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04-10

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July 2004

Abstract

A considerable literature seems to argue the use of *person trade-offs* to estimate the quality-adjustment factor in Quality-Adjusted Life Years (QALY) models. A similar practise is followed by the WHO to estimate the disability weights used in calculation of Disability-Adjusted Life Years (DALY) for assessment of region- and disease-specific burden of disease. In this note we show that QALY (and DALY) models based on person trade-off scores generally violate the Pareto principle.

Keywords: Person trade-off, QALY, DALY, Pareto principle, social welfare.
JEL Classification Number: H4, I1, D6.

*I would like to thank Kristian Schultz Hansen and Carmen Herrero for very helpful comments. The usual disclaimer applies.

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1 Introduction

It seems widely recognized in the literature that a social policy of maximizing the sum of health related individual utilities may fail to capture social preferences for treating the severely ill before the less severely ill. The specific interpretation of individual utility is here Quality-Adjusted Life Years (QALYs) where the quality-adjustment factor reflects how an individual trades off improvements in health state versus gains in life years (e.g. Wagstaff [36], Dolan [4], Bleichrodt [2], Nord [21], Østerdal [39]). Individual *time trade-off* and *standard gamble scores* are examples of data used for estimating the quality-adjustment factor.

A number of papers in the last decade have proposed, or have been strongly influenced by, a specific method for integrating social preferences in the QALY framework (e.g. Nord [17][18][19][20], Nord et al. [22], Richardson and Nord [29], Dolan and Green [5], Ubel et al. [34], and Schwarzinger et al [31]). In this method the quality-adjustment factor is estimated from *person trade-off scores*, i.e. estimates of the number people that should receive a specified health improvement (for example one extra life year at a certain health state) so that it is equally socially preferred to a fixed number of other people receiving a given health improvement (for example one extra life year in perfect health). Likewise, the Disability-Adjusted Life Years (DALY) model used by the World Health Organization (WHO) for assessment of region- and disease-specific burden of disease[1] is also based on disability weights (where 0 indicates "perfect health" and 1 indicates "equivalent to death") estimated by person trade-off protocols [37] (for details, see Murray and Lopez [15]).

Despite the popularity of health indices based on person trade-offs, the-

[1] One DALY can be thought of as one lost year of "healthy" life and the burden of disease as a measurement of the gap between the current health of a population and an ideal situation where everyone in the population lives into old age in full health ([37], p. 95).

oretical support for its use in a QALY (or DALY) framework has not been investigated (Dolan [4], Green [8], Mansley and Elbasha [11]).

In this note, we consider a standard QALY model and show that if the quality-adjustment factor is constructed from person trade-off scores, then social welfare functions based on aggregation of QALYs generally violate the Pareto principle.

Our focus is the QALY framework due to its simplicity and popularity and since it is well-founded in standard decision models (e.g. Bleichrodt [3], Miyamoto et al. [13], Miyamoto [12], Østerdal [39]). The issue raised in this note does, however, also apply to the DALY framework which is a variation of the use of QALYs for social welfare assessment, and the same basic problems are present with the use of person trade-off methods to estimate the disability weights.

The paper is structured as follows: In the next section we define the basics and give two possible definitions of person trade-off indices. Section 3 presents the main result, and discuss implications. An example illustrates that a combination of individual time trade-offs and person trade-offs can be needed for estimating relevant parameters. Finally, Section 4 discusses extensions and limitations and contains a concluding remark.

2 Basics

We consider the simplest possible QALY model ([39]). We assume that health states are constant over time. A health profile for person i is a pair (a_i, t_i) where a_i is a health state, and $t_i \geq 0$ is the number of life years at a_i. Let $\succsim_i$ be binary relation representing person i's preferences for health profiles.

We assume that for any health state a_i the individual preference relation $\succsim_i$ is continuous in t_i, and no health state is equivalent to death in the sense that there is not a non-degenerate interval of life years for which any number of life years within this interval is equally preferred. Further, we assume for simplicity that there is a health states a^* (called "perfect health") such that $(a_i^*, t_i) \succsim_i (a_i, t_i)$ for all a_i and t_i.

For a finite population of n individuals, a social preference relation $\succsim$ is defined on distributions of individual health profiles. A social welfare function U represents $\succsim$ if

$$\begin{array}{rcl} [(a_1, t_1), ..., (a_n, t_n)] & \succsim & [(a_1', t_1'), ..., (a_n', t_n')] \\ & \Updownarrow & \\ U[(a_1, t_1), ..., (a_n, t_n)] & \geq & U[(a_1', t_1'), ..., (a_n', t_n')] . \end{array}$$

The social preference relation $\succsim$ satisfies the (*strong*) *Pareto principle* if

$$[(a_1, t_1), ..., (a_n, t_n)] \succ [(a_1', t_1'), ..., (a_n', t_n')] ,$$

when $(a_i, t_i) \succsim_i (a_i', t_i')$ for all i and $(a_i, t_i) \succ_i (a_i', t_i')$ for some i.

