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A SIMPLE, TWO-STAGE, LOTTERY-BASED ALGORITHM

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ABSTRACT

Recent publications have acknowledged the theoretical superiority of the healthy years equivalent (HYE) concept over quality-adjusted life-years (QALYs), but have raised questions about the practicality of measuring them. We describe a simple, two-stage, lottery-based approach to measure HYE for the case of a decision tree type analysis. The suggested algorithm follows the general approach to HYE measurement suggested by Mehrez and Gafni, and is based on the standard gamble (SG) method, which is well-established and empirically well-tested. We further discuss issues relating to the burden (i.e., number and complexity of questions posed) the measurement process imposes on the respondent. We show that there is no a priori reason why HYE must always involve greater measurement burden than QALYs. Moreover, for many treatment alternatives in which death is not a realistic option, HYE also offers an empirical advantage of reduced cognitive burdens for respondents.

Keywords: Expected utility theory, decision trees, QALYs, HYE.
INTRODUCTION

The validity of research findings on the cost-utility of alternative health care technologies is crucially dependent on the methods used for the measurement of the outcome of the alternative technologies. Quality-adjusted life-years (QALYs) were developed as a way of incorporating both quantity and quality into a general (i.e., non-disease specific) measure of outcome. Although adopted widely in the literature, in recent years the conceptual basis of the QALY as a representation of individual or societal preferences has been challenged. Attempting to deal with these limitations, Mehrez and Gafni\(^1\) have suggested a new measure of outcome - the healthy years equivalent (HYE). As a result, the choice of outcome measure in cost-utility analysis has been the subject of much recent debate, with the discussion centred mainly around the theoretical properties of QALYs and HYEs\(^2\^-\(^8\).\)

Recently Johannesson\(^9,10\) compared the ranking properties of QALYs and HYEs under conditions of certainty and uncertainty. Because outcomes of health care interventions are probabilistic at the individual level (and that uncertainty cannot be ignored at a group level\(^11\)), preference-based measures of outcome for use in economic evaluations of health care interventions necessarily require measures of preference under uncertainty and hence the rest of this note will focus on these measures\(^(1)\). Furthermore, many analyses are conducted using a decision tree format and therefore analysts are explicitly or implicitly (in most cases) assuming that individuals follow von-Neumann Morgenstern (vNM) expected utility theory.

In the case of uncertainty (i.e., the case of probabilistic outcomes) and for individuals who follow vNM expected utility theory, Johannesson shows\(^10\) that ex-ante (EA) HYEs, being the certainty equivalent number of healthy years that produces utility equal to that of the risky health profiles, always rank risky health profiles in the same way as expected utility, without the need for additional assumptions regarding the individual’s utility function. This represents a major theo-

\(^{(1)}\) Nevertheless, it is worth noting that Johannesson’s work\(^9,10\) concluded that in the case of certainty, HYEs always rank health profiles according to individual preferences, whereas QALYs do so only under very specific conditions (constant proportional trade-off and additive independence).
retical strength of the EA-HYE, given the absence of either empirical or normative support for the additional assumptions. Having established the theoretical superiority of the EA-HYE, Johannesson goes on to question the feasibility of measuring EA-HYEs. In particular he argues that “[I]n principle, it should be possible to estimate the number of EA-HYEs in a time trade-off (TTO) question, where the risky health profile to be assessed is framed as a probability distribution and is equated to the certainty number of healthy years. Whether this could be done in practice still remains to be seen, since it is unclear whether that type of information can be processed in a meaningful way” (10,p.46-47).

The purpose of this note is to address the issues of measurement feasibility for what Johannesson calls EA-HYEs, which we shall call simply HYE for the rest of this note. We first describe a simple two-stage, lottery-based approach to measure HYE for the case of probabilistic outcomes described by a decision tree. This measurement approach follows the general approach to HYE measurement suggested by Mehrez and Gafni and has been mentioned briefly elsewhere. We also discuss issues of practical feasibility in terms of the number and complexity of the questions posed to respondents. Finally, the measurement approach is shown to offer an additional potential advantage over QALYs for evaluating health care interventions where the use of death as the worst case scenario in the standard gamble (SG) question can create cognitive problems.

**Measuring HYE: The Case of a Decision Tree Analysis**

HYEs are fully defined elsewhere, but for convenience we begin by defining the general case. A potential life-time health profile for an individual can be described as a vector \( Q = [q_i] \), where \( q_i \) is the i-th element of the vector. Let \( q_i \) be the health state of the individual at the i-th period (where each period is measured in years). For simplicity of presentation but without loss of generality, assume that all periods are of equal length. Denote “perfect health” as \( q \) during a period and the worst possible health state as \( q \). Again, for simplicity but without the loss of generality we assume that \( q \) is equal to immediate death. Denote \( Q_{T} = [q_{1},...,q_{T}] \) as a potential lifetime health profile for an individual who has T additional periods (years) to live. Let \( U(Q_{T}) \) represent a vNM utility function over the individual’s life-time health profile, which describes the utility of the health profile as currently viewed by the individual. Let \( H \) be years (or periods) in full health and \( H^* \) be the healthy years
equivalent. (i.e., U(Q_{H^*}) = U(Q_T) where Q_{H^*} = \{q_1, ... q_{H^*}, q_{H^*+1}, ... q_T\} and T is maximum possible survival).

**Figure 1**

**A Hypothetical Decision Tree Describing a Choice Between Two Potential Treatments**

To illustrate the use of the two-stage lottery-based method, we use a simple example using the decision tree in Figure 1. The task is to determine the preferred treatment option, A or B. Each treatment can result in two potential life-time health profiles which can occur with probabilities p_j (we write these observed probabilities from the tree in lower case to distinguish them from the probabilities used in the
standard gamble (SG) method below). Suppose that the individual’s rank order of these potential life-time health profiles is: $Q^1_T > Q^2_T > Q^3_T > Q^4_T$. Using a two-stage, lottery-based, procedure, in Stage I we calculate the utility of each potential life-time health profile (i.e., $U(Q^i_T)$ for $i = 1, 2, 3, 4$). This is done by asking lottery questions, with probability denoted by $P$, to determine the indifference level of $P$ between (see also Figure 2):

$$\{(P,Q_T);((1-P),Q_T)\} \text{ vs. } Q^i_T$$

where $Q_T = [q_1, \ldots, q_T]$; $Q^i_T = [q_1, \ldots, q_T]$ and $T$ is the maximum possible survival (which in our example is equal to $T$). Probability $P$ is varied until the individual is indifferent between the two alternatives. Denote $P^*_i$ as the probability at the indifference point for the case of potential life-time health profiles $Q^i_T$. At this point, setting $U(Q^i_T) = 1$ and $U(Q_T) = 0$, then under expected utility theory the utility of the health profile, $U(Q^i_T)$, is equal to the indifference probability $P^*_i$ from the lottery (i.e., $U(Q^i_T) = P^*_i$).

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Figure 2
A Standard Gamble Type Question to Determine the Utility Value of a Potential Life Time Health Profile, $Q^i_T$

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 A                       P
    |                      |
    V                      V
Alternative 1            Alternative 2
    |                      |
    V                      V
$P^*_i$                  $1-P$

* The probability $P$ is varied until the individual is indifferent between the two alternatives.
The first stage, therefore, gives us a utility value for each health profile associated with each treatment. Before proceeding to Stage II, the expected utility of each potential treatment is calculated (denoted as \( EU^A \) - the expected utility from treatment A and \( EU^B \) - the expected utility from treatment B). Given the probabilities of the different potential outcomes \( p_j^* \) in Figure 1 and the utility values for each potential outcome, from stage I, we can calculate the expected utility of each treatment in the usual way (i.e.; as the probability-weighted sum of the utilities for health profiles defined within the tree). In the case of our example this would be:

\[
EU^A = p_1 U(Q^{1_T}) + (1 - p_1) U(Q^{4_T}) = p_1 P^* + (1-p_1) P^*
\]

\[
EU^B = p_2 U(Q^{2_T}) + (1-p_2) U(Q^{3_T}) = p_2 P^* + (1-p_2) P^*
\]

We now proceed to Stage II to measure the HYE of each treatment option (or EA-HYEs\(^9,10\)) as follows.\(^{(2)}\) Lottery questions are asked to determine the indifference level of \( H \), denoted \( H^* \), between (see also Figure 3):

\[
\{(EU^A, Q_T); ((1-EU^A), Q_T)\} vs. Q_{t_H} \quad \text{to find } H^*(A)
\]

and

\[
\{(EU^B, Q_T); ((1-EU^B), Q_T)\} vs. Q_{t_H} \quad \text{to find } H^*(B)
\]

where \( Q_{t_H} = [q_1, ... q_H, q_{H+1}, ... q_T] \) and \( H \)

The number of periods in full health (\( H \)) is varied until the individual is indifferent between the two alternatives for each treatment. Thus \( H^*(A) \) and \( H^*(B) \) define the certainty equivalent number of years in full health (HYEs) that produces utility equal to that of the expected utility of treatments A and B respectively.

\(^2\) Note that at this point, by comparing \( EU^A \) with \( EU^B \) one can determine which treatment is preferable for an expected utility maximizing type individual. However, as already explained elsewhere\(^1\) the units used to measure utility (i.e., utils) are difficult to understand for decision makers and thus the need to use a more intuitively appealing unit of measurement, such as years in full health.
In more general terms the two-stage procedure described above can be summarized as follows. For the case of a decision tree and an expected utility maximizing individual, the HYEs of a treatment option is calculated by finding $H^*$ (i.e., the number of years in full health or HYEs) such that $U(Q_H) = EU(Q^i)$. $Q^i$ is a vector describing a potential outcome (expressed as a lifetime health profile) $i$, and $i$ is an index describing all potential outcomes from a given treatment ($i=1, ..., I$). $Q_H$ is a vector describing the outcome of living $H$ years in full health followed by death. $U$ denotes a uNM utility function and $E$ denotes the expectation operator. In stage I we use the standard gamble method to measure $U(Q^i)$ for all $i$ and secondly we calculate $EU(Q^i)$ for each treatment option. In stage II we measure $H^*$ (i.e., the healthy years equivalent of a treatment option) again using the SG method.

* The number of periods in full health, $H$, is varied until the individual is indifferent between the two alternatives

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**Figure 3**

A Standard Gamble Type Question to Determine the HYE of a Treatment Option

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The number of periods in full health, $H$, is varied until the individual is indifferent between the two alternatives.
Feasibility of measurement and discussion

Having established the theoretical superiority of the HYE (i.e., “...always rank risky health profiles the same way as expected utility” (10,p.40), Johannesson questions whether the measurement could be done in practice. There are a number of issues that warrant discussion regarding feasibility of measurement using the suggested algorithm. First, it is important to emphasize that the foundation of this approach is the SG method, which is well-established and empirically well-tested. Even the combined use of the two different certainty equivalent lottery questions, each of which had been used separately in the past in different studies, has been tested and found to be satisfactory. The main additional ‘burden’ that this algorithm imposes is a computational one for the interviewer, who must calculate the expected utility for each treatment option before the second lottery can be posed. But the advent of computer-assisted interviewing makes this task trivial. Computational formulae can be programmed ahead of time so that the probability values (i.e., EUs) used in the second lottery, which are conditional upon the respondents first lottery answers, can be calculated automatically and instantaneously. We are currently involved in different studies where such computer-assisted interviewing is being successfully used. Our experience has been that the need to calculate expected utility adds little if any additional burden to the measurement process.

The second feasibility issue is the cognitive burden the measurement process imposes on the respondent; this is likely to be a function of both the number and the complexity of questions posed. First let us consider the issue of the number of measurements required. When measuring QALYs the strong assumptions of the model currently used allow researchers to measure a utility for a “timeless health state”. This value is then multiplied by the time duration spent in each health state to arrive at the QALY value for a potential life-time health profile. Let n represent the number of different potential health states (not including full health and death) for a given decision tree problem. In the case of HYE one has to measure the utility value of each life-time health profile. Let m represent the number of different potential life-time health profiles for the same decision tree problem (i.e., $Q_i^T$ in Figure 1).

For a given decision tree the total number of measurements required to calculate the expected QALYs for all treatment options is equal to n. The number of
measurements required, using the HYE approach described in the previous section, is equal to $m+l$ (where $l$ is the number of different treatment options). Whether $n$ is greater than, equal to or less than $m+q$ depends on the characteristics of the specific problem being studied. Where $m+l>n$, one could reduce the number of measurements by introducing the assumptions identified by Johannesson$^{9,10}$ that underlie the QALYs approaches. In the latter case, when choosing which measure to use, the analyst faces the following trade-offs: (i) what is the additional respondent burden associated with additional questions? and (ii) what are the additional measurement assumptions one is willing to impose in order to simplify the measurement procedure? (The implications, in terms of descriptive validity and normative appeal, of imposing such assumptions are discussed in detail elsewhere$^7$).

Now let’s consider the issue of complexity of the questions asked. The key question here is how difficult is it to describe a potential life-time health profile versus a potential health state alone? Intuitively it seems that describing a health state alone (e.g., being in pain) might be simpler than describing a life-time health profile. However “holistic designs” or “holistic approaches” have been used successfully in the past in preference measurements$^{16}$. It is also interesting to note that Johannesson’s suggestion to measure HYE using the TTO approach is one which can reduce the number of questions being asked. However, it seems that Johannesson doubts “...whether that type of information can be processed in a meaningful way” (10, p.47). We agree with Johannesson that this is an empirical question. The irony is that the TTO was originally suggested as an empirical substitute for the SG that would offer a simpler measurement approach but (hopefully) would provide the same (or similar) results, and it was only later related to a behavioural theory$^{17}$. In the context of a decision tree analysis, it appears that “going back” to the SG method results in asking “simpler” questions.

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$^3$ $m$ represents the number of measurements needed to complete stage I and $l$ represents the number of measurements needed to complete stage II.
A third measurement feasibility issue arises when dealing with a treatment or disease where death is not a consideration (e.g., living with mild headache for the rest of life). In such a situation asking an individual a lottery question that involves death as a possible outcome may create a cognitive burden due to, for example, anxiety, disbelief or confusion. For QALY calculations in these situations, it has been suggested that preferences for such health states (which are common) be measured using a two-stage lottery procedure known as ‘cascading’\textsuperscript{18}. In the first stage the preference for the health state is measured relative to a less preferred state which is not death. In the second stage the less preferred state is measured relative to death as the worst scenario. This value is used to relate the value measured in the first stage for the less preferred state to the 0 - 1 (death - full health) scale. Note that this procedure, required for QALY calculations, adds more measurements to the process.

Under the HYE approach there is an easy way to eliminate this cognitive burden without increasing the number of questions asked. As noted in the previous section, the upper and lower bounds of the lottery questions (i.e., best possible and worst possible lifetime health scenarios) should be kept the same in both stages. However, the lower bound does not have to be death. It can be anything which is worse than the worst health profile in our problem. For example, if the worst lifetime health profile in our problem is mild headache for the remainder of life, the lower bound for the SG questions could be ‘living with severe headache for the remainder of life’. By changing the lower bound from death to another health profile we remove the cognitive burden \textit{without} the need to increase the number of measurements.

In summary, we have described a simple, two-stage, lottery-based approach measuring HYE$s in the context of a decision tree and discussed the issues concerning the feasibility of using such approach. We hope that the suggested approach will help researchers to evaluate the outcome of medical interventions in a way consistent with expected utility theory and without the need to impose additional behavioural assumptions.


REFERENCES


