EXAMINING THE MARGINAL VALUE OF HEALTH WITH RESPECT TO TIME.

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1. Forward

This paper falls into two sections. Section A examines some theoretical issues concerning the diminishing marginal utility (and value) of time. Section B reports a feasibility study to examine ways of establishing diminishing marginal value of time in the region of 'maximal endurable time'.

In some respects our analysis adopts a slightly different language to that which is usually employed by health economists. Traditionally health economists have viewed the tariffs as unitless weightings that are applied to time. This means that we can express poor states of health experienced for some specified amount of time an equivalent value as time spent in perfect health. Time in perfect health is then used as a proxy for utility. This approach does not readily lend itself to a marginal approach, rather it 'fixes' the weighting as an inflexible entity. Our approach has been to consider marginal utility flows in the theoretical discussion (or marginal value flows in the empirical work). By doing this we allow for the possibility that such marginal flows may themselves be a function of time.

The approach that we adopt, ie the use of utility space in time and health, also allows us to distinguish the assumptions that we make about different regions within that space. Specifically proportionality of utility to time may well exist in some parts of that space but not in others, with very different implications for the valuation methods and the way that we use them.

SECTION A

2. Introduction

This section examines the characteristics of indifference curves for health and length of life, and the underlying utility functions given the existence of generally accepted beliefs about preferences over health and length of life. Specifically, we consider the possibility of diminishing marginal utility in states of poor health, 'maximum endurable time' (Sutherland et al., 1982; Dolan and Stalmeier, 2003; Tsuchiya and Dolman, 2005) and states worse than being dead (Patrick et al., 1994; Macran and Kind P, 2001; Robinson and Spencer 2006) as violations to constant proportionality. In doing so, we demonstrate fundamental and non-trivial problems with the way health values are currently used to estimate QALYs that we think merit wider debate among health economists.

We begin by setting out some of the basic properties of utility space used in both the TTO and the construction of QALYs. Then, given empirical evidence suggesting the existence of 'maximal endurable time' and states worse than

being dead, we construct plausible utility to time functions. The relationships are transposed into utility space, and interpolated to construct a hypothetical utility mapping.

3. "Well behaved" numeraires and valuands

Suppose that each year in perfect health is valued at 1 util. If this were the case, time in perfect health might provide a 'well behaved' measure of value or 'numeraire'. (Recall that the TTO values a specified state of health for a specified period of time as a number of years in perfect health.)

The thing being valued (the *valuand*) is time spent in poor health. We refer to a 'well behaved valuand' as one in which utility is proportional to the time spent in the relevant state. The nature of this relationship would not be of concern providing that we are only attempting to value a specific combination of length of life and health state - for example, if our aim were to value 10 years in poor health. If we determine that the utility of 10 years in poor health is equivalent to 5 years in perfect health, we would value it at 5 utils. However, the relationship between utility and time in poor health does become material if we attempt to determine the *average* flow of utility through time, as we do when we construct an index. In the example above, we observe that the 5 utils are experienced over the 10 years of poor health, so the average flow of utility is 0.5 utils *per year*, or simply, as in the sort of value sets that are published and widely used in cost utility analysis (CUA), an index number of 0.5 for the health state of interest.

This can create a serious problem if we were to apply the average flow of utility, elicited from some specified time period, to value the experience of living in that state of health for a *different* period of time.

An example of a utility map with a well behaved numeraire and well behaved valuands is illustrated by Figure 1. The corresponding length of life to utility functions (derived from the same mathematical model[1]) are shown in Figure 2 and the corresponding marginal utility schedules in Figure 3. Figure 1 suggests that utility is always increasing in both health and in length of life.

In the hypothetical examples used here, time (T) is scaled from 0 years to 10 years. Health (H) is scaled from 0 to 1000. This latter scaling was chosen to avoid potential confusion with the utility 'index' (more properly, the utility flow) associated with states of health. The interpretation of 'health' is best thought of as some physical measure of 'healthiness'. If it helps, the reader is encouraged to imagine this measure of health to be something like the maximum distance a person can walk before their pulse rate reaches some specified value.

Note that any distinctive characteristics of the TTO – as opposed to other valuation methods such the standard gamble (SG) or willingness to pay (WTP) – arise in relation to the behaviour of the *numeraire*. This is because it is the choice of numeraire (time in TTO; risk in SG; and money in WTP) which differentiates these approaches. However, since for illustrative purposes we

[1] The mathematical model used to produce Figures 1 to 3 is U = H/1000*T/10.

have assumed a well behaved numeraire, it follows that the consequences of a breakdown of the conditions for a 'well behaved' valuand, would give rise to problems *irrespective of the valuation technique*.

4. Sources of non-proportionality and non-monotonicity in the relationship between time and utility

First we consider diminishing marginal utility in time. This is plausible *a priori*, particularly for states of health that are less than perfect[2]. Thus, as length of life is increased, the addition to utility from later years in a poor health state may be less than the addition to utility from earlier years in that state. This is illustrated for the intermediate state of health labelled 'H = 500' in Figures 4 and 5[3].

[2] A related issue, which we do not discuss here, is whether there is also a satiation point for perfect health. If we were guaranteed to remain in perfect health, would be wish to live forever?

[3] Figures 4, 5 and 6 are produced using the expression U =H/1000*T/10-0.4*((1-H/1000)*(T/10)^2)

Figure 1 Utility as a function of health and length of life - an 'ideal' case

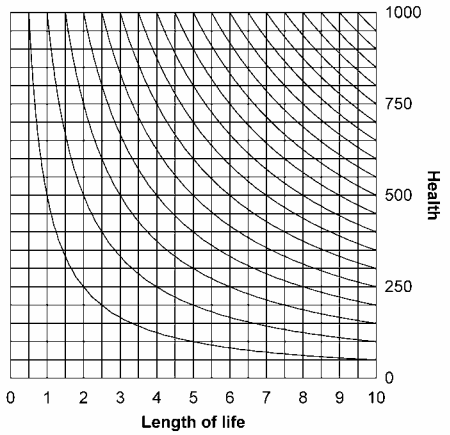


Figure 2 Utility as a function of length of life illustrating proportionality at all health states

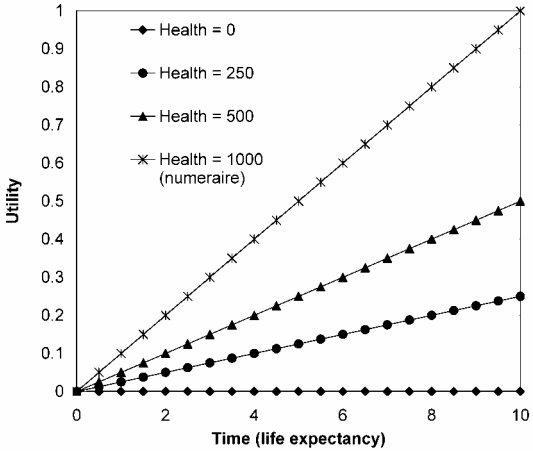


Figure 3 Marginal utility in length of life illustrating proportionality for all health states

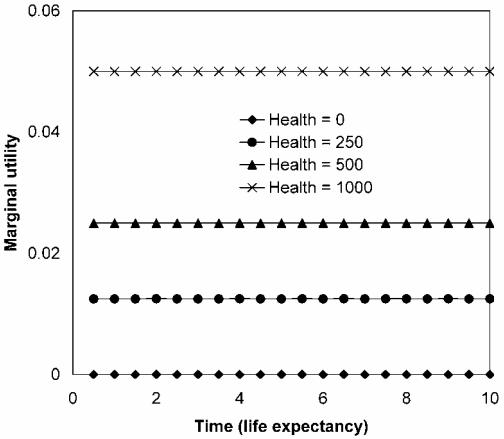


Figure 4 Utility as a function of length of life illustrating non-proportionalities

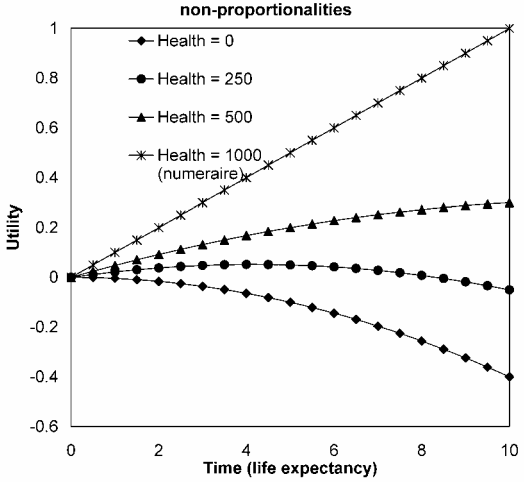


Figure 5 Marginal utility in length of life illustrating non- proportionalities

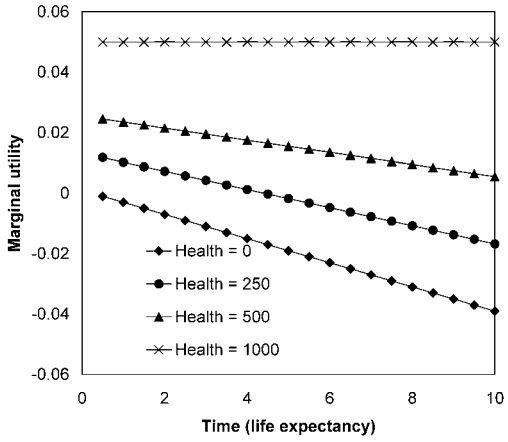
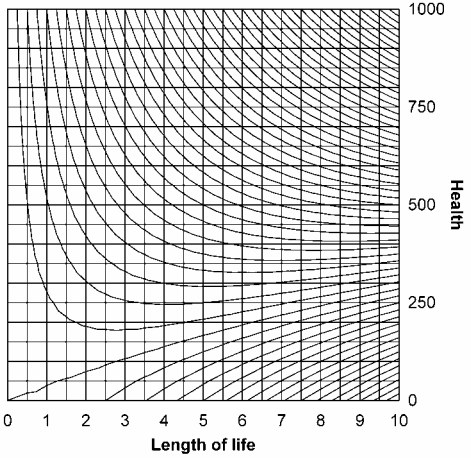


Figure 6 Utility as a function of health and length of life showing MET



Now consider the possibility of 'maximal endurable time'. The intuition is appealing: namely, that there exist states of health so severe that people would only willingly endure them for a limited time (for example to allow them to 'put their affairs in order'). One might speculate that the 'maximal endurable time' would be longer for states of health that are less severe, and shorter for states of health that are more so.

The health state labelled 'H = 250' provides an example of 'maximal endurable time'. We observe that, in the example shown in Figure 4, the total utility of years of life in that state increases up to approximately 4 years, after which further increases in length of life in that state lead to lower utility. In other words, the marginal utility of time after approximately 4 years becomes negative as shown in Figure 5. Further, in this example if the length of life experienced in this state exceeds 8 years, *total* utility becomes negative.

Now consider states worse than dead[4]. The health state labelled as 'H = 0' in Figure 4 provides an example of a state worse than dead for all lengths of life. We see that the utility associated with living in such a state is negative over the entire domain of longevity.

5. Implications for the utility map

We now consider the implications for the indifference mapping (Figure 6) suggested by non-proportionality and non-monotonicity in the relationship between time and utility.

Let utility be a function of time (T) and health (H):

$$U = U(T, H) \qquad [1]$$

We will assume that utility is always a positive function of health ($\delta U/ \delta H > 0$), so that we always prefer more health to less health for any life expectancy. However, given diminishing returns and 'maximal endurable time', the marginal utility of T may be either greater than, equal to, or less than zero.

The change in utility arising from any change in the amount of H and T available is given by:

$$dU = dT * \delta U/ \delta T + dH * \delta U/ \delta H \qquad [2]$$

As one moves along an indifference curve, the increase in utility resulting from a given increase in H must be exactly offset by a corresponding reduction in utility arising from the reduction in T since, by definition, utility is identical at every point along the indifference curve. Because utility is equal at all points along the indifference curve, dU = 0, hence

$$dH/dT = - \delta U/ \delta T * \delta H/ \delta U \qquad [3]$$

Three results follow:

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[4] A weakness of this empirical literature is that states are considered to be either *always* better than, or *always* worse than, dead – irrespective of the time those states are experienced for. Further, the methods used to value states worse than dead, particularly for TTO, rely on separate valuation procedures, and some caution should be applied to their interpretation of values for these states.

i. The marginal rate of substitution ($MRS_{H,T)}$ of health for time (dH/ dT) is always of opposite sign to the marginal utility of time, δU/ δT.

ii. (dH/ dT) equals zero when δU/δT = 0.

iii. As the marginal utility of time (δU/ δT) assumes larger negative values, so the gradient of the indifference curves (dH/ dT) assumes larger positive values and vice versa.

We can now infer the shape of the indifference curves in Figure 6 from the relationships portrayed in Figures 4 and 5.

For the intermediate state of health H = 500, Figure 5 shows that marginal utility with respect to time to be universally positive but falling. Correspondingly, in Figure 6, as we move horizontally across at H = 500, we see that the indifference curves are downward sloping (in accordance with result i), but with reducing slope (in accordance with result iii).

For health state H = 250 we see the effect of 'maximal endurable time' on the utility map. Moving across Figure 6 at H = 250, we begin with positive marginal utility of time (as shown in Figure 5) and corresponding downward sloping indifference curves (($MRS_{H,T}$ is negative, in accordance with result i). We see in Figure 5 that the marginal utility of time = 0 at approximately T = 4. This corresponds to the 'maximal endurable time'. In Figure 6 we see that the indifference curves are horizontal (δU/ δT = 0 in accordance with result ii). For H = 250 and T > 4 (approximately) the marginal utility of time is seen in Figure 5 to be negative. and increasingly so with increases in time Correspondingly, we see in Figure 6 that the indifference curves slope upwards ($MRS_{H,T}$ is positive, in accordance with result i), and that the slope increases as time increases (in accordance with result iii).

Observe that in Figure 6 the minima on the indifference curves shift to the right as health increases, representing a plausible situation in which 'maximal endurable time' is longer for better states of health.

For health state H = 0, Figure 5 shows that the marginal utility with respect to time is universally negative and decreasing with increasing time. This corresponds to the situation in Figure 6, where indifference curves are always upward sloping ($MRS_{H,T}$ is positive in accordance with result i) and increasingly so (in accordance with result iii).

We have shown, in terms of rudimentary consumer choice theory, the characteristics of the utility function underlying the TTO and QALYs which would be compatible with observed non-proportionalities in the utility/time relation. An advantage of this approach is that it allows non-proportionalities, including 'maximal endurable time', and states worse than dead, to be defined in the precise language of utility theory.

However, more importantly, speculating on the characteristics of the utility map reveals some quite fundamental problems with the way health state value sets are currently used to calculate QALYs.

6. The implication for QALYs

With non proportionalities generally, but particularly in the case of poor states of health, where 'maximal endurable time' is more likely, it could be highly inadvisable to use utility flows (indices or tariffs) to estimate QALYs for periods other than the period used in their construction. Consider the case of H = 250. To begin, observe that we could not apply a conventional TTO with a 10 year time horizon, because the health state experienced for that period does not correspond with *any* length of life in perfect health.

It would, however, be feasible to value health over a 7 year time horizon. Seven years in H = 250 is approximately of equal utility (is on the same indifference curve) as 6 months in perfect health. Unfortunately we would have derived approximately the same equivalent time in perfect health if we had asked respondents to value H = 250 using a 1 year time horizon. Converting the results into *average* utility flows, the mean utility flow over the 7 year time horizon = 0.5/7.0 (approximately 0.07 utils per year). The mean utility flow over a 1 year time horizon is 0.5/1.0 (0.5 utils per year). Neither of these results is wrong. They differ simply because they apply to different periods of time.

The consequence of applying an index derived from one time horizon to produce QALYs for a different time horizon is clearly illustrated in the example. If we estimated the utility of spending 1 year in the health state using the index derived from 7 years spent in that state, we would estimate the utility as 0.07 utils (or QALYs) instead of the 0.5 utils (or QALYs) we 'know' it to be.

Conversely if we had used the utility established from a 1 year time horizon to estimate the utility of 7 years in that state of health, we would have estimated it to be 3.5 utils (QALYs) rather than the 0.5 utils (QALYs) we 'know' it to be.

Accordingly, it makes little sense to advocate particular durations when estimating utility flows (indices or 'tariffs') if the aim is to avoid problems that arise from 'maximal endurable time'.

In an empirical investigation of 'maximal endurable time' and constant proportionality Dolan and Stalmeier(2003) conclude that problems might arise for the generation of QALYs if they are based upon TTO valuations. Our analysis suggests the issue is more fundamental. If 'maximal endurable time' results in problems for QALYs the problems do not relate to the properties of the TTO, but to the nature of the valuand. As we show, even values derived from a perfect value elicitation technique, if applied to a time scale other than that used in their elicitation, would incorrectly estimate utility using the QALY methodology. In short, if 'maximal endurable time' is a real phenomenon, it cannot also be an artefact of the valuation methodology.

A theoretically acceptable solution to the problems that effectively arise from the use of average utility flows, would be to integrate the marginal utility of time spent in various health states. The possibility of such an approach would depend upon the availability of such marginal rates. The remainder of this paper describes an early feasibility study of a method of deriving them.

SECTION B A feasibility study to derive marginal rates under maximal endurable time

1. Methods

The content of the questionnaire

The focus of this feasibility study was ‘maximal endurable time’. If this exists it is likely to vary from person to person and from health state to health state. If the assumption of proportionality utility to length of life does indeed break down at ‘maximal endurable time’ it is important, firstly, to be sure that ‘maximal endurable time’ exists for the respondents in our study, and secondly that we frame questions that identify preferences within the range of ‘maximal endurable time’. Accordingly the first part of our questionnaire was aimed at establishing the existence of ‘maximal endurable time’.

The questionnaire began with a brief description of a health state based upon the EuroQol descriptive framework. We experimented with alternative EuroQol Health states, asking some respondents to imagine health state 22222 and other respondents to imagine health state 22322. then asked the following questions:

‘Question 1

If you were offered the choice of living like that for as long as you choose, or the opportunity of immediate painless oblivion, would you accept the offer of oblivion? Yes/ No
If your answer is ‘yes’, please return the questionnaire.

‘Question 2

Remember that we have asked you to imagine living in the poor state of health described above. If you had a choice, would you prefer to live like that for ever (for all eternity), or to live for a shorter period of time?

I would prefer to live like that for ever Yes/ No

If your answer is ‘yes’, please return the questionnaire.’

Between them questions 1 and 2 attempt to establish whether the respondent has a ‘maximal endurable time for the health state in question. If they would neither like immediate oblivion, nor like to live for ever, this would imply the existence of a ‘maximal endurable time’. The word oblivion was used in preference to ‘death’ to dissociate the concept with ideas of immediate execution and in an attempt to minimise any religious connotations of an afterlife.

The next question sought to determine the extent of ‘maximal endurable time’.

‘<u>Question 3</u>

Remember that we have asked you to imagine living in the poor state of health described above. If you could choose with certainty your length of life in that state, how long would you choose to live in that state of health?

(Give your answer in days, months or years as you prefer.)

……. days/ months/ years (delete as appropriate)’

Questions 4 and 5 asked the respondents to calculate half this period (referred to for convenience as a ‘half life’) and on quarter of the period (referred to as a ‘quarter life’).

Questions 6 to 9 asked respondents to state how long they would give up to achieve good health for each of the durations specified in Questions 3 to 5 and also for their ‘three quarter life’ (the sum of their half life and their quarter life). Effectively this enables us to calculate TTO valuations for their personal ‘maximal endurable time’ as well as for: a quarter, a half; and three quarters of their personal ‘maximal endurable time’.

‘The next questions ask you to consider living for different lengths of time in the state of poor health described in the box on page 1, and ask how much of that time you would be prepared to give up if you could be certain instead of enjoying perfect health for the remainder of that time.

Question 6

Imagine you have to live in the state of poor health, for the period of time you stated in your answer to question 3.

What is the maximum amount of that length of life that you would be prepared to give up to live in perfect health?

……. days/ months/ years
(delete as appropriate)

Question 7

Imagine you have to live in the state of poor health, for the period of time you stated in your answer to question 4 (your ‘half life’).

What is the maximum amount of that length of life that you would give up to live in perfect health?

……. days/ months/ years
(delete as appropriate)

Question 8

Imagine you have to live in the state of poor health, for the period of time you stated given in your answer to question 5 (your ‘quarter life’).

What is the maximum amount of that length of life that you would give up to live in perfect health?

……. days/ months/ years
(delete as appropriate)

Question 9

Imagine you have to live in the state of poor health, for the period of time you stated in your answer to question 4 plus the time given in your answer to question 5.

What is the maximum amount of that length of life that you would give up to live in perfect health?

……. days/ months/ years
(delete as appropriate).’

It might have been useful to have collected detailed information about the respondents, however, both the context (as part of staff seminars in New Zealand) and the fact that the sample size would have made it difficult to have examined the impact of a wide range of variables, caused us to decide against doing so.

As a minimum set of background information, we asked respondents to state their age and whether they had dependents for whom they were providing support.

The sample and questionnaire administration

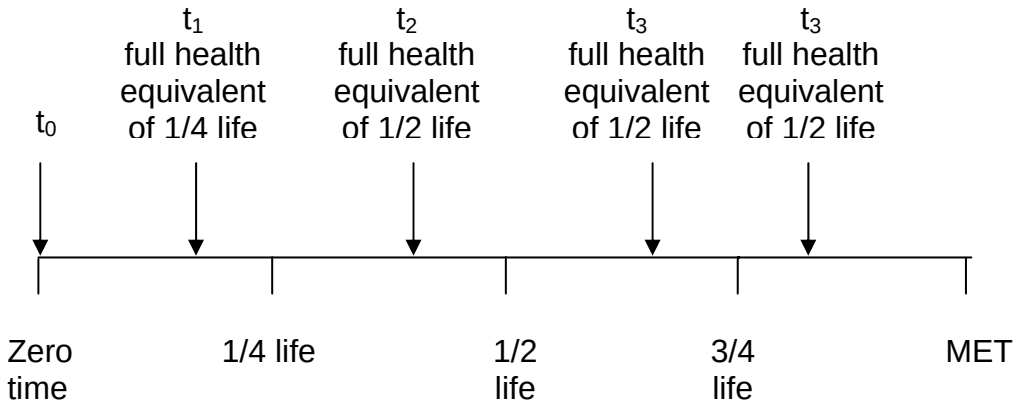
In New Zealand the questionnaires were administered to two groups of mixed clinicians and academics attending seminars given by one of the authors (KB). The questions were explained, with repeated emphasis on the health state under consideration. The implications of their answers was explained to the respondents using examples.

The London sample comprised students attending economics classes in City University. They completed their questionnaires unassisted.

Data analysis

Under normal QALY assumptions utility would increase in proportion to time spent in a health state. This would imply constant marginal utility with respect to time in all health states. However, while the theory is expressed in terms of utility, our empirical work can only proceed in terms of value (ie the amount of the numeraire, ie time in perfect health) that is equivalent to time in poor health. Using the numeraire, we can estimate the value and the marginal value of time spent in health states. If we observe that marginal values are not constant, we could not with certainty exclude the possibility that this results from non proportionality of the numeraire of value. (Metaphorically, our measuring stick might be bent.) If we observe diminishing marginal values, and if we wish to infer that marginal utilities are also diminishing, we must assume that diminishing marginal utility of time in perfect health is less pronounced than diminishing marginal utility of time in poor health. With this caveat, we test for marginal values over the range from to their quarter life, from their quarter life to their half life, from their half life to their three quarter life, and from their three quarter life to their full maximal endurable time. These values are illustrated in Figure 7. Where t_1, t_2 , t_3 and t_4 are shown in Figure 7, the marginal value of the quarter life is $t_1 - t_0$; the marginal value of the half life is $t_2 - t_1$; the marginal value of the three quarter life is $t_3 - t_2$. The marginal value of the maximal endurable time is $t_3 - t_2$.

Figure 7 Time in poor health (below the line) and equivalent time in perfect health (above the line).



We acknowledge that these could be quite wide margins. For a person with and MET of 20 years, we would be looking for marginal changes over 5 year periods.

2. Results

The summary statistics for the original questions are shown in Table 1.

Table 1 Summary statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Accept immediate oblivion?	34	0.15	0.36	0	1
Live for ever?	32	0.16	0.37	0	1
Maximal endurable time	24	237.67	171.78	4	600
Time traded at maximal endurable time	23	68.83	73.03	0	300
Time traded at quarter maximal endurable time	23	11.85	17.76	0	75
Time traded at half maximal endurable time	23	27.70	34.69	0	150
Time traded at three quarters maximal endurable time	22	44.11	50.36	0	225
age	22	40.18	10.68	22	61
dependents (a binary variable)	21	0.52	0.51	0	1

Of the 34 respondents who answered the question, five would have accepted immediate oblivion. Table 2 shows that the proportion did not differ significantly between those in EQ5D state 22222 and those in state 22322.

Table 2 Cross tabulation of numbers reporting that the health state was worse than being dead

	Accept immediate oblivion?		
	No	Yes	Total
EQ5D state = 22222	21	4	25
EQ5D state = 22322	8	1	9
Total	29	5	34
Pearson chi2(2)= 0.1261 Pr = 0.723			

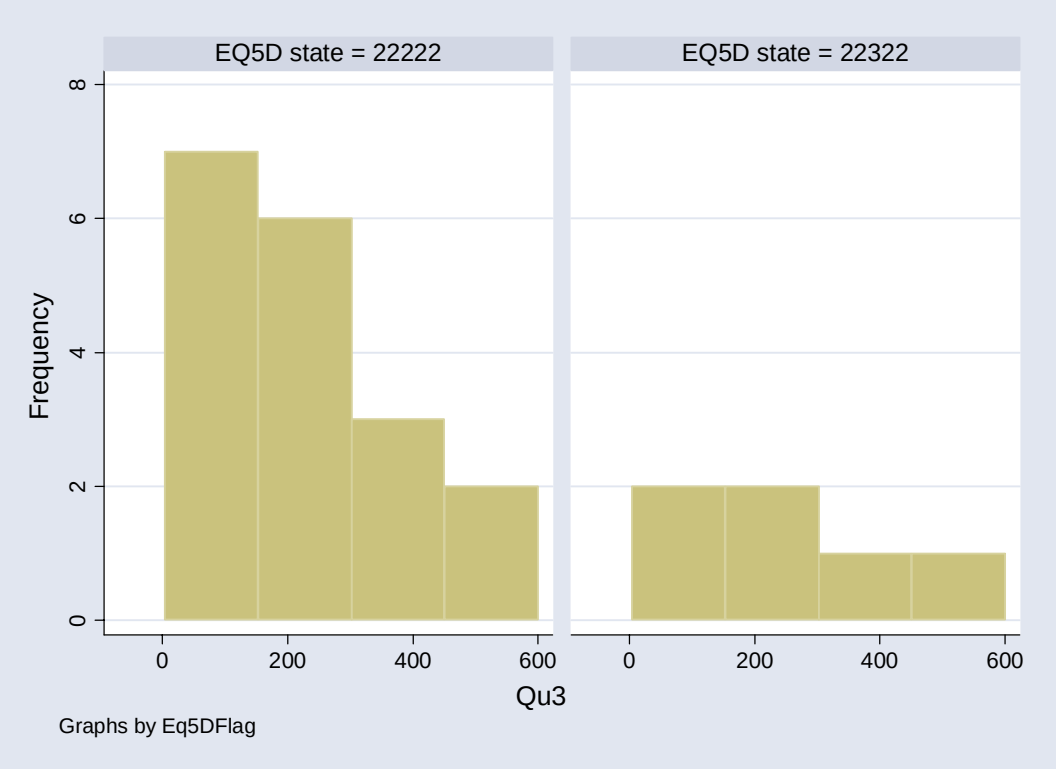
Of the 32 respondents who answered the question, five would have wished to live for ever. Table 3 shows that, again, the proportion did not differ significantly between those in EQ5D state 22222 and those in state 22322.

Table 3 Cross tabulation of numbers reporting that they would live for ever

	Live for ever?		
	No	Yes	Total
EQ5D state = 22222	21	3	24
EQ5D state = 22322	6	2	8
Total	27	5	32
Pearson chi2(2)= 0.7111 Pr = 0.399			

By implication, the majority of respondents would have lived for a definable length of time. The distributions of durations, measured in months, for the 24 respondents to question 3 (which asked how long people would choose to live) are shown in Figure 8.

Figure 8 Distributions of 'Maximal Endurable Time' by Health State



Although we would expect the marginal value of living longer than the 'maximial endurable time' to be negative (because, by definition, we would not expect people to wish to live longer than that amount of time) we would nevertheless expect the maximal endurable time to have a positive value, and hence we would expect that such a value could be measured using normal valuation techniques. To enable comparison between the valuation of 'maximal endurable times' for the different respondents, we firstly report the mean value flow (equal to the conventional TTO index) by calculating the following statistic for all respondents:

average value flow = (MET – Time Traded from MET)/ MET

(MET = 'maximal endurable time')

The distribution of these value flows is shown in Figure 9 and Table 4. We can see that the respondents did indeed assign a positive value to the time spent at 'maximal endurable time'.

Figure 9 Distributions of average value flows (TTO index) at 'Maximal Endurable Time' by Health State

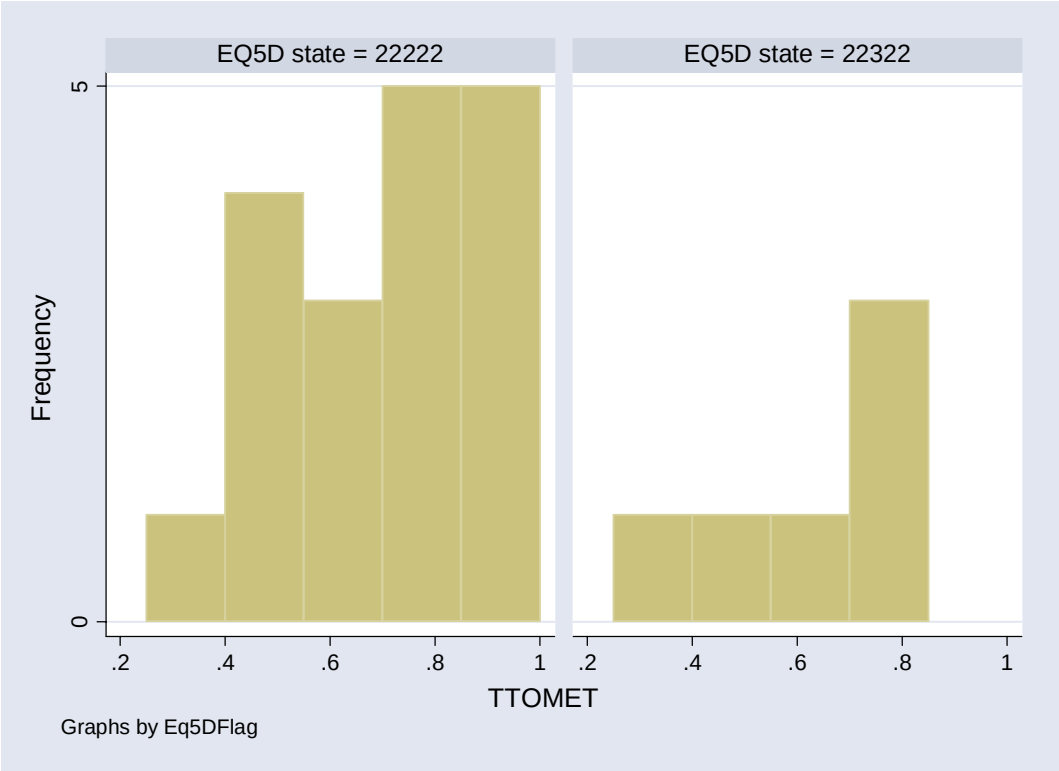
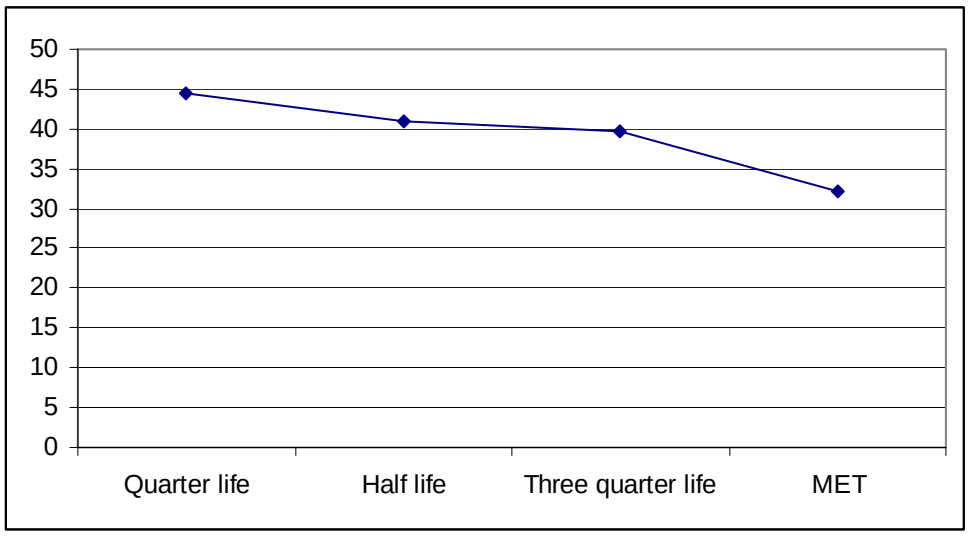


Table 4 Average value flows (TTO index) at 'Maximal Endurable Time' by Health State

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Confidence interval]	
EQ5D state 22222	19	0.72	0.04	0.20	0.63	0.81
EQ5D state 22322	6	0.63	0.07	0.16	0.46	0.80
combined	25	0.70	0.04	0.19	0.62	0.78
diff		0.09	0.08		-0.09	0.27

Figure 10 shows the marginal values of time at various points in time relative to maximal endurable time. We see that the marginal value of time (measured in months per period) is declining as we approach 'maximal endurable time' however the decline is not particularly pronounced.

Figure 10



3. Discussion

The aim of a feasibility study is to examine whether the methods work (for example, is the questionnaire correctly understood) and perhaps to consider what actually happens when we try to interpret the data. Some of the wording of our questionnaire did in fact appear problematic. The meaning of ‘oblivion’ gave rise to problems to some respondents in each of the group. The issues varied from the philosophical to one of comprehension. The idea of eternity similarly gave rise to some problems, primarily as being unrealistic. The concepts we needed to convey were quite difficult. We feel that personal interviews may be required to enable them to be adequately explained. It is probably too much for respondents to complete get the questionnaire unaided.

One encouraging finding was the fact that, for the health states under consideration, 25 out of 34 people did report maximal endurable times. These were all within the range from four months to 600 months. This implies that self reported maximal endurable times arise for a significant number of people.

However, we wonder whether respondents were serious when they claimed that they would prefer oblivion, or maximal endurable times. It may have been that there was a certain amount of bravado, or perhaps an initial reaction to the thought of enduring such states. As elsewhere in the valuation of health states, the question of ‘whose values’ is one that arises. Many people do in fact choose to live in the health states that we describe. It may be reasonable to suppose that many elderly people have problems walking about, in doing work, in washing themselves, are in moderate pain and are moderately depressed, but nevertheless would not choose an early death.

It would be a mistake to place too much confidence in the numerical values tht we have estimated in this feasibility study, however it is interesting to note that the marginal value of time spent, although declining does not approach zero, as we might expect as we near ‘maximal endurable time’. If these results were

confirmed, they would be encouraging for the use of QALYs. It would imply that average values were a relatively good approximation of marginal values over most of the range of ‘maximal endurable time’. It is interesting to speculate why this might be the case. If maximal endurable time exists, then ‘a priori’ it must be the case that the marginal value of time becomes zero or negative at that point. It may be that this occurs very close to maximal endurable time, and, by ‘slicing’ time up into quarters of maximal endurable time does not allow us to detect the effect. This question should be addressed in future research. It might, however, be the case that people are tempted to understate their maximal endurable time, so that when they actually value time spent in poor health, they do value additional time (ie they are not prepared to give up all the extra time they could spend in poor health). Some qualitative research to explicitly explore this issue with respondents might help clarify the point.

There may be a flaw in the logic of maximal endurable times. If we would not choose oblivion now, why would we choose oblivion at the end of the maximal endurable time? However, some participants within the seminars in which these questions were asked reported knowing people who did, in fact, make such decisions.

Another point that we need to test is the assumption that non proportionality in perfect health is likely to be less severe than in poor health, ie we need to test the relative performance of the numeraire. We might do so by using valuation techniques that are less dependent upon time. One possibility would be to ask standard gamble questions that ask what risk of death people would accept to live in perfect health for different durations. We would then be using survival probabilities as the valuand to value time in perfect health.

This feasibility study has shown that the question of examining the marginal value of time spent approaching ‘maximal endurable time’ is indeed a researchable question.

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