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Quality-Adjusted Life-Years without Constant Proportionality

Benjamin M. Craig, PhD[1,*], *Kim Rand, PhD*[2,3], *Henry Bailey, PhD*[4,5], *Peep F.M. Stalmeier, PhD*[6]

[1]Department of Economics, University of South Florida, Tampa, FL, USA; [2]Department of Health Management and Health Economics, University of Oslo, Oslo, Norway; [3]Health Services Research Centre, Akershus University Hospital, Lørenskog, Norway; [4]Arthur Lok Jack Global School of Business, The University of the West Indies, Trinidad and Tobago; [5]HEU, Centre for Health Economics, The University of the West Indies, Trinidad and Tobago; [6]Health Evidence, Radboud University Medical Centre, Nijmegen, The Netherlands

A B S T R A C T

Background: A quality-adjusted life-year is a common unit of measurement in health valuation. Under its constant proportionality assumption, the value of a quality-adjusted life span is defined as the product of preference weight and life span. **Objectives:** To empirically identify an alternative functional relationship between life span and value by relaxing the constant proportionality assumption. **Methods:** Using an online survey, 5367 respondents completed 30 to 40 paired comparisons where each involved a choice between two health outcomes: one with a longer life span and health problems (five-level EuroQol five-dimensional questionnaire) and the other with a shorter life span and no problems (time trade-off pair). Using 2670 pairs, a saturated model with indicator variables for 27 life spans and 90 health problems of varying duration and severity was estimated by maximum likelihood. Its coefficients empirically illustrate the relationship between life span and value on a quality-adjusted life-year scale. **Results:** The results reject constant proportionality ($P < 0.01$) and support the use of a power function to describe the relationship between life span and value, namely, value = preference weight × life span$^{\beta}$. The estimate of power ($\beta = 0.415$; 95% confidence interval 0.41–0.42) appears to depend on whether life span was expressed in a temporal unit of days (0.403), weeks (0.509), months (0.541), or years (0.654). **Conclusions:** Raising life span to a power less than 1 implies decreasing marginal value of life span and greatly improved model fit, and confirms previous violations of proportionality. This power function may replace conventional assumptions in health valuation studies. Nevertheless, governmental agencies may favor a longer time horizon than that of the general population.

Keywords: cost-utility analyses, EQ-5D-5L, quality-adjusted life-years.

Introduction

Governmental agencies have the responsibility to allocate public resources toward health interventions that maximize population health, namely, health-related quality of life (HRQOL) and life span of the general population [1,2]. To inform these resource allocation decisions, health economists formally summarize the costs and consequences of alternative interventions. Instead of summarizing health outcomes in monetary units (i.e., cost-benefit analysis), most analysts summarize these outcomes in terms of their value on a quality-adjusted life-year (QALY) scale (i.e., cost-utility analyses) [3].

On a QALY scale, "immediate death" has the value of 0 and "starting today, a year with no health problems" has a value of 1 QALY. In health economics, this unit serves as a nonmonetary numéraire in cost-utility and other decision analyses (similar to a bushel of corn, a barrel of oil, or an ounce of gold). Health preference researchers conduct surveys to identify the value of health outcomes on a QALY scale [4]. Many researchers have expressed concern about valuation methods and the interpretation of this numéraire [5–11]; nevertheless, its motivation (i.e., to summarize health outcomes using preference evidence from the general population to inform decision making) is well accepted [12].

In practice, health valuation studies typically assume that the value of a quality-adjusted life span is the product of quality and quantity of life: value = w_h × life span, where w_h is a preference weight for HRQOL that proportionally adjusts life span for the burden of poor health. For example, this assumption was applied in all eight national valuation studies in the United States [13–20]. This product implies constant proportionality on a QALY scale: the general population is willing to sacrifice a constant proportion of their remaining life-years to achieve a given improvement in their health, irrespective of the number of life-years that remain [6]. This assumption, however, poorly characterizes the health preferences of the general population: multiple valuation studies have rejected constant proportionality on the basis of empirical evidence [5–9,21–24]. Yet, no study, to our knowledge,

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* *Address correspondence to:* Benjamin M. Craig, Department of Economics, University of South Florida, 4202 East Fowler Avenue, CMC206A, Tampa, FL 33620.

E-mail: bcraig@usf.edu.

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has proposed a specific alternative value function for use in national valuation studies.

In economic evaluations, decision analysts typically discount future costs and consequences (e.g., discounted QALYs) under the assumption that future outcomes have less value than present ones. Such discounting is not the only potential violation of constant proportionality. For example, it may not properly capture the effects of transitions, such as onset or remission of health problems, and their timing. Furthermore, the discount rate may vary with the duration and severity of health problems. For example, under the maximum endurable time (MET), a respondent may prefer a short life span with debilitating health problems than immediate death or a longer life span [8].

Our objective was to identify a value function that can more accurately summarize health outcomes using preference evidence from the general population. For this purpose, we conducted a survey in the US general population to value health outcomes on a QALY scale and estimate the value of multiple health outcomes with a range of life spans and diverse health problems of varying duration and severity without assuming constant proportionality Table 1.

