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Consumption Framework**

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Valuing health risk changes using a life-cycle consumption framework

Abstract

Government agencies routinely use the “value of a statistical life” (VSL) in benefit-cost analyses of proposed environmental and safety regulations. Here I review an alternative approach for valuing health risks using a “life-cycle consumption framework.” This framework is based on an explicit individual-level lifetime utility function over health and income at all ages, and so could be used to examine any pattern of health risk changes over a person’s lifespan. I discuss several potential advantages of this framework, both positive and normative. From a positive perspective, this framework can support a functional benefit transfer approach that is more flexible and potentially more accurate than the standard point-value benefit transfer approach based on the VSL, and it can be used to evaluate mortality and morbidity effects simultaneously in an internally consistent model. From a normative perspective, it provides a natural foundation for a social welfare function and therefore could facilitate a unified evaluation of efficiency and equity, as a supplement to traditional benefit-cost analysis.

Keywords: VSL, life-cycle model, benefit-cost analysis, social welfare analysis, QALY, health-wealth tradeoff

JEL classification: I18, J17, Q51

1 Introduction

Government agencies routinely use the “value of a statistical life” (VSL) when evaluating proposed health, safety, and environmental regulations. In this paper I discuss an alternative approach, based on the “life-cycle consumption framework,” for evaluating the changes in health risks associated with such policies. Versions of this general framework have appeared in the economics literature for at least 45 years (e.g., Yaari 1965, Usher 1973, Shepard and Zeckhauser 1984, Cropper and Sussman 1990, Rosen 1994, Ehrlich 2000, Sun and Ng 2009), but to date it has been used mainly for theoretical research rather than quantitative policy analysis. My aims in this paper are to discuss the potential advantages of this framework for valuing human health risks in regulatory analyses over the current approach based mainly on the VSL, and to note the challenges involved in bringing the framework out of the realm of pure theory and into the toolkit of policy analysts.

I begin in this introductory section with a discussion of the VSL, focusing on its conceptual basis and proper interpretation. The VSL serves as a convenient point of departure because it is so familiar to health valuation practitioners and so maligned by many others. In Section 2, which forms the heart of the paper, I discuss the life-cycle consumption framework. I first give a very brief formal description of the framework and explain how it can be used as an alternative to the VSL for valuing health risk changes in benefit-cost analyses. I then discuss some potential advantages of this framework, from both positive and normative perspectives. In the context of discussing its potential positive advantages, I use a simple example to illustrate how the framework can tie together several distinct but fundamental concepts in the health valuation literature, namely “cost of illness” (COI), “quality adjusted life years” (QALY), and “willingness to pay” (WTP) measures of health outcomes. I conclude in Section 3 with a brief discussion of some of the challenges that must be overcome before the life-cycle consumption framework can be put to practical use in the assessment of real-world regulations.

The VSL is the subject of numerous studies by academic economists and is routinely used by policy analysts to evaluate a wide variety of health, safety, and environmental policies and regulations. At the same time, the VSL is often disparaged and possibly misunderstood by many non-specialists and others in the general public.

In their expansive critique of benefit-cost analysis, *Priceless: On Knowing the Price of Everything and the Value of Nothing*, Ackerman and Heinzerling (2004) open their chapter on the VSL with an understatement: “Putting a price on human life makes

most people uncomfortable.” They go on to note, however, that since the VSL plays such a prominent role in the quantitative evaluation of many environmental, health, and safety regulations it is important to “...pay some attention to the details of this troubling calculation and to the troubled theories on which it rests.” In this section I aim to pay enough attention to the theory behind the VSL to explain why, when properly understood, this concept is not as troubling as is often implied in popular writings.

First, many criticisms of the VSL seem to be based in part on a misunderstanding of its very meaning. The VSL is *not* intended to represent the intrinsic worth of a human life. The VSL also is *not* an estimate of how much money any individual or group would or should be willing to pay to prevent—or the amount of money they would be willing to accept to cause—the certain death of any particular individual.¹ So it is misleading to say that the VSL represents “a price on human life.” Rather, the VSL is the average marginal rate of substitution between income and mortality risk in a year among the general population (or some subset thereof). An individual’s marginal rate of substitution between income and mortality risk is the amount of income he or she would be willing to trade—that is, the amount of money he or she would be willing to pay—for a reduction in mortality risk on the margin. The phrase “on the margin” means that this is a per unit value that applies to small changes in risk from the current level. (Because the VSL refers to small changes in mortality risk on the margin, it would be more accurate to refer to this concept as “the price of risk” [e.g., Black and Kniesner 2003] rather than “the price of life.”)

To be precise about this quantity, it is helpful to clearly specify its dimensions and units of measurement. An individual’s marginal rate of substitution between income and mortality risk has dimensions of money per change in risk per time, and could be measured in units of, for example, \$/micro-mort/yr/person, where a micro-mort/yr represents a one in one million chance of dying in a year. If an individual’s marginal rate of substitution were v \$/micro-mort/yr, then the individual would be willing to pay $v \times \Delta m$ dollars in a particular year for a reduction in mortality risk of Δm micro-morts in that year, provided that Δm is sufficiently small that v can be treated as constant over this range. So the VSL should be thought of as the slope of a willingness-to-pay function at a particular point on the Δm axis.²

¹ See Cameron (2009, 2010) for an extended argument against the VSL terminology, largely based on the persistent misunderstandings among non-specialists, journalists, and the general public that this label seems to inspire.