There are two basic variants of person trade-offs. The first variant involves fixed health states and hypothetical gains in life years. The respondent is for example presented with some health state a, and considers how many people $k(a)$ at health state a that should gain one life year before it from a societal point of view is equally preferred to one life year to thousand people at perfect health. The quality-adjustment factor is then defined as $p^1(a) = \frac{1000}{k(a)}$. More precisely, we can define

$$p^1(a) = \left\{ \begin{array}{c} \frac{1000}{k} \mid \left[\overbrace{(a^*, 1), ..., (a^*, 1)}^{1000}, \overbrace{(a^*, 0), ..., (a^*, 0)}^{n-1000} \right] \\ \sim \left[\overbrace{(a, 1), ..., (a, 1)}^{k}, \overbrace{(a^*, 0), ..., (a^*, 0)}^{n-k} \right] \end{array} \right\} . \quad (1)$$

The second variant involves a trade-off between gains in life years for one group of people and improvements in health for another group of people. For example, we may consider an initial distribution

$$\left[\overbrace{(a^*,0),...,(a^*,0)}^{1000},\overbrace{(a,1),...,(a,1)}^{n-1000}\right],$$

and determine the number of people k living for one year that should be taken from health states a to perfect health so that it from a societal point of view is equally preferred to taking thousand people from death to perfect health in one year. That is,

$$p^2(a)=\left\{\begin{array}{c} 1-\frac{1000}{k} \mid \left[\overbrace{(a^*,1),...,(a^*,1)}^{1000},\overbrace{(a,1),...,(a,1)}^{n-1000}\right] \\ \sim \left[\overbrace{(a^*,0),...,(a^*,0)}^{1000},\overbrace{(a^*,1),...,(a^*,1)}^{k},\overbrace{(a,1),...,(a,1)}^{n-1000-k}\right] \end{array}\right\}. \quad (2)$$

One may notice that $p^1(a)$ or $p^2(a)$ might be empty sets (due to an integer problem or due to that indifference cannot be established for any k), or multiple-valued (in case that social welfare is not monotonic in individual utility). In the following, we disregard these technical issues and consider a given real-valued person trade-off index.[2]

The potential gain in life years ("1") and the number of people at perfect health ("1000") is arbitrarily selected in this construction, but the idea is that we can formulate assumptions ensuring that in principle an arbitrary choice can be made (disregarding the integer problem).

[2] A third variant of person trade-offs involves fixed lifetime and improvements of health states. This method is, however, unable to reveal trade-offs between gains in life years and improvements in health.

3 Pareto efficient health-related social welfare evaluation

Despite the importance of the Pareto principle for the construction of a theoretically sound outcome measure based on person trade-offs, its implications in this context seems to have been neglected the literature.[3]

Theorem *Let the social welfare function be the sum of QALYs in the population where the index p (for example a person trade-off index p^1 or p^2) is used as quality-adjustment factor and where v is a strictly increasing transformation, i.e.*

$$U((a_1, t_1), ..., (a_n, t_n)) = \sum_{i=1}^{n} v(p(a_i)t_i). \tag{3}$$

Then the Pareto principle is satisfied if and only if every individual's preferences are represented by a linear QALY function and the quality-adjustment factor coincides with the person trade-off index p, i.e.

$$(a_i, t_i) \succsim_i (a_i', t_i') \Leftrightarrow p(a_i)t_i \succsim_i p(a_i')t_i'.$$

Proof: If every individual's preferences are represented by a linear QALY function where the quality-adjustment factor coincides with the person trade-offs, i.e. if

$$(a_i, t_i) \succsim_i (a_i', t_i') \Leftrightarrow p(a_i)t_i \succsim_i p(a_i')t_i',$$

for all (a_i, t_i) and (a_i', t_i'), then U satisfies the Pareto principle: If $(a_i, t_i) \succsim_i (a_i', t_i')$ for all i with strict preference for at least some i then $p(a_i)t_i \geq p(a_i')t_i'$

[3]For related work see however Kaplow and Shavell [10], Østerdal [39], Hasman and Østerdal [9].

for all i and $p(a_i)t_i > p(a'_i)t'_i$ for some i hence

$$\sum_{i=1}^{n} v(p(a_i)t_i) > \sum_{i=1}^{n} v(p(a'_i)t'_i).$$

It remains to prove that if the social welfare function satisfies the Pareto principle then

$$(a_i, t_i) \succsim_i (a'_i, t'_i) \Leftrightarrow p(a_i)t_i \geq p(a'_i)t'_i, \tag{4}$$

for all i. We therefore show that if (4) does not hold, then the Pareto principle is violated. If (4) does not hold, then for some player i either

$$(a_i, t_i) \succsim_i (a'_i, t'_i) \text{ and } p(a_i)t_i < p(a'_i)t'_i. \tag{5}$$

or

$$(a_i, t_i) \prec_i (a'_i, t'_i) \text{ and } p(a_i)t_i \geq p(a'_i)t'_i, \tag{6}$$

for some (a_i, t_i) and (a'_i, t'_i).

