4.4)$$

4.2.1 WTP per QALY

Let V be the individual’s WTP per QALY. V is obtained by totally differentiating equation (4.4) holding utility constant to obtain

$$V = -\frac{dw}{dQ} = \frac{rQ^{r-1}a(w)}{Q^r a'(w) + b'(w)} + \frac{\partial w}{\partial Q}. \qquad (4.5)$$

In general, WTP per QALY is not constant but depends on wealth, total QALYs, and risk posture with respect to longevity. The first term in equation (4.5) represents the pure WTP for improvements in health and longevity. The second term represents the feedback effect of changes in health and longevity on lifetime wealth. The magnitude of $\frac{\partial w}{\partial Q}$ may depend on whether QALYs are gained by improvements in health or increases in longevity. For example, Meltzer (1997) and Bleichrodt and Quiggin (1999) assume lifetime wealth depends on longevity but not on health. In the remainder of this section, I focus on pure WTP for health and longevity. Letting $\frac{\partial w}{\partial Q} = 0$, equation (4.5) simplifies to

$$V = -\frac{dw}{dQ} = \frac{rQ^{r-1}a(w)}{Q^r a'(w) + b'(w)}. \quad (4.6)$$

Consider a few special cases. First, let the individual be risk neutral with respect to longevity (r = 1, the case usually assumed in applications). Equation (4.6) simplifies to

$$V = \frac{a(w)}{Qa'(w) + b'(w)} \quad (4.7)$$

and so marginal WTP per QALY is a decreasing function of the number of QALYs.

In the case where the individual is indifferent to the level of his bequest (b'(w) = 0), equation (4.6) becomes

$$V = \frac{r}{Q}\frac{a(w)}{a'(w)}. \quad (4.8)$$

Again, WTP per QALY decreases with total QALYs. In addition, WTP increases with r. Since the individual's degree of relative risk aversion with respect to longevity is equal to 1 – r, an increase in r decreases risk aversion (increases risk proneness) with respect to longevity, so WTP per QALY depends on the risk posture for longevity. Specifically, an increase in risk aversion with respect to longevity decreases marginal WTP per QALY.[20]

Consider the general case given by equation (4.6). In the following subsections I investigate the dependence of WTP per QALY on wealth, health, and longevity.

4.2.2 Effect of Wealth on WTP per QALY

The effect of wealth on WTP per QALY can be examined by differentiating equation (4.6) with respect to wealth to obtain

$$\frac{\partial V}{\partial w} = \frac{rQ^{r-1}\{a'[Q^r a' + b'] - a[Q^r a'' + b'']\}}{[Q^r a' + b']^2} \quad (4.9)$$

where w is suppressed to simplify notation. Further algebraic manipulation yields

$$\frac{\partial V}{\partial w} = V\left[\frac{a'(w)}{a(w)} + \pi(w)\right] \quad (4.10)$$

where π(w) is the measure of local risk aversion.[21] Equation (4.10) shows that the effect of wealth on V depends on V and on the sum of the local boldness coefficient for a(w) (*i.e.*, a'(w)/a(w)) and the local risk

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[20] This result contrasts with the common but erroneous claim that risk aversion increases VSL (Eeckhoudt and Hammitt, 2004).

[21] $$\pi(w) = -\frac{\frac{\partial^2}{\partial w^2}u(q,L,w)}{\frac{\partial}{\partial w}u(q,L,w)} = -\frac{Q^r a''(w) + b''(w)}{Q^r a'(w) + b'(w)}.$$

aversion with respect to wealth. As both a(w) and a'(w) are greater than zero, the local boldness coefficient is positive. Hence an increase in wealth will increase WTP per QALY whenever $\pi(w) \geq 0$, *i.e.*, whenever the individual is risk averse or risk neutral with respect to wealth. Wealth can decrease V only if the individual is sufficiently risk seeking with respect to wealth. This result is analogous to the result for WTP to reduce mortality risk, where VSL increases with wealth except when the individual is sufficiently risk seeking in the states of life or death (Weinstein *et al*., 1980). The finding that, under reasonable conditions, WTP per QALY increases with wealth is unsurprising and has been previously recognized (*e.g.*, Gold *et al*., 1996; Garber and Phelps, 1997).

4.2.3 Effects of Health and Longevity on WTP per QALY

To evaluate the dependence of WTP per QALY on health and longevity, differentiate equation (4.6) with respect to Q to obtain

$$\frac{\partial V}{\partial Q} = \frac{Q^{2(r-1)} ra\left[-a' + (r-1)b'\right]}{\left[Q^r a' + b'\right]^2}. \quad (4.11)$$

The sign of equation (4.11) depends on the risk posture with respect to longevity and the marginal utility of bequests. If the individual is risk neutral or risk averse with respect to longevity ($r \leq 1$) or the marginal utility of bequest is zero ($b' = 0$), then the marginal WTP per QALY decreases with increasing QALYs. In contrast, V may increase with Q if the individual is risk seeking with respect to longevity ($r > 1$) and assigns positive marginal value to his bequest ($b'(w) > 0$). The only case in which V is constant occurs when the term in brackets in the numerator vanishes, which requires that the increase in the marginal utility of wealth with respect to QALYs (*i.e.*, a'(w)) bears a specific relationship to the marginal utility of a bequest (b'(w)). Because $a' > 0$ and $b' \geq 0$, this can occur only when $b' > 0$ (*i.e.*, the marginal utility of a bequest is positive) and for values of $r > 1$, *i.e.*, when the individual is risk seeking with respect to longevity.