² The following mental picture may help to explain this idea further. Imagine a willingness-to-pay function drawn on a pair of Cartesian axes. Let the x -axis represent the reduction in an individual’s risk of dying in the current year (so $x=0$ corresponds the individual’s baseline survival probability), and let the y -axis

Unfortunately, the VSL usually is not reported in units of \$/micro-mort/yr/person, or some other relatively small unit of risk that is in the neighborhood of the individual-level risk reductions caused by most environmental or safety regulations (Cameron 2010) or over which it is safe to assume that the VSL will remain roughly constant. Rather, the VSL is typically reported in units of \$, as in “the VSL is \$7 million.” When reported in this way the value matches the total amount of money a large group of people would be willing to pay for small reductions in their individual-level mortality risks such that we would expect one fewer death among the group in a year.³ This can be understood as follows. Suppose each person in a group of N individuals is asked how much he or she would be willing to pay for a 1-in- N reduction in their risk of dying over the next year (where N is a large number, say, 10,000 or more). By construction, we would expect one fewer death among the group during the year. One fewer expected death per year is sometimes described as “one statistical life saved,” so the sum of the individual responses to this hypothetical question would be the “value of a statistical life.”

Certainly any particular quantitative estimation or application of the VSL may be questioned on empirical or methodological grounds, but with this understanding of the theory behind the VSL clearly in view the concept itself does not seem especially troubling. People make choices that simultaneously involve small changes in their income and their mortality risk on a regular basis—for example, when they pay a higher price for a safer car, purchase safety devices such as smoke alarms and fire extinguishers, accept a more risky job for a higher wage, pay for medical treatments or drugs that may reduce their risks of heart attacks or other life threatening conditions, and so on. It is not clear what objections could be raised against estimating the terms under which people are willing to make such tradeoffs.⁴

represent the amount the individual would be willing to pay for that risk reduction. The curve representing the individual’s willingness-to-pay as a function of the size of a reduction in her mortality risk would start at the origin and rise as we move to the right along the x -axis. The VSL is the slope of this curve at the origin. Importantly, it is *not* the height of this curve at the value 1 on the x -axis! This is because the WTP function usually will not be linear—rather, it will increase at a decreasing rate—and because the farthest relevant point on the x -axis corresponds to the individual’s baseline mortality risk in that year (less than 0.01 up to around age 60 for a “typical” individual with an expected lifespan at birth around 75 years), so $\Delta m = 1$ is far outside of the relevant range for most individuals.

³ So the (implicit) units of the VSL should be understood as, e.g., \$/micro-mort/yr/million persons, not \$/mort/yr/person!

⁴ Some writers clearly understand this distinction but still object to the VSL on other grounds. For example, two notable critics of benefit-cost analysis have written, “It is true that risk (or ‘statistical life’) and life itself are distinct concepts. In practice, however, analysts often ignore the distinction between valuing risk and valuing life. Many regulations reduce risk for a large number of people and avoid actual death for a much smaller number. A complete cost-benefit analysis should, therefore, include valuation of

The disadvantages of the VSL that I take as motivation for considering the life-cycle consumption framework as an alternative approach for evaluating health risk changes have nothing to do with moral objections to “valuing lives”—in the crude sense of the mugger who says, “Your money or your life!”—since the VSL is not designed to do such a thing. Rather, there are three main advantages of the life-cycle framework relative to the VSL that will be the focus of the remainder of this paper. First, the VSL is sometimes estimated, and is almost invariably applied, as if a single number is appropriate for all cases without regard to the circumstances of the of the individuals at risk or the nature of the risk changes in question (e.g., Sunstein 2004, Baker *et al.* 2008, Scotton and Taylor 2009). Second, the VSL pertains to mortality risk changes alone, so any associated morbidity effects must be handled separately and this typically is done in an ad hoc fashion. And third, the VSL is useful for benefit-cost analysis only, which leaves equity and distributional issues unexamined. The life-cycle consumption framework provides an approach for “individuating” our evaluations of health risk changes and for handling mortality and morbidity effects in an integrated fashion. It also can provide a natural foundation for a more comprehensive social welfare analysis. The next section describes the life-cycle consumption framework and how it could be used in policy evaluations, and discusses the potential advantages of this approach in more detail.

2 The life-cycle consumption framework

2.1 The framework and its application

The life-cycle consumption framework is based on an explicit individual-level lifetime utility function that can be written in the following form (e.g., Yaari 1965, Rosen 1988, Freeman 2003 p 311-321):

$$U_a(Y, \mathbf{h}, \mathbf{m}) = \sum_{t=a}^T u(y_t, h_t, t) s_{a,t} e^{-\rho(t-a)}, \text{ where } s_{a,t} = \prod_{\tau=a}^{t-1} (1 - m_\tau). \quad (1)$$

both of these benefits. However, the standard practice is to calculate a value only for ‘statistical’ life and to ignore life itself” (Ackerman and Heinzerling 2002 p 1564-1565). The problem here is the implication that “reducing risk for a large number of people” and “avoiding actual death for a much smaller number” are distinct effects. If “actual deaths for a small number of people” is intended to mean “the certain death of a specific small group of people,” then no regulations do this and so the second part of the statement is false on its own terms. If “actual deaths for a small number of people” is intended to mean “the difference in the expected number of deaths in a year with versus without the policy,” then this is just a different way of describing “statistical lives saved” and so the second part of the statement is redundant and therefore would lead to double-counting the value of the risk reductions. (See Pratt and Zeckhauser [1996] for a formal examination of the effect of “concentrated risks” on aggregate willingness to pay.)

In expression (1), U_a is the individual's remaining lifetime utility at age a (think of this as a stock variable); T is the individual's maximum possible lifespan; $u(\bullet)$ is the one-period utility function (think of this as a flow variable); m_τ is the probability of dying before age $\tau + 1$ given that the individual is alive at the beginning of age τ , so $s_{a,t}$ is the probability of surviving to the beginning of age $t + 1$ given that the individual is alive at the beginning of age a ; and ρ is the individual's utility discount rate. In this formulation, the flow of utility at any age t is assumed to depend on consumption (income minus the change in savings), y_t , health status, h_t , and possibly age itself, t . Y is the individual's current wealth (i.e., accumulated assets and expected future earnings), and \mathbf{h} and \mathbf{m} are vectors containing the individual's expected future health states and mortality risks, respectively.⁵

People's consumption patterns, health states, and mortality risks over their life cycle are (in principle) observable or estimable using survey and actuarial data. To use a life-cycle consumption model for quantitative policy analysis, a specific form for the one-period utility function $u(\bullet)$ must be chosen and all parameters of the lifetime utility function must be estimated or calibrated. Perhaps the most straightforward way to operationalize a life-cycle model would be to use a "preference calibration" approach, which involves finding the parameter values for a relatively parsimonious utility function that make the model match a small set of summary results from one or a few previous empirical studies (Smith *et al.* 2002, 2006). A more sophisticated approach would use statistical methods to find the parameters of the lifetime utility function that give the best fit of the model to a relevant set of individual-level behavioral data or survey responses (e.g., Khwaja 2010). Hybrid approaches that combine preference calibration with statistical estimation also are possible (Pattanayak *et al.* 2003). In any case, the task at this stage is to parameterize a lifetime utility function that gives the most faithful representation possible of how people would choose among the status quo

⁵ At the risk of unnecessarily imposing a psychological/intentional rather than a merely descriptive/revealed-preference interpretation on expression (1), we can loosely translate this into plain English as follows. Think of an individual's life as a continuous series, or flow, of more or less satisfying moments. The individual's life satisfaction at any particular moment may depend on many factors, including but not limited to her income and health status. The individual is "better off" to the degree that she expects a higher sum of future satisfactions from now through the end of her life. In this expected sum, future satisfactions are weighted by the likelihood that the individual will survive long enough to experience them, and possibly by an additional subjective factor that places lower value on a later relative to an earlier satisfaction even if the individual fully expects to survive to experience them both.

and new policies that would affect both their health risks and their incomes. So this is a purely positive exercise in model fitting and parameter estimation.

Once parameterized, a life-cycle consumption model could be used to estimate an individual's willingness to pay for a policy that would cause her wealth and future health states and mortality risks to shift from $(Y, \mathbf{h}, \mathbf{m})$ to $(Y', \mathbf{h}', \mathbf{m}')$ by finding the largest value of WTP that satisfies the following equation:

$$U_a(Y' - WTP, \mathbf{h}', \mathbf{m}') \geq U_a(Y, \mathbf{h}, \mathbf{m}). \quad (2)$$

That is, WTP is the maximum amount of money that the individual would be willing to sacrifice out of her current wealth under the policy scenario and still be at least as well off as under the baseline scenario.

2.2 Positive advantages

The potential positive (non-normative, empirical) advantages of the life-cycle consumption framework are at least three-fold. First, the framework can provide a foundation for a structural benefit transfer function. Real world policy evaluations often rely heavily on "benefit transfers," which involve the use of results from previous economic valuation studies to estimate the benefits of new policies. The simplest form of benefit transfer applies unit values from one or more previous studies to the policy case. For example, the average value per fishing trip estimated in a study of recreational fishing in the Chesapeake Bay may be transferred to a new policy that would increase the number of fishing trips elsewhere in the country. A more sophisticated approach is to apply benefit transfer functions rather than unit values to the policy case. For example, the statistical relationship between the anglers' estimated values per fishing trip and their demographic characteristics and the environmental conditions at the recreation sites in a study in the Chesapeake Bay may be applied to a new policy that would change the environmental conditions elsewhere in the country where the demographic characteristics of the anglers are different. It is generally recognized that functional benefit transfer approaches are in principle superior to unit value approaches, since the former allow the analyst to account for more of the factors that distinguish the study case from the policy case, which should in turn lead to improved predictions of policy outcomes (e.g., Kirchhoff *et al.* 1997, Brouwer and Bateman 2005, Ready and Navrud 2005).

Use of the VSL to evaluate all variety of government policies and regulations that affect mortality risks, regardless of the characteristics of the individuals affected or

other particular features of the policies, is a classic example of the unit value benefit transfer approach. It assumes that an individual's willingness to pay for mortality risk reductions does not depend on his or her income or age or baseline mortality risk or the source of the mortality risk reduction or other dimensions of the individual's health status or any other factors that may plausibly affect his or her values. Numerous studies have examined the heterogeneity of willingness to pay for mortality risk reductions with respect to a wide range of individual-level and policy attributes (e.g., Eeckhoudt and Hammit 2001, Leeth and Ruser 2003, Viscusi 2003, Alberini *et al.* 2004, Hammitt and Liu 2004, Itaoka *et al.* 2005, Alberini *et al.* 2006, Kniesner *et al.* 2006, Aldy and Viscusi 2008, Cameron *et al.* 2008, Evans and Smith 2008, Scotton and Taylor 2009, Alberini and Ščasný 2010). The results of these studies are themselves heterogeneous, but on the whole they suggest that a variety of individual- or policy-specific factors are correlated with people's willingness to pay for risk reductions. In particular, most studies have found that WTP increases with income, many have found an inverted "U" pattern over age for the VSL, and some have found differences in WTP for reductions of mortality risks associated with especially dreadful health conditions such as cancer (National Research Council 2008 p 147-150, USEPA 2010b). So to completely ignore these factors is to severely limit the potential accuracy of our health and environmental policy evaluations.⁶

The life-cycle consumption framework explicitly accounts for the timing characteristics of a policy such as latency or cessation lags and income and age differences among individuals (e.g., Shepard and Zeckhauser 1984, Cropper and Sussman 1990, Aldy and Smyth 2006, National Research Council 2008 p 132-134). It also can account for other individual-level characteristics such as health status through the structure and parameterization of the one-period utility function (e.g., Rosen 1994,

⁶ The reasons for the current standard practice of using a single VSL for all cases was succinctly summarized by the National Research Council (2008): "For ethical and practical reasons, government agencies generally do not adjust the WTP estimates they use to reflect these differences [in income, wealth, age, health status, sex, race, and baseline risk]. A practical reason is the lack of knowledge of how WTP varies with individual characteristics. An ethical reason is a policy judgment that differences due to, say, income should not be relevant for policy. Typically, an average WTP for the population is used, making no explicit distinction in WTP across population groups" (p 143). A life-cycle framework could be used as a research aid for overcoming the practical barriers cited here, or at least as a vehicle for transferring the findings of new research on these factors to policy evaluations. The ethical reasons given in support of the standard practice apply more broadly to the fundamental theoretical underpinnings of benefit-cost analysis, not just to the valuation of mortality risks. In my view, these ethical issues should be handled transparently in a formal "social welfare analysis," rather than obscured in a compromised benefit-cost analysis (more on this in Section 2.3 below).

Ehrlich 2000, DeShazo and Cameron 2004, Murphy and Topel 2006, Khwaja 2010). This flexibility permits evaluation of mortality and morbidity risk changes in a single internally consistent analytical framework.

The life-cycle framework is not the only way that these policy- and individual-specific factors could be included in a benefit transfer function. A purely statistical approach, perhaps based on a meta-regression of many previous study results, also could account for such factors (e.g., Bergstrom and Taylor 2006, Dekker *et al.* 2008, Braathen *et al.* 2009). This leads to a second potential advantage of the life-cycle consumption framework, which is that it can provide theoretical structure for what might amount to otherwise “atheoretic” statistical models used to estimate people’s marginal rate of substitution between income and risk. That is, the life-cycle consumption framework can aid the researcher in the unavoidable task of narrowing the range of functional forms and parameter restrictions used in regression analyses of behavioral or survey data (or meta-analyses of the summary results of such studies) designed to estimate people’s willingness to pay for health risk reductions.⁷ While some sub-fields of economics are currently heavily influenced by an “experimentalist” or “theory free” approach to empirical studies, there remains an important role for structural models informed by theory to aid in understanding the raw results of such studies and translating their findings to policy settings (Keane 2010). Whether it is used to shape the empirical estimation itself (e.g., Khwaja 2010), or merely to aid in interpreting the estimated parameters of a reduced form model (e.g., Alberini *et al.* 2004, Aldy and Viscusi 2007), the life-cycle consumption framework can provide a useful conceptual lens through which revealed or stated preference data can be understood and ultimately integrated and applied to new policy cases.

A third advantage of the life-cycle consumption framework is that it can be used to evaluate both mortality and morbidity risks in an integrated fashion. A corollary is that the framework can be used to examine simultaneously several fundamental health valuation concepts that are typically treated separately in the literature. These

⁷ As Leamer (1983) put it, “The econometric art as it is practiced at the computer terminal involves fitting many, perhaps thousands, of statistical models. One or several that the researcher finds pleasing are selected for reporting purposes. This searching for a model is often well intentioned, but there can be no doubt that such a specification search invalidates the traditional theories of inference... the fundamental problem facing econometrics is how adequately to control the whimsical character of inference, how sensibly to base inferences on opinions when facts are unavailable... One can go mad trying to report completely the mapping from assumptions into inferences since the space of assumptions is infinite dimensional. A formal statistical analysis therefore has to be done within the limits of a reasonable horizon. An informed convention can usefully limit this horizon.” The life-cycle consumption framework is a natural candidate for such an “informed convention” when using statistical methods to estimate people’s marginal rates of substitution between income and health risks.

measures include cost of illness (COI), quality adjusted life years (QALY), and willingness-to-pay (WTP) associated with changes in health outcomes. The following sub-section takes a brief detour from the main flow of the paper to illustrate how this can be done using a simplified example.

2.2.1 DETOUR: Cost of illness, quality adjusted life years, and willingness to pay

Consider an individual who is diagnosed with an adverse health condition at a particular age, a . To keep the example as simple as possible, assume that the individual optimizes her present value of utility by completely smoothing her future consumption, so prior to the diagnosis the individual's planned consumption is y in every future year.⁸ The cost of the illness (expenditures on treatment and lost wages) annualized over the individual's remaining lifespan is coi (assumed here for simplicity, but unrealistically, to be independent of income). The individual's discounted expected remaining lifespan at this age without the illness is $L = \sum_{t=a}^T s_{a,t} e^{-\rho(t-a)}$ and with the illness is $L' = \sum_{t=a}^T s'_{a,t} e^{-\rho(t-a)}$, and let l denote the ratio L'/L . The illness reduces the flow of utility over the remainder of the individual's lifespan by a constant factor $h \in [0, 1]$. Finally, assume that the individual's one-period utility function is $u(y, h) = hy^{1-\eta}$, where $0 \leq \eta \leq 1$. Using these definitions and assumptions and the life-cycle utility function in (1), we can define the relationship between the cost of the illness and the annualized willingness to pay to avoid the illness altogether, wtp , as

$$\sum_{t=a}^T (y - wtp)^{1-\eta} s_{a,t} e^{-\rho(t-a)} = \sum_{t=a}^T h(y - coi)^{1-\eta} s'_{a,t} e^{-\rho(t-a)}, \quad (3)$$

and we can solve explicitly for the willingness to pay to give:

$$wtp = coi + (y - coi) \left\{ 1 - (hl)^{1/(1-\eta)} \right\}. \quad (4)$$

⁸ In a simple life-cycle model where the individual can save or borrow against future earnings at a common market interest rate, the optimized consumption profile grows at a rate equal to the difference between the market interest rate and the individual's pure rate of time preference (or the "rate of depreciation in the capacity to derive utility" [Ng 1992]). In reality, life-cycle consumption patterns often exhibit a hump shape, increasing in the early working years and decreasing in later years of life, which could be caused by liquidity constraints and precautionary saving (Carroll and Summers 1991) or changes in household size for a representative individual, among other factors (Attanasio and Weber 2010).

The second term on the right-hand-side of (4) is the “dollar value of the utility loss of illness” (Rosen 1994). This is the component of willingness to pay that is excluded from the observable cost of illness comprised of medical expenditures and lost wages. The factor $1 - (hl)^{1/(1-\eta)}$ scales the individual’s flow of consumption with the illness net of medical expenditures and lost wages, $y - coi$, to give the consumption-equivalent value of the additional lost utility due to the illness. To be concrete, assume for the moment that $\eta = 0$, so the individual’s marginal utility of consumption is constant. If the individual’s lifespan is shortened but her quality of life is not impaired, then the dollar value of the utility loss of the illness is simply $(y - coi)(1 - l)$. Similarly, if the individual’s quality of life is impaired but her expected remaining lifespan is not shortened, then the dollar value of the utility loss of the illness is $(y - coi)(1 - h)$. In the first case, the flow of utility is not diminished but the span of time over which the individual experiences it is reduced. In the second case, the flow of utility is diminished but the span of time over which the individual experiences it is not reduced. If both the individual’s expected remaining lifespan is shortened and her quality of life is impaired, then the dollar value of the utility loss of the illness will involve both of these effects and so will be larger than either one alone. And if $\eta > 0$ then the value is correspondingly larger still. That is, if the individual’s marginal utility of consumption decreases with higher consumption then she would be willing to sacrifice more income for the same health improvement, all else equal.

This simple example can be extended to also consider the “quality-adjusted life year” (QALY) measure of health outcomes. First, note that the number of (undiscounted) QALYs lost due to the illness is

$$QALY = \sum_{t=a}^T s_{a,t} - \sum_{t=a}^T h s'_{a,t} = G - hG', \quad (5)$$

where G is the individual’s expected remaining lifespan.⁹ Solving (5) for h and substituting the result into (4) gives:

⁹ I am assuming that the QALY estimates available to the analyst were calculated according to equation (5) using accurate estimates of the mortality risks due to the illness, which determine the shift from \mathbf{s} to \mathbf{s}' , and accurate estimates of the quality-of-life impacts of the illness, represented by h , based on well-designed health status and quality of life surveys.

$$wtp = coi + (y - coi) \left\{ 1 - \left(\frac{G - QALY}{G' L / L'} \right)^{1/(1-\eta)} \right\}. \quad (6)$$

This way of expressing the willingness to pay shows that the dollar value of the utility cost of the illness can be estimated using the lost quality-adjusted life years associated with the illness and the individual's discounted and undiscounted expected remaining lifespan with and without the illness.¹⁰ The practical usefulness of (6), or an analogous version thereof based on a more general set up, is that it gives a means of estimating willingness to pay for illnesses where only COI and QALY estimates are readily available.

To get some feeling for the implications of equation (6) we can consider a few examples, shown in Table 1. All cases assume $y = \$30,000$ per year. Example 1 involves an individual at age 30 diagnosed with an illness with annualized costs of treatment and lost wages of \$1,000 per year and that will reduce her expected remaining lifespan by 2 years, with an associated loss of 3 quality adjusted life years. Examples 2 and 3 involve older individuals with smaller reductions in remaining lifespan and QALYs but higher annual costs of illness. Estimates of the willingness to pay to avoid the illness that emerge from the life-cycle model, using equation (6) and all combinations of three plausible levels for each of the parameters ρ and η , are given in the lower right region of Table 1. All examples use a common baseline survival curve, which is used to plot the expected remaining undiscounted life years, G , and discounted life years, L , for three values of ρ in Figure 1.

The first four rows of Table 1 contain the information that is assumed to be known by the analyst for each example. The relative quality-of-life with the illness, h , is calculated using the estimated loss of expected remaining life years, $G - G'$, and the

¹⁰ If an estimate of the discounted rather than undiscounted QALYs lost due to the illness were available, then equation (6) would have L and L' in place of G and G' . Also note that if $L' = LG'/G$, then the denominator of the quotient in parentheses on the right hand side of (6) reduces to G , and so in these cases the annualized willingness to pay to avoid the illness is independent of L and L' and therefore the pure rate of time preference ρ . This simplification would hold if the illness had the effect of changing the individual's annual mortality risk only in period a , since in this case both L and G would be scaled by the same factor. Otherwise, the divergence between L'/L and G'/G will depend upon how the individual's survival curve over her remaining lifespan is shifted, and so in general direct calculation of G' and L' would be needed.

estimated loss of quality adjusted life years, $QALY$, using equation (5). All examples assume that the illness increases the individual's annual mortality rate in all remaining life years by a fixed amount, Δm , which is calculated by adjusting the survival curve to match the given estimate of G' . Then the adjusted survival curve is used to calculate $L - L'$ for each value of ρ , which then allows calculation of wtp using equation (6).

Of course the results shown in Table 1 are conditional on the particular simplifying assumptions used to set up this example, but two main messages are likely to be robust to more realistic versions and alternative plausible functional forms. First, the willingness to pay to avoid an illness can be several times larger than the measurable cost of the illness. That WTP typically will exceed COI has been long understood—at least since Schelling (1968) and Harrington and Portney (1987)—and is by now conventional wisdom (e.g., National Research Council 2008 p 130, USEPA 2010a p 7-14). The main point of this exercise is to show how the life-cycle framework could be used to estimate the size of this divergence based on the nature of the illness and ancillary estimates of QALYs. This could aid in the extrapolations of previous empirical findings (e.g., Alberini and Krupnick 2000) to new policy contexts and improve methods for combining WTP and COI data in the evaluation of health and safety regulations.

Second, willingness to pay estimates that emerge from a life-cycle model can vary considerably depending on the parameter values. In the examples in Table 1, the wtp estimates are fairly robust to variations in ρ , but the estimates nearly double over the examined range of η . This highlights the need to use as much revealed and stated preference data that can be brought to bear to calibrate or estimate the parameters of a generalized life-cycle consumption model, as well as the need to characterize the associated model and parameter uncertainty. These are important tasks for research and model development before some version of the life-cycle framework can be used for quantitative policy evaluations.¹¹

¹¹ Another important aspect of health risk valuation that a life-cycle framework can help to inform is the behavioral responses of individuals to policy changes. For example, consider the so-called “health-wealth tradeoff,” which is based on the observation that wealth and longevity tend to be positively correlated. Some researchers have suggested that this means the costs of implementing environmental, health, and safety regulations could increase people's mortality risks and these effects should be incorporated into benefit-cost analyses of such policies (Keeney 1997). As emphasized by Revesz and Livermore (2008), it is not clear that wealth causes health rather than the converse. But even accepting the premise that wealthier individuals are healthier on average because they spend more money on personal health and safety, it still does not necessarily follow that this effect should be included in a benefit-cost analysis. To see why, first note that the standard approach to valuing the risk reductions from an environmental regulation can be summarized as follows. We assume that utility for a representative individual is a

2.3 Normative advantages

Setting aside the practical issues discussed above, the VSL is in principle suitable for benefit-cost analysis because it aims to estimate people's willingness to pay for mortality risk reductions. The life-cycle consumption framework also can be used to estimate willingness to pay, as explained in Section 2.1, and therefore also is suitable for benefit-cost analysis. However, unlike the VSL the life-cycle consumption framework can provide a natural foundation for a social welfare function, which can be used to conduct a unified analysis of both efficiency and equity impacts.

Before considering social welfare analysis, it is helpful to recall the conceptual foundations of benefit-cost analysis (BCA). The conceptual foundation for BCA is the Kaldor (1939) and Hicks (1940) "potential compensation" test, which loosely goes as follows: if those who would gain from a policy change would still gain after fully compensating those who would lose from the change, then the policy represents a potential Pareto improvement and therefore passes the benefit-cost test. Note that the compensation to which this test refers is purely hypothetical; it is not paid in reality. So this test rests entirely on a thought experiment in which money can be transferred among individuals with no transaction costs or incentive effects or other impacts not

function of income (for now assumed to be devoted entirely to consumption), Y , and health status, S , which in turn is a function of environmental quality, Q : $U = U(Y, S(Q))$. The change in utility from a regulation that would reduce the individual's income by dY and increase environmental quality by dQ is $dU = -U_Y dY + U_S S_Q dQ$, where subscripts indicate partial derivatives. The maximum willingness to pay for the policy (i.e., the $-dY$ and dQ pair) is $WTP = (U_S S_Q / U_Y) dQ - dY$. This standard approach has been criticized by some because it does not account for the "health-wealth tradeoff"—that is, it ignores the behavioral responses of individuals as they may reduce their personal expenditures on health and safety after their disposable income is reduced by the cost of the regulation. So consider an alternative model that explicitly recognizes this effect. In this case we would assume $U = U(C, S(Q, D))$, where now total income, Y , is allocated between consumption, C , and expenditures on personal health and safety, D , i.e., $C = Y - D$. A necessary condition for utility maximization by the individual is $U_C = U_S S_D$. Now the change in utility from the policy is $dU = -U_C [1 - D_Y] dY + U_S [S_Q dQ - S_D D_Y dY]$ and the maximum willingness to pay for the policy is $WTP = U_S S_Q dQ / (U_C [1 - D_Y] + U_S S_D D_Y) - dY$. Using the necessary condition for utility maximization noted just above, this simplifies to $WTP = (U_S S_Q / U_C) dQ - dY$, which is identical to the first case where the "health-wealth tradeoff" was ignored altogether. This is a straightforward instance of the envelope theorem: if $y(\alpha) = \max_x f(x, \alpha)$, then $dy/d\alpha = \partial f(x, \alpha) / \partial \alpha$ evaluated at $x = x^*(\alpha)$, where $x^*(\alpha) = \arg \max_x f(x, \alpha)$. So to a first order approximation—which is accurate for small risk changes and small regulatory costs at the individual level—the "health-wealth tradeoff" does not properly appear in a benefit-cost analysis. If the risk changes or regulatory costs are large enough, then the second order effects could be important. How large is large enough could be examined with the aid of a life-cycle consumption model.

already subsumed in the individual willingness to pay estimates themselves. If a policy passes the benefit-cost test, and if the potential compensation payments that form the theoretical basis of the test would in fact occur under the policy scenario, then the policy would represent an actual Pareto improvement and would be deemed desirable under any normative theory of public choice that respects the consensus preferences of all individuals who comprise the society. But because in reality such compensation payments do not occur, we generally expect some individuals to prefer the policy change and some to prefer the status quo whether the policy is potentially Pareto improving or not. Economists often describe BCA as a method of assessing the “economic efficiency” of a policy, leaving considerations of equity or distributional consequences to be addressed separately. This refers to the fact that BCA weights all individual-level WTPs equally, irrespective of differences in wealth or any other potentially welfare-relevant personal characteristics among the individuals that comprise society, which follows directly from the logic of the Kaldor-Hicks potential compensation test.

At this very basic conceptual level, the advantages and disadvantages of BCA can be succinctly stated. The advantage of BCA is that it can be used to assess the economic efficiency of policy changes with no assumptions about how individual utility levels or utility changes should be compared among individuals and combined, both of which involve inherently normative judgments. It can avoid making such normative judgments by instead adopting the (purely fictional) assumption of the possibility of unrestricted lump sum transfers of wealth among individuals. Thus, BCA can proceed on strictly positive grounds: estimate everyone’s WTP for the policy and simply add these values to determine if the policy represents a potential Pareto improvement.

The disadvantage of BCA is that the potential compensation test gives an incomplete answer to the fundamental question of whether a policy is socially desirable, since by design BCA does not assess the equity or distributional impacts of the policy.¹² So, if a comprehensive notion of “social welfare” includes both efficiency and equity concerns—which by virtually all ethical theories it does¹³—then passing a benefit-cost

¹² While the BCA criterion itself is insensitive to the distribution of willingness-to-pay among individuals, the information used in BCA often can be helpful for supplemental analyses of distributional impacts (e.g., USEPA 2000 Ch 9).

¹³ This includes classical utilitarianism (e.g., Harsanyi 1975 p 313, Kaplow 2008 p 377-378), which should *not* be confused as synonymous with benefit-cost analysis. Even economists are sometimes lax in maintaining this basic but important distinction. For example, Lind and Schuler (1998 p 84) state that “...utilitarianism distributes the burdens and benefits in ways that provide the greatest good for the greatest numbers without regard to the extent of inequality (this is the welfare criterion implicit in any discounted net present value sum of benefits and costs over time.)” As emphasized in the main text above, the sum of benefits and costs as measured by willingness-to-pay indicates only whether a policy is potentially Pareto improving, which is in general *not* the same as a utilitarian social welfare function. Only

test is neither necessary nor sufficient for a policy to increase social welfare. It is important to fully appreciate this point, but at the same time it should not be overstated. Here I agree with Sunstein (2007 p 243), who argues that BCA “does not come close to telling regulators all that they need to know—but without it, they will know far too little.” That is, BCA only goes so far, but it is useful as far as it goes.

To go further, by conducting an integrated assessment of both efficiency and equity, requires an explicit “social welfare function” (SWF). An SWF takes the welfare of each individual in society as input and returns a single number that indicates the overall desirability of a projected status quo or policy scenario. Here it is not possible even to sketch the various competing notions of social welfare and different mathematical forms that an SWF might reasonably take.¹⁴ For the purposes of this discussion I claim only that a more complete assessment of public policy options requires us to go beyond BCA, and in my view some form of social welfare analysis—using an explicit SWF as understood in the welfare economics literature—is among the most promising ways forward on this front (Buccola 1988).

Using an explicit SWF forces the analyst to be concrete about normative matters that are by design left un-examined in benefit-cost analysis and therefore left up to the decision-makers or other consumers of the BCA to interpret or impute themselves. In this way a social welfare analysis can help to map out more of the terrain of public choice problems than benefit-cost analysis is equipped to do on its own. Of course, basic best-practices for policy analysis require that the positive and normative aspects of any social welfare analysis be clearly delineated, and sensitivity analyses over key positive and normative parameters be conducted and reported. This will allow the decision-makers and other consumers of the analysis to separate the facts from values and thereby more easily see the policy conclusions to which their own beliefs and values, and those of others, lead (Robert and Zeckhauser 2010).

Under the premise that some form of social welfare analysis can be a useful supplement to BCA, the normative advantages of the life-cycle consumption framework stem from the fact that it is based on an individual-level lifetime utility function and so it can provide a natural foundation, or at least a key building block, for an explicit SWF (e.g., Adler 2008). Much has been written about alternative theories of welfare or well-being, the proper interpretation of utility, revealed preference theory, inter-personal

under the special (and arguably highly unrealistic) case where all individuals’ utility functions are linear in wealth will these concepts coincide for practical purposes.

¹⁴ For an entry into the large literature on these and related topics, see Bergson (1938), Harsanyi (1955, 1975), Samuelson (1977, 1981), Dasgupta (2002), Kaplow and Shavell (2002), and Kaplow (2008 Ch 13 and 14).

comparisons of utility, the aggregation of individual-level measures of welfare into an SWF under certainty and uncertainty, the discounting of future consumption or utility under alternative forms of the SWF, and more. These are important topics for social welfare analysis—all of them outside the domain of traditional benefit-cost analysis based on the Kaldor-Hicks potential compensation test, but within the larger domain of welfare economics—and each deserves an extended treatment in its own right. The key point I want to stress here is that measures of individuals' willingness to pay are not the fundamental ingredients of a social welfare function; measures of individuals' utility or welfare are. Thus, the lifetime utility function at the heart of the life-cycle consumption framework provides a more fundamental starting point for social welfare analysis than does the VSL or any other measure of WTP.¹⁵

3 Conclusions and challenges

The life-cycle consumption framework has a number of potential advantages, both positive and normative, over the traditional use of the VSL to evaluate health risk changes. From a positive perspective, the life-cycle framework can provide a foundation for a benefit transfer function that can evaluate mortality and morbidity risks simultaneously, and it can provide theoretical structure for statistical models fit to data on people's observed choices or stated preferences regarding tradeoffs between income and health risks. From a normative perspective, the life-cycle framework provides a natural foundation for a social welfare function, which can supplement traditional benefit-cost analysis by facilitating an integrated assessment of both efficiency and equity impacts.

These potential advantages come at the cost of additional data requirements for positive analysis and explicit ethical assumptions for normative analysis. To parameterize and validate a life-cycle model that is applicable over a wide range of age, income, and other personal characteristics and that includes measures of contemporaneous health status and quality of life suitable for analyzing mortality and morbidity risk changes simultaneously would require data on observed or stated choices by very many individuals under very many different real or hypothetical choice contexts. The stated preference research of Cameron and colleagues provides some indication of the likely complexity of such empirical studies (e.g., Deshazo and Cameron

¹⁵ Additional support for the life-cycle consumption framework from a normative perspective might draw on Broome's (1999 Ch 12) arguments in favor of structured versus unstructured benefit-cost analysis. The argument is reminiscent of (perhaps even a normative analogue to) Leamer's (1983) reasons for using structural "informed conventions" to help guide positive analysis, mentioned above in footnote 8.

2004, Cameron *et al.* 2008). So there may be a substantial research program required to span the gap between the current state of the literature and that needed to operationalize a life-cycle consumption model for practical policy evaluations.¹⁶ As a first step in this direction it may be possible to use a form of preference calibration to parameterize a simplified version of a lifetime utility function, but even this may require a more sophisticated application of this approach than has been carried out to date (Smith *et al.* 2006).

The explicit ethical assumptions that would be needed to conduct a social welfare analysis are the standard ones in welfare economics: those regarding interpersonal comparisons of utility or well-being (e.g., Harsanyi 1990, Fleurbaey and Hammond 2004, Binmore 2006), and those regarding the aggregation of individual measures of well-being into a single indicator of overall social welfare (e.g., Donaldson 1992, Mueller 2003 Ch 23). No clear consensus currently exists regarding a single best set of normative assumptions around which to build a social welfare function. However, even now it may be possible to identify a reasonably small group of leading contenders that could define the range of sensitivity analyses over normative parameters as one element of a preliminary set of best-practices for social welfare analysis.

¹⁶ The NRC (2008) emphasized the research hurdles as follows: “There is likely to be good reason to use a non-constant VSLY [value of statistical life year] or a non-constant VSL, once the empirical literature is sufficient to support this transition. The committee stresses, however, that the status quo of using a uniform VSL should be continued until there is sufficient empirical evidence of how WTP for mortality-risk reduction varies with differences in remaining life expectancy and other factors, which the committee concludes is not yet available” (p 157).

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Figures and Tables

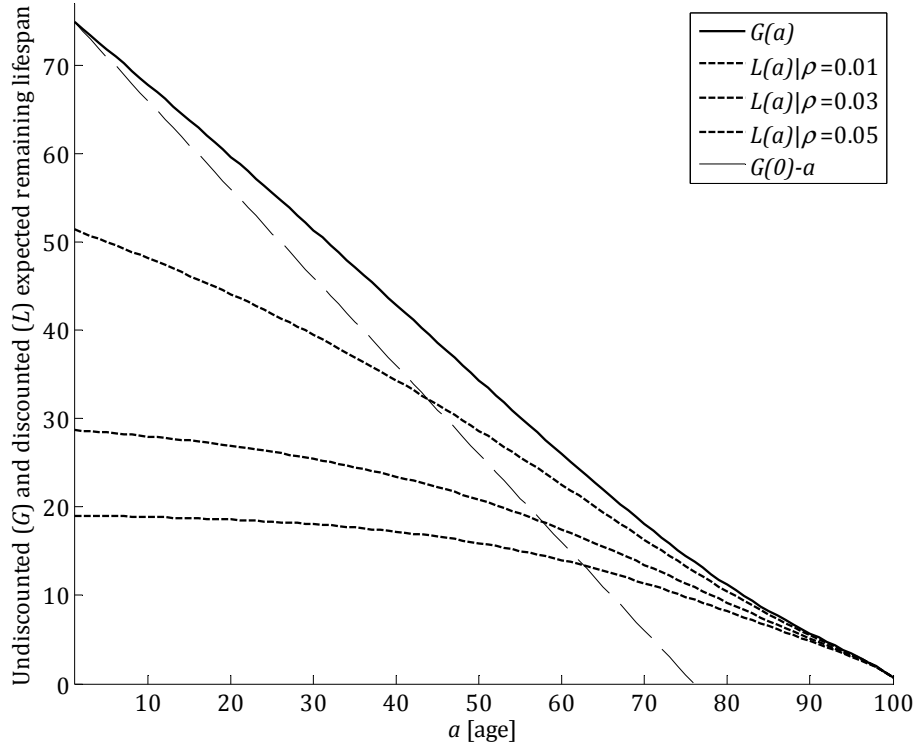


Figure 1. Undiscounted and discounted expected remaining lifespan as a function of age, based on a Gompertz survival function: $m_a = \theta_0 + e^{\theta_1 + \theta_2 a}$, and $s_{a,t} = \prod_{\tau=a}^t (1 - m_\tau)$, with $\theta_0 = 0.00285$, $\theta_1 = -11.5$, and $\theta_2 = 0.1$. This gives an expected lifespan at birth of approximately 75 years.

Table 1. Three examples using a basic life-cycle consumption model with constant consumption to illustrate the relationships between cost of illness, quality adjusted life years, and willingness to pay measures of health outcomes.

		Example 1	Example 2	Example 3
age [yr]		30	50	70
coi [\$ yr ⁻¹]		1,000	3,000	5,000
$G - G'$ [yr]		2	1.5	0.5
$QALY$ [yr]		3	2	1
h		0.9798	0.9848	0.972
Δm		1.39E-3	2.21E-3	2.35E-3
$L - L'$	$\rho = 0.01$	1.39	1.15	0.43
	$\rho = 0.03$	0.71	0.71	0.32
	$\rho = 0.05$	0.40	0.46	0.25
		wtp [\$ yr ⁻¹]		
$\eta = 0.25$	$\rho = 0.01$	3,000	5,000	6,800
	$\rho = 0.03$	2,800	4,700	6,700
	$\rho = 0.05$	2,600	4,600	6,600
$\eta = 0.5$	$\rho = 0.01$	4,100	5,900	7,600
	$\rho = 0.03$	3,700	5,600	7,500
	$\rho = 0.05$	3,400	5,300	7,400
$\eta = 0.75$	$\rho = 0.01$	6,800	8,400	10,000
	$\rho = 0.03$	6,100	7,900	9,800
	$\rho = 0.05$	5,600	7,400	9,600