Methods

Quality-Adjusted Life Span and Its Value

To express the value of a life span, we considered four functions: constant, discount, logarithmic, and power. A quality-adjusted life span refers to a person's remaining time alive (e.g., life-years, survival) adjusted for losses in HRQOL ("h").

Constant : $\quad \text{Value} = w_h \times \text{Life span};$

Discount : $\quad \text{Value} = w_h \times \sum_{t=1}^{\text{Life span}} (1+r)^{1-t};$

Logarithmic : $\quad \text{Value} = w_h \times \ln(1-(1-e) \times \text{Life span});$ and

Power : $\quad \text{Value} = w_h \times \text{Life span}^{\beta}.$

For each of the four functions (constant, discount, logarithmic, and power), the value of immediate death is 0 and the value of a 1-year life span is the preference weight w_h On a QALY scale, w_h equals 1 if there are no health problems (i.e., full health) and w_h equals 0 if "dead." Figure 1 illustrates the shape of the marginal value and value functions for life span using discount rates such that each function produces a similar value for a life span of 20 years.

Under constant proportionality, each year of life has the same value. For example, a person may be in good health, such that $w_h = 0.9$. If she lives for 10 years starting today and then dies, the value of this health outcome is 9 QALYs (0.9×10). Under constant proportionality, extending such a person's life span from 10 to 11 years has the same additive effect on value as extending her life span from 50 to 51 years (i.e., constant marginal value of life span).

In economic evaluation, the values of future costs and consequences are discounted to better represent their present values. At a constant discount rate of 0.03 per year, the discounted value of 10 years in $w_h = 0.9$ is 7.91 QALYs (i.e., $0.9 \times \sum_1^{10}(1+0.03)^{1-t}$). This discount function may violate the constant proportionality assumption by allowing the rate to be nonzero [24–26]. If the discount rate is positive (negative), the function has decreasing (increasing) marginal value with respect to life span. If the rate is 0, the function is the same as under constant proportionality.

Not only are future costs and consequences discounted, wealth is also known to have a decreasing marginal value. The relationship between wealth as a stimulus and the mental appreciation of it has long been studied [27]. In 1728, Bernoulli described two alternative functions: logarithmic and power [28]. Under his logarithmic function, value $= \alpha \times \ln(\text{wealth})$, the value of each dollar becomes less as the number of dollars increases. By adjusting the input component of this logarithmic function, it can also represent the relationship between life span and value on a QALY scale.

A lesser known alternative to Bernoulli's logarithmic function is the Cramer power function. If the power β is less than (greater than) 1, this power function has decreasing (increasing) marginal value with respect to wealth. According to a review of multiple experiments by Stevens [27], power β is approximately 0.45 for wealth [27]. By replacing wealth with life span, the power function can represent the relationship between life span and value on a QALY scale. The power function has the constant proportional function nested within (i.e., power = 1).

Separating the Effects of Life Span and Duration of Health Problems

Some health problems can last for the rest of a person's life (i.e., duration = life span; Fig. 2, left side) and others are more transient (duration < life span; Fig. 2, right side). Instead of applying the same w_h to the entire life span, each of the four value functions can be adjusted to allow for an initial duration with health problems followed by additional time without problems (i.e.,$w_h = 1$) :

Constant : $\quad \text{Value} = \text{Life span} - (1-w_h) \times \text{Duration};$

Discount : $\quad \text{Value} = \sum_{t=1}^{\text{Life span}} (1+r)^{1-t} - (1-w_h) \times \sum_{t=1}^{\text{Duration}} (1+r)^{1-t};$

Logarithmic : $\quad \text{Value} = \ln(1-(1-e) \times \text{Life span}) - (1-w_h) \times \ln(1-(1-e) \times \text{Duration});$ and

Power : $\quad \text{Value} = \text{Life span}^{\beta} - (1-w_h) \times \text{Duration}^{\beta}.$

In each function, the effect of life span on value is separate from the effects of health problems of varying duration and severity. Specifically, the value of a health outcome is the value of life span minus losses due to health problems (i.e., the ideal minus life's imperfections).

Health Preference Survey

We conducted a health preference survey and estimated the coefficients for indicator variables for 27 life spans and 90 health problems of varying duration and severity, thereby allowing the results to illustrate which of the aforementioned four functions is closest to the truth.

Between September 1, 2015, and January 11, 2016, 12,051 US adults, aged 18 years and older, were recruited from a nationally representative panel to participate in a 25-minute online survey. The survey instrument had four components: screener, health, paired comparison, and follow-up. The screener captured the respondent's consent and demographic and socioeconomic characteristics. Respondents who passed the screener were asked to complete the health component including the five-level EuroQol five-dimensional questionnaire (EQ-5D-5L) on general health and the visual analogue scale (range worst to best, 0–100) on general health. After viewing three examples of paired comparisons, each respondent completed 30 to 40 time trade-off (TTO) pairs. Screenshots of the survey instrument are provided in Appendix C in Supplemental Materials found at https://doi.org/10.1016/j.jval.2018.02.004.