4.3 Summary

Empirical evidence suggests that WTP to reduce risks to health is a non-linear function of the expected gain in QALYs. Typically, WTP increases less than in proportion to both the duration of the impaired health condition and to its severity as measured by the decrement in HRQL. A theoretical model reveals that, if an individual's preferences for health and longevity are consistent with QALYs, then (under reasonable conditions) individual WTP per QALY increases with wealth. For most reasonable assumptions, WTP per QALY decreases with QALYs, although it can increase with QALYs when the individual is risk seeking with respect to longevity. Individual WTP per QALY can be a constant, independent of QALYs, but only when the increase in the marginal utility of wealth with respect to QALYs bears a specific, precise relationship to the marginal utility of a bequest. This relationship cannot be satisfied when the individual is risk neutral (as typically assumed) or risk averse with respect to longevity, or when he is indifferent to the size of his bequest.

For applications to evaluating measures to evaluate environmental-health risk, the likelihood that individual WTP per QALY is not constant (and hence that WTP is not proportional to expected QALYs gained) does not necessarily mean that one should not convert between these measures. For small changes in health (*e.g.*, where the change in HRQL is small), it may be possible to obtain a reasonable estimate of WTP using a local approximation to WTP per QALY. Note however that a recent US Institute of Medicine panel recommended against using estimated changes in QALYs as a basis for estimating WTP because of the differences in their underlying theoretical bases and in the types of tradeoffs they elicit (Lawrence *et al*., 2006).

5. Differences between children and adults

Most of the literature on valuing health risks is oriented toward valuing risks to adults. Both WTP and QALY frameworks take as a starting point the notion of an autonomous individual who is knowledgeable about the consequences of various health risks and is able to gauge the effects on his or her well-being of changes in health state, probability of health impairments, and changes in income and thus consumption of other goods.

In considering valuation of risk to children, three points appear to be central: (1) differences in cognitive ability and legal status between children and adults, (2) the expectation that children will progress through a series of developmental stages, ultimately becoming adults, and (3) the timing of the exposure to a risk, manifestation of health consequences, and duration of those consequences.

The idealized rational, informed, and autonomous individual of economic theory is not an accurate picture of a typical child, and society does not generally view children as autonomous economic agents. Most children do not earn income or make economically significant choices regarding their health and well-being. Children may also differ from adults in their view of death and may exhibit higher degrees of risk-taking behavior, perhaps because of their undeveloped cognitive abilities and limited practical experience (Harbaugh, 1999). Young children often have difficulty imagining and understanding death in the same way that adults do. They may view death as a type of sleep or as an event that happens only to bad people (Carey, 1985). Compared with adults, both children and adolescents may have shorter time horizons, discount the future at higher rates, and underestimate the value of future consumption (Harbaugh, 1999). In short, all of these observed differences present problems for the standard economic assumptions of informed and rational behavior.

Differences in apparent rationality and autonomy between children and adults may be overdrawn, however. It is well known that adults often make decisions and express preferences that are inconsistent with basic axioms of rational decision making. There is a wealth of experimental evidence showing violations of expected utility theory and decisions are often influenced by which of several alternative but logically equivalent descriptions of a choice are presented (Kahneman *et al*., 1982). Responses to contingent valuation questions that are widely used to estimate WTP to reduce health risk almost invariably violate the prediction of standard economic theory that WTP should be nearly proportionate to the change in probability of death or illness (Hammitt and Graham, 1999).

Moreover, few adults are autonomous. Most function as part of a multi-person household and a larger community, both of which influence their decisions and control over resources. Although conventional estimates of WTP are often described as measures of individual preferences, it seems more tenable to interpret them as measures of household WTP. In some cases, the change in health risk is to a defined individual (*e.g.*, the worker in studies of compensating wage differentials). In other cases, the risk change may benefit the entire household (*e.g.*, studies valuing risks from air pollution or contaminated drinking water, Hammitt and Liu, 2004). In all cases, the opportunity cost of a mortality risk reduction is a decrease in household disposable income. Depending on how a household allocates consumption among its members, some or all of them must have lower consumption as a result.

The difference between "children" and "adults" is in many ways more a continuum than a discrete difference, with children gradually merging into adults as they age. From a economic-theory perspective, the reason to reject basing a measure of valuation on children's own preferences is not that children are qualitatively different from adults, but rather because children differ more from the idealized theoretical decision maker than adults differ from this idealization.

Differences in cognitive ability suggest that most children cannot make informed and considered choices about actions that may affect their health, and so it would not be appropriate to rely on children's responses to stated-preference surveys to measure preferences. While children may be able to answer questions describing their health, perhaps as part of a generic health utility instrument (*e.g.*, EQ-5D, HUI), this is not sufficient to allow their responses to be used in estimating QALYs because it remains necessary to have a scoring function to translate the multi-attribute classification of a health state to an HRQL for that health state. It is not apparent how one could either construct a scoring function for children's preferences, or validate the applicability to children's preferences of an existing scoring function (*e.g.*, one for adults' preferences), if it is accepted that children's judgments about tradeoffs between length and quality of life are not normatively acceptable. Hence for both WTP and QALY approaches, reliance on proxy respondents appears necessary.

An alternative reason to treat children and adults as distinct arises from social policy judgments. Legal distinctions are frequently made between adults and children concerning rights and responsibilities, including a wide range of behaviors (driving, drinking, voting, entering contracts) and sanctions (different criminal justice systems). Societies always face the issue of defining membership, rights, and responsibilities, and a common position is that children are qualitatively different from adults and do not have the same legal standing. There are no bright lines between "child" and "adult" and so legal definitions differ between issues and societies. From this perspective, the child's preferences about health risks could be judged to be of limited relevance to policy decisions, even if there were no concerns about children's decision-making abilities.

Societies often express a special interest in children that may over-ride the interests of the children's parents or guardians. In part, these interests reflect children's lack of autonomy and their dependence on parents and other adults to make decisions on their behalf, and society is interested in protecting innocent children from poor decisions by their parents or guardians. This interest may be related to the finding that people are often more fearful of risks they perceive as less subject to their own control (*e.g.*, being a passenger rather than a driver in an automobile). Because children have less autonomy than adults, they have less individual control over exposure to many risks, and so society may be particularly concerned to protect them.

For WTP measures of value, household WTP appears to be an appropriate starting point. Understandably, parents know and care about their children's health, and they are accustomed to making economic decisions that affect their children. To some extent, economists may view parental choices as altruistic behavior, but they may also regard households as unitary economic agents with preferences and behaviors that are the result of some intra-household decision-making process.

For QALY measures, two views may be supported. The utility-theory justification for QALYs is based on an individual's preferences, and surely the individual is the one who most directly experiences his or her health status and longevity. But other household members are influenced by an individual member's health and longevity as well, and so it is possible that a household could be viewed as having a utility function defined over its members' health, just as it can be viewed as having a utility function over its members' consumption of conventional goods. In the QALY framework, it would appear that effects on household utility could be constructed by summing the expected changes in household members' QALYs, perhaps including any effects on one household member's health or another's (*e.g.*, through care-giving). Alternatively, QALYs are sometimes viewed as a standard measuring rod, independent of any specific individual's preferences. One justification for this approach is provided by an extra-welfarist perspective, in which QALYs are justified as a socially adopted measure, not because they represent any individual's preferences but rather because society adopts them as the measure to be maximized.

It should be noted that adopting a household perspective raises complications that the idealized individual perspective avoids. First, it is well known that methods for group decision making typically do not result in choices that can be described as maximizing a standard utility function (Arrow, 1963). A variety of household allocation models have been developed, including consensus parental preference models, in which parents act as if they are maximizing a single utility function (Behrman *et al*., 1995; Dockins *et al*., 2002). Conditions for testing whether households act as if they maximize a single utility function have been developed by Browning and Chiappori (1998). Moreover, household composition changes over time, in both predictable and unexpected ways. Households may gain members when new children are born or are adopted, may lose members through death or when a child matures and establishes her own household, and may dissolve entirely through divorce. In principle, the current preferences of a household should recognize these future possibilities and their implications for members' welfare.

Valuation of health risks may depend on the timing of exposure and the manifestation and duration of potential effects. Exposures that occur in childhood may lead to health impairments that occur only in childhood, that begin in childhood but extend into adulthood, and that do not begin until adulthood. From the individual perspective, the distinction between health effects experienced as a child and as an adult may be important because one's role in a household or society differs between childhood and adulthood, and health impairments may have different effects on ability to perform these roles. From the social perspective, to the extent that the special concern for children reflects an interest in protecting them from poor decisions made by others (*e.g.*, parents, guardians) on their behalf, the critical issue seems to be the timing of exposure (and of the decisions leading to exposure) rather than the issue of whether the health impairment first manifests in childhood or is delayed until the child reaches adulthood.

6. Conclusions

WTP and QALYs are alternative and frequently used approaches for valuing environmental and other health risks. The methods rely on somewhat different theoretical underpinnings. WTP is the more flexible approach. It imposes few constraints on individual preferences with respect to health risks. QALYs impose more structure and require that the value of a health effect be proportional to its severity (as measured by a health-related quality of life scale) and duration.

QALYs are defined in terms of the health effect experienced by an individual and do not allow for variation in preferences associated with characteristics of the risk that may produce a change in health state, such as controllability, voluntariness, and dread. In principle, effects of risk characteristics could be included by defining a health state to include characteristics of the risk that produced it, but this approach has not been examined or tested. WTP can include preferences related to these risk characteristics. There is only limited empirical evidence concerning the magnitude of the effects of these characteristics on WTP, and there is a danger that over-reaction to risk characteristics may lead to biases in estimated WTP (in either survey or revealed-preference contexts).

The structured nature of QALYs implies that the value of mortality risk is clearly related to factors such as the life expectancy and likely future health of the affected individual, the latency of the risk, and the magnitude of competing mortality risks. In contrast, the relationships between WTP to reduce mortality risk and life expectancy, likely future health, and latency of the risk are theoretically ambiguous.

The relationship between WTP and QALYs does not appear to be straightforward. Although the relationship is likely to be at least close to monotonic, the notion that there is a simple transformation between the two measures, as would be the case if individual WTP per QALY were constant, for example, is not supported by empirical evidence. Moreover, economic theory suggests that a linear relationship is possible only under highly restrictive assumptions.

For policy evaluation, WTP measures provide, in principle, a more accurate measure than QALYs of the preferences of the affected individuals. This follows because, unlike QALYS, WTP measures do not impose restrictive conditions on preferences for health and longevity. However, this added flexibility comes at the potential cost of greater difficulty in estimating values. In stated-preference surveys (and perhaps also in the behavior that is observed in revealed preference studies), there is a risk that respondents may be over-sensitive to some aspects of a risk (*e.g.*, certain qualitative attributes) and under-sensitive to others (*e.g.*, probability or duration of effect), providing misleading information about their preferences. By constraining values of health effects to be proportional to duration, severity (as measured by HRQL), and probability of occurrence, an evaluation using expected QALYs may be less subject to these elicitation difficulties. In effect, QALYs may provide a more accurate measure than WTP of individual preferences if the reduction in error (either systematic or random) that results from constraining values exceeds the bias introduced by imposing restrictive assumptions that conflict with preferences.

An alternative justification for using QALYs rather than WTP is that QALYs may provide a fairer or otherwise preferred measure of the social value of policies that affect health risk in a population. This extra-welfarist justification explicitly rejects the conventional economic notion that public policies should be chosen in large part to maximize the self-assessed well-being of the affected population and relies instead on a notion of preferences for social outcomes that are distinct from (and may conflict with) private preferences (*e.g.*, Gold *et al*., 1996; Williams, 1997).

Valuation of environmental-health risks to children presents challenges in addition to those faced when valuing risks to adults. These include differences in cognitive ability, practical and legal autonomy, and the apparently greater social interest in protecting children than adults. It is useful to recognize that exposures to environmental-health risks in childhood may produce health effects that manifest in childhood (and may or may not continue into adulthood), or may manifest only in adulthood. As the decisions that influence these health effects must precede exposure, it appears that the timing of exposure rather than the manifestation of health effects is most important in valuing these risks to children.

REFERENCES

Arrow, K.J., *Social Choice and Individual Values*, John Wiley and Sons, New York, 1963.

Behrman, J.R., R.A. Pollack, and P. Taubman, *From Parent to Child: Intrahousehold Allocations and Intergenerational Relations in the United States,* University of Chicago Press, Chicago, 1995.

Bleichrodt, H., and Quiggin, J., "Life-Cycle Preferences over Consumption and Health: When is Cost-Effectiveness Analysis Equivalent to Cost-Benefit Analysis?" *Journal of Health Economics* 18: pp. 681-708, 1999.

Bleichrodt, H., and Johannesson, M., "The Validity of QALYs: An Experimental Test of Constant Proportional Tradeoff and Utility Independence," *Medical Decision Making* 17: pp. 21-32, 1996.

Bleichrodt, H., Wakker, P., and Johannesson, M., "Charcterizing QALYs by Risk Neutrality," *Journal of Risk and Uncertainty* 15: pp. 107-114, 1997.

Brouwer, W.B.F., Koopmanschap, M.A., and Rutten, F.F.H., "Productivity Cost Measurement through Quality of Life? A Response to the Recommendation of the Washington Panel," *Health Economics* 6: pp. 253-259, 1997.

Browning, M., and Chiappori, P.A., "Efficient Intra-Household Allocations: A General Characterization and Empirical Tests," *Econometrica* 66: pp. 1241-1278, 1998.

Carey, S., *Conceptual Change in Childhoo*d, MIT Press, Cambridge MA, 1985.

Cookson, R., "Incorporating Psycho-Social Considerations into Health Valuation: An Experimental Study," *Journal of Health Economics* 19: 369-401, 2000.

Cropper, M.L, and Portney, P.R., "Discounting and the Evaluation of Lifesaving Programs," *Journal of Risk and Uncertainty* 3: pp. 369-379, 1990.

Cropper, M.L., and Sussman, F.G., "Valuing Future Risks to Life," *Journal of Environmental Economics and Management* 19: pp. 160-174, 1990.

Dockins, C., Jenkins, R.R., Owens, N., Simon, N.B., and Wiggins, L.B., "Valuation of Childhood Risk Reduction: The Importance of Age, Risk Preferences, and Risk Perspective," *Risk Analysis* 22: pp. 335-346, 2002.

Dolan, P., "The Measurement of Health-Related Quality of Life for Use in Resource Allocation Decisions in Health Care," pp. 1724-1760 in *Handbook of Health Economics*, Volume 1, A.J. Culyer and J.P. Newhouse, eds., Elsevier Science B.V., 2000.

Drèze, J., "L'Utilitè Sociale d'une Vie Humaine," *Revue Française de Recherche Opèrationelle* 6: pp. 93-118, 1962.

Eeckhoudt, L.R., and Hammitt, J.K., “Background Risks and the Value of a Statistical Life,” *Journal of Risk and Uncertainty* 23: pp. 261-279, 2001.

Eeckhoudt, L.R., and Hammitt, J.K., “Does Risk Aversion Increase the Value of Mortality Risk?” *Journal of Environmental Economics and Management* 47: pp. 13-29, 2004.

Gold, M.R., Siegel, J.E., Russell, L.B., and Weinstein, M.C., *Cost-Effectiveness in Health and Medicine*, Oxford University Press, Oxford, 1996.

Hammitt, J.K., “How Much is a QALY Worth? Admissible Utility Functions for Health and Wealth,” Harvard Center for Risk Analysis, Boston, 2002a.

Hammitt, J.K., “QALYs versus WTP,” *Risk Analysis* 22: pp. 985-1001, 2002b.

Hammitt, J.K., “Willingness to Pay and Quality Adjusted Life Years,” Chapter 7, pp. 239-272 in *Economic Valuation of Environmental Health Risks to Children*, OECD, Paris 2006.

Hammitt, J.K., and Graham, J.D., “Willingness to Pay for Health Protection: Inadequate Sensitivity to Probability?” *Journal of Risk and Uncertainty* 18: pp. 33-62, 1999.

Hammitt, J.K., and Liu, J.-T., “Effects of Disease Type and Latency on the Value of Mortality Risk,” *Journal of Risk and Uncertainty* 28: pp. 73-95, 2004.

Hanemann, M.W., “Willingness to Pay and Willingness to Accept: How Much Can They Differ?” *American Economic Review* 81: pp. 635-647, 1991.

Haninger, K., and Hammitt, J.K., “Willingness to Pay for Quality-Adjusted Life Years: Empirical Inconsistency Between Cost-Effectiveness Analysis and Economic Welfare Theory,” Harvard Center for Risk Analysis, Boston, 2006.

Harbaugh, W.T, “Valuing Children’s Health and Life: What Does Economic Theory Say about Including Parental and Societal Willingness to Pay?” EPA workshop on Valuing Health for Environmental Policy with Special Emphasis on Children’s Health Protection, March 1999.

Itaoka, K., Saito, A., Krupnick, A., Adamowicz, W., and Taniguchi, T., “The Effect of Risk Characteristics on the Willingness to Pay for Mortality Risk Reductions from Electric Power Generation,” *Journal of Risk and Uncertainty* 33: pp. 371-398, 2006.

Johannesson, M., Pliskin, J.S., and Weinstein, M.C., “A Note on QALYs, Time Tradeoff, and Discouning,” *Medical Decision Making* 14: pp. 188-193, 1994.

Johannesson, M., Johansson, P-O., and Lofgren, K-G., “On the Value of Changes in Life Expectancy: Blips Versus Parametric Changes,” *Journal of Risk and Uncertainty* 15: pp. 221-239, 1997.

Jones-Lee, M.W., “The Value of Changes in the Probability of Death or Injury,” *Journal of Political Economy* 82: pp. 835-849, 1974.

Jones-Lee, M.W., and Loomes, G., “Scale and Context Effects in the Valuation of Transport Safety,” *Journal of Risk and Uncertainty* 11: pp. 183-203, 1995.

Jones-Lee, M.W., Loomes, G., and Philips, P.R., “Valuing the Prevention of Non-fatal Road Injuries: Contingent Valuation vs. Standard Gambles,” Oxford Economic Papers 47: pp. 676-695, 1995.

Jones-Lee, M.W., Hammerton, M., and Philips, P.R., "The Value of Safety: Results of a National Sample Survey," *The Economic Journal* 95: pp. 49-72, 1985.

Kahneman, D., Slovic, P., and Tversky, A., eds., *Judgment Under Uncertainty: Heuristics and Biases*, Cambridge University Press, Cambridge, 1982.

Keeler, E.B., and Cretin, S., "Discounting of Life-Saving and Other Nonmonetary Effects," *Management Science* 29: pp. 300-306, 1983.

Keeney, R., and Raiffa, H., *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*, John Wiley and Sons, New York, 1976 (republished by Cambridge University Press, Cambridge, 1993).

Kimball, M.S., "Precautionary Saving in the Small and in the Large," *Econometrica* 58: pp. 53-73, 1990.

Krupnick, A., Alberini, A., Cropper, M., Simon, N., O'Brien, B., Goeree, R., Heintzelman, M., "Age, Health, and the Willingness to Pay for Mortality Risk Reductions: A Contingent Valuation Survey of Ontario Residents," *Journal of Risk and Uncertainty* 24: pp. 161-186, 2002.

Lawrence, R.S., Anderson, H.A., Burnett, R.T., Cranor, C.F., Cropper, M.L., Daniels, N., Fryback, D.G., Garber, A.M., Gold, M.R., Hammitt, J.K., Iezzoni, L.I., Jacobson, P.D., Keeler, E.,. Manning, W.G., Poole, C., and Schkade, D.A., *Valuing Health for Regulatory Cost-Effectiveness Analysis*, Institute of Medicine, National Academies Press, Washington, D.C., 2006.

Loomes, G., and McKenzie, L., "The Use of QALYs in Health Care Decision Making" *Social Science and Medicine* 28: pp. 299-308, 1989.

Maas, A., and Wakker, P.P., "Additive Conjoint Measurement for Multiattribute Utility," *Journal of Mathematical Psychology* 38: pp. 86-101, 1994.

Magat, W.A., Kip Viscusi, W., and Huber, J., "A Reference Lottery Metric for Valuing Health," *Management Science* 42: pp. 1118-1130, 1996.

McDaniels, T.L., Kamlet, M.S., and Fischer, G.W., "Risk Perception and the Value of Safety," *Risk Analysis* 12: pp. 495-503, 1992.

McMichael, A.J., Anderson, H.R., Brunekreef, B., and Cohen, A.J., "Inappropriate Use of Daily Mortality Analyses to Estimate Longer-Term Mortality Effects of Air Pollution," *International Journal of Epidemiology* 27: pp. 450-453, 1998.

McNeil, B.J., Weichselbaum, R., and Pauker, S.G., "Speech and Survival: Tradeoffs Between Quantity and Quality of Life in Laryngeal Cancer," *New England Journal of Medicine* 305: pp. 982-987, 1981.

Mendeloff, J.M., and Kaplan, R.M., "Are Large Differences in 'Lifesaving' Costs Justified? A Psychometric Study of the Relative Value Placed on Preventing Deaths," *Risk Analysis* 9: pp. 349-363, 1989.

Mitchell, R.C., and Carson, R.T., "*Using Surveys to Value Public Goods: The Contingent Valuation Method*," Resources for the Future, Washington, DC, 1989.

Miyamoto, J.M., and Eraker, S.A., "Parameter Estimates for a QALY Model," *Medical Decision Making* 5: pp. 191-213, 1985.

Miyamoto, J.M., Wakker, P.P., Bleichrodt, H., and Peters, H.J.M., “The Zero-Condition: A Simplifying Assumption in QALY Measurement and Multiattribute Utility,” *Management Science* 44: pp. 839-849, 1998.

Ng, Y.-K., “The Older the More Valuable: Divergence Between Utility and Dollar Values of Life as One Ages,” *Journal of Economics* 55: pp. 1-16, 1992.

Pliskin, J.S., Shepard, D.S., and Weinstein, M.C., “Utility Functions for Life Years and Health Status,” *Operations Research* 28: pp. 206-224, 1980.

Pratt, J.W., and Zeckhauser, R.J., “Willingness to Pay and the Distribution of Risk and Wealth,” *Journal of Political Economy* 104: pp. 747-763, 1996.

Robinson, L.A., “Current Federal Agency Practices for Valuing the Impacts of Regulations on Human Health and Safety,” Prepared for the Committee to Evaluate Measures of Health Benefits for Environmental, Health, and Safety Regulation, Institute of Medicine, Washington, DC, 2004.

Salkeld, G., Phongsavan, P., and Oldenburg, B., “The Cost-Effectiveness of a Cardiovascular Risk Reduction Program in General Practice,” *Health Policy* 41: pp. 105-119, 1997.

Savage, I.,“An Empirical Investigation into the Effect of Psychological Perceptions on the Willingness-to-Pay to Reduce Risk,” *Journal of Risk and Uncertainty* 6: pp. 75-90, 1993.

Schwartz, J., “Harvesting and Long-Term Exposure Effects in the Relationship between Air Pollution and Mortality,” *American Journal of Epidemiology* 151: pp. 440-448, 2000.

Schwartz, J., “Is There Harvesting in the Association of Airborne Particles with Daily Deaths and Hospital Admissions?” *Epidemiology* 121: pp. 55-61, 2001.

Shepard, D.S., and Zeckhauser, R.J., “Survival versus Consumption,” *Management Science* 30: pp. 423-439, 1984.

Sloan, F.A., Viscusi, W.K., Chesson, H.W., Conover, C.J., and Whetten-Goldstein, K., “Alternative Approaches to Valuing Intangible Health Losses: The Evidence for Multiple Sclerosis,” *Journal of Health Economics* 17: pp. 475-97, 1998.

Slovic, Paul, *The Perception of Risk*, Earthscan Publications, London, 2000.

Smith, V.K., Kim, H., and Taylor, D.H., “Do the ‘Near’ Elderly Value Mortality Risks Differently?” paper presented at the Association of Environmental and Resource Economists workshop, Bar Harbor, Maine, June 2001.

Stalmeier, P.F.M., Bezembinder, T.G.G., and Unic, I.J., “Proportional Heuristics in Time Tradeoff and Conjoint Measurement,” *Medical Decision Making* 16: pp. 36-44, 1996.

Stiggelbout, AM., Keibert, G.M., Kievit, J., Leer, J.W.H., Stoter, G., and de Haes, J.C.J.M., “Utility Assessment in Cancer Patients: Adjustment of Time Tradeoff Scores for the Utility of Life Years and Comparison with Standard Gamble Scores,” *Medical Decision Making* 14: pp. 82-90, 1994.

Subramanian, U., and Cropper, M., “Public Choices Between Life Saving Programs: The Tradeoff Between Qualitative Factors and Lives Saved,” *Journal of Risk and Uncertainty* 21: pp. 117-149, 2000.

Tsuge, T., Kishimoto, A., and Takeuchi, K., “A Choice Experiment Approach to the Valuation of Mortality,” *Journal of Risk and Uncertainty* 31: pp. 73-95, 2005.

Vassanadumrongdee, S., and Matsuoka, S., “Risk Perceptions and the Value of a Statistical Life for Air Pollution and Traffic Accidents: Evidence from Bangkok, Thailand,” *Journal of Risk and Uncertainty* 30: pp. 261-287, 2005.

Verhoef, L.C.G., de Haan, A.F.J., and van Daal, W.A.J., “Risk Attitude in Gambles with Years of Life: Empirical Support for Prospect Theory,” *Medical Decision Making* 14: pp. 194-200, 1994.

Viscusi, W.K., and Evans, W.N., “Utility Functions that Depend on Health Status: Estimates and Economic Implications,” *American Economic Review* 81: pp. 353-374, 1990.

Weinstein, M.C., Shepard, D.S., and Pliskin, J.S., “The Economic Value of Changing Mortality Probabilities: A Decision-Theoretic Approach,” *Quarterly Journal of Economics* 94: pp. 373-396, 1980.

Williams, A., “Intergenerational Equity: An Exploration of the ‘Fair Innings’ Argument,” *Health Economics* 6: pp. 117-132, 1997.

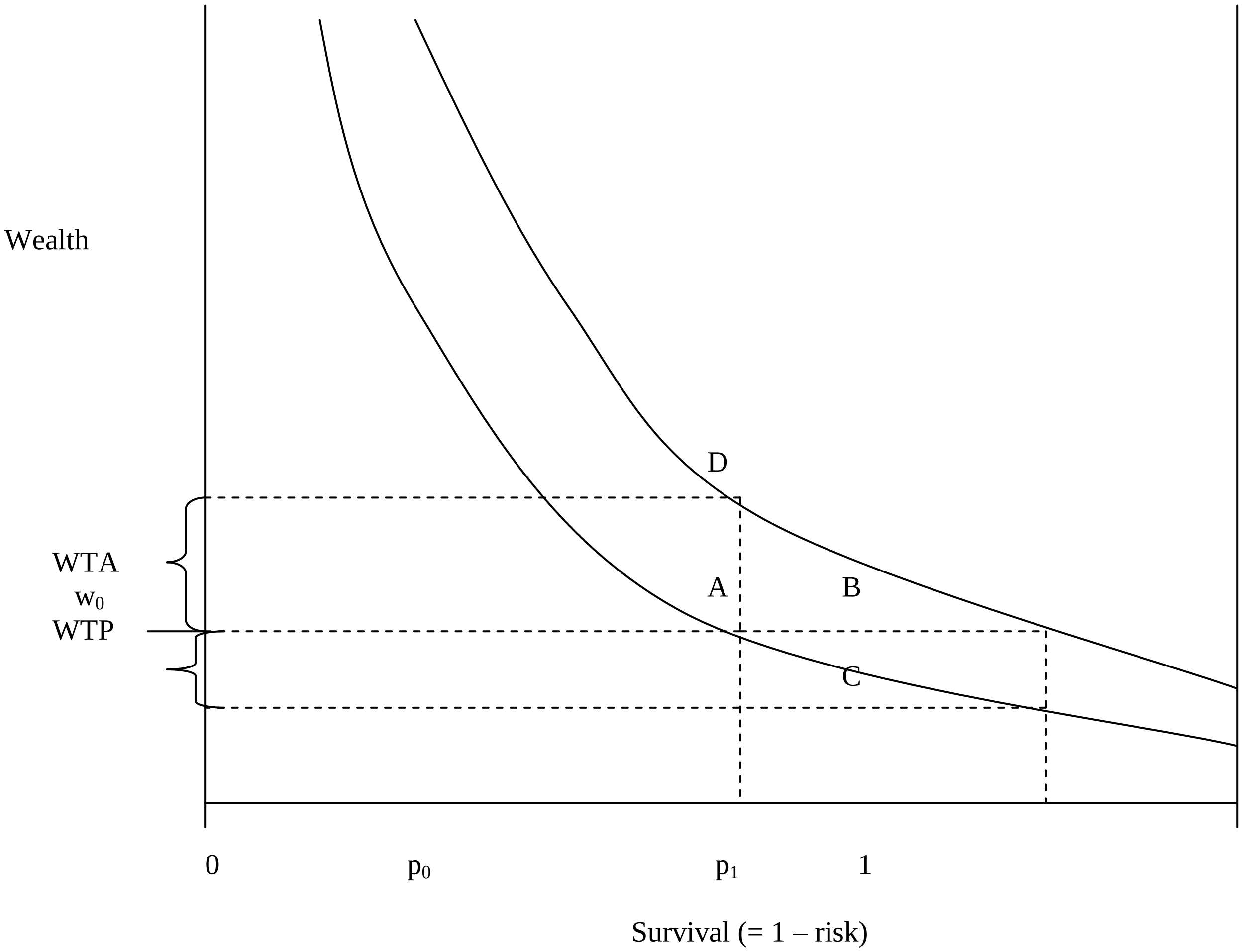

Figure 1. Indifference curves for survival probability and wealth

Starting from A, WTP to improve the probability of surviving the current period from p_0 to p_1 is equal to the distance B – C. WTA compensation in place of improving health from p_0 to p_1 is equal to the distance D – A. The distance B – C also represents WTP to prevent a reduction from p_1 to p_0, and the distance D – A represents WTA compensation to permit a reduction from p_1 to p_0.

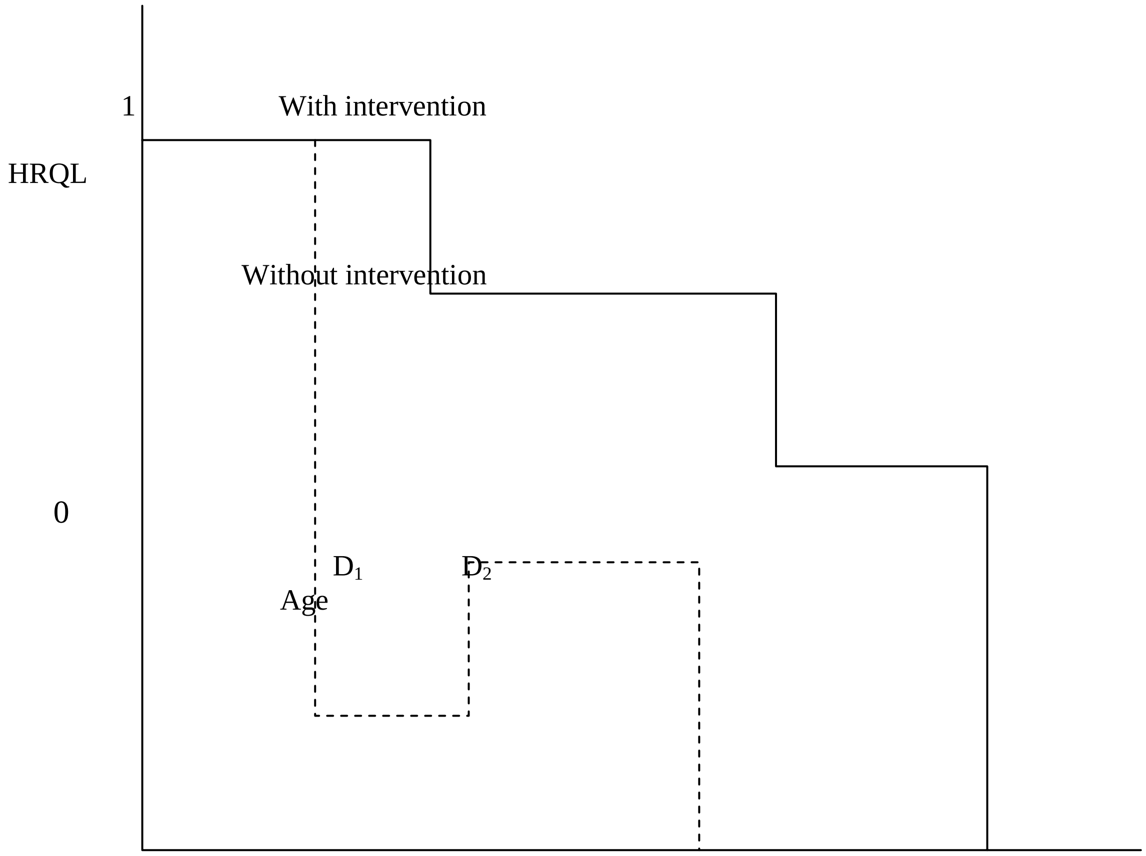

Figure 2. QALYs for two hypothetical health profiles

The intervention improves health at all ages after an initial period and extends longevity from D_1 to D_2. The difference in QALYs is the area between the two health profiles.