If (6) holds we have

$$(a_i, t_i) \prec_i (a'_i, t'_i)$$

for some player i and some (a_i, t_i) and (a'_i, t'_i), and

$$(a_j, t_j) \precsim_j (a_j, t_j)$$

for all $j \neq i$ and arbitrary health profiles (a_j, t_j). But then

$$v(p(a_i)t_i) + \sum_{j \neq i} v(p(a_j)t_j) \geq v(p(a'_i)t'_i) + \sum_{j \neq i} v(p(a_j)t_j),$$

which contradicts the Pareto principle.

If (5) holds then if $(a_i, t_i) \succ_i (a'_i, t'_i)$ we have (6) and the argument above applies. Hence assume that $(a_i, t_i) \sim_i (a'_i, t'_i)$. Since $p(a_i)t_i < p(a'_i)t'_i$ it is clear that $t_i > 0$ or $t'_i > 0$. Hence by the non-equivalence-to-death assumption there is ε sufficiency close to zero such that either

$$(a_i, t_i + \varepsilon) \succ_i (a_i', t_i') \text{ and } p(a_i)(t_i + \varepsilon) < p(a_i')t_i',$$

or

$$(a_i, t_i) \succ_i (a_i', t_i' + \varepsilon) \text{ and } p(a_i)t_i < p(a_i')(t_i' + \varepsilon).$$

We then have either

$$v(p(a_i')t_i') + \sum_{j \neq i} v(p(a_j)t_j) > v(p(a_i)(t_i + \varepsilon)) + \sum_{j \neq i} v(p(a_j)t_j),$$

or

$$v(p(a_i')(t_i' + \varepsilon)) + \sum_{j \neq i} v(p(a_j)t_j) > v(p(a_i)(t_i)) + \sum_{j \neq i} v(p(a_j)t_j).$$

for arbitrary (a_j, t_j), all $j \neq i$, contradicting the Pareto principle. Q.E.D.

The theorem explicates the limitations with use of person trade-offs in QALY models: If (3) is the criterion used for (health-related) evaluation then only if individual preferences are symmetric and linear and the person trade-off index coincides with the individual quality-adjustment index this social welfare function is consistent with the Pareto principle.

We shall not argue against the *symmetry* assumption, since it may well be reasonable under limited information, and the preference foundations for *linearity* have been discussed elsewhere ([3][13][39]). However, since the point of departure of the QALY literature proposing person trade-off based indices was, or is, that such indices and individual quality-adjustment indices measure two different things (which they in fact also do in the general model), and since experiments have indicated considerable discrepancies between these indices ([26][29][27]), inherent in this approach therefore is a conflict with the Pareto principle. Even assuming that QALYs can be used for representations of individual and societal preferences, making use of a model such as (3) has no theoretical justification and may lead to suboptimal health care distribution.

The whole idea of establishing a person trade-off index only makes sense if the underlying social preference relation preferences satisfies anonymity and independence across individuals, i.e. if social welfare can be evaluated by a symmetric and separable social welfare function

$$U((a_1,t_1),...,(a_n,t_n)) = \sum_{i=1}^{n} v(f(a_i)t_i). \tag{7}$$

However, only in the special case

$$U((a_1,t_1),...,(a_n,t_n)) = \sum_{i=1}^{n} f(a_i)t_i, \tag{8}$$

the two person trade-off indices coincide[4,5], as well as being independent of the specific parameters selected (i.e. "1" year and "1000" people). But note that if (8) is used for (health-related) social welfare assessment then again

[4]Note that under (8)

$$p^1(a) = \left\{ \frac{1000}{k} \mid 1 \times 1000 = kf(a) \right\} = f(a),$$

and

$$\begin{aligned} p^2(a) &= \left\{ 1 - \frac{1000}{k} \mid 1 \times 1000 + (n-1000)f(a) = k + (n-1000-k)f(a) \right\} \\ &= \left\{ 1 - \frac{1000}{k} \mid 1000 = k(1-f(a)) \right\} \\ &= f(a). \end{aligned}$$

[5]A recent paper by Mansley and Elbasha [11] raised a critique of forcing consistency of p^1 and p^2 in the sense that $\frac{1000}{p^1} = 1 - \frac{1000}{p^2}$ in elicitation procedures used for estimating the health index to be used in a DALY model. However, the critique was not based on a DALY (or QALY) model, but rather based on the observation that this consistency check would not apply under some alternative welfare criteria. However, these criteria were themselves inconsistent with the Pareto principle, and, contrary to the authors' claim, not in accordance with standard welfare functions applied to health (as in [36]). For details, see Østerdal [40].

only if individual preferences are linear and the time trade-off indices coincide with the person trade-off index this social welfare function is consistent with the Pareto principle.

If (8) is *not* the underlying social welfare function, there is no reason to expect that the two person trade-off indices coincide, and these indices will not be independent of the parameter indicating the gain in life years (i.e. "1" year). In particular, for social welfare evaluations the information contained in the person trade-off index is a supplement to, but cannot replace, the information on individual preferences that is contained in time trade-offs.

For a simple illustration, suppose that individual preferences are symmetric and social preferences $\succsim$ are represented by the social welfare function

$$U((a_1,t_1),...,(a_n,t_n)) = \sum_{i=1}^{n}(f(a_i)t_i)^\alpha,$$

where $\alpha > 0$ is a parameter which reflects the degree of aversion towards inequality.[6] Defining the *time trade-off index* h as

$$h(a) = \{t \mid (a^*,t) \sim_i (a,1)\},$$

then f is positive linear transformation of h, and we can use time trade-off scores $h(a)$ as quality-adjustment factor $f(a)$.

Now, consider a health state a, and assume that $h(a) = \frac{1}{2}$, and $p^1(a) = \frac{1000}{1500} = \frac{2}{3}$. From this we can estimate the parameter α. We have

$$\sum_{i=1}^{1000} 1 = \sum_{i=1}^{1500}(\frac{1}{2})^\alpha,$$

which gives $1000 = 1500(\frac{1}{2})^\alpha$, or $\alpha = \frac{\log\frac{1000}{1500}}{\log\frac{1}{2}} \approx 0.58$.

[6] See e.g. Wagstaff [38], Dolan [4] and Williams [38] for examples of the Bergson family of social welfare functions applied to QALYs. For an axiomatic characterization, see Østerdal (2002).

4 Discussion and conclusion

The assumptions made, a deterministic framework with chronic health states, was mainly for ease of exposition and for being able to point to the fact that a conflict with the Pareto principle has nothing to do with complications related to uncertainties and non-chronic health states.[7]

The DALY model does technically not come under the analysis in the previous section because of variations in its definition that (among other things) involves a special form of age-weighting and discounting. But it has exactly the same problems as the QALY with use of a person trade-off index synonymous with quality-adjustment factors (here called disability weights). Such practise has no underlying theoretical justification and, assuming that the DALY model is intended to measure a welfare loss, an inconsistency with the Pareto principle can be shown in an entirely analogous way.[8]

We have deliberately not imposed any specific interpretation of "life years" which enters the definition of a health profile. The usual interpretation is that life years involved are *gains* relative to some status quo distribution (which may or may not have been specified), but it could also refer to the total number of life years for individuals. It is worth noticing that under the former interpretation handling person trade-offs and time trade-offs is actually not easy as the estimates will be related to status quo biases (Tversky and Kahneman [32], Dolan and Robinson [6], Munro and Sugden [14]).

[7] Variations of the theorem could be formulated under more general structural assumptions along these dimensions.

[8] We focus in this paper on person trade-off based indices. Related procedures called *veil-of-ignorance* methods have also recently drawn some attention (e.g. Murray et al.[16], Nord [23], Pinto-Prades and Abellán-Perpiñán [27]). Although these methods may refer to a probabilistic framework which is different from ours (depends on the specific interpretation of the questions involved), the same basic problem is present with the use of a veil-of-ignorance based index as quality-adjustment factor in a QALY model (or disability weight in a DALY model). An interesting recent experiment [27] has indicated that a *veil-of-ignorance* based index is closer to an individual quality-adjustment factor than a person trade-off based index, which therefore in this respect reduces the potential conflict with the Pareto principle.

It should be emphasized that our critique is not of person trade-offs *per se*, but of the way it has been proposed integrated with the QALY framework. Not all papers concerned with person trade-offs have suggested this specific application of person trade-offs, and our critique does of course *not* relate to the papers where QALY or DALY models play only a minor role (if any); e.g. Patrick et al. [25], Olsen [24], Pinto Prades [26], Pinto Prades and Lopez-Nicolás [28], Ubel et al. [33], Baron et al. [1], Green [8], Rodríguez-Míguez and Pinto Prades [30], Ubel et al. [35], Dolan and Tsuchiya [7].

In parts of the QALY literature there has been an unfortunate lack of explicitness with regard to the models underlying analysis and argument. This means that, although we have been unable to find alternative interpretations of the approach of the papers considering person trade-offs for use in a QALY framework (i.e. [17][18][19][20][22][29][5][34][31]), there is some room for interpretation, and further debate can add clarification and nuances.

It is perhaps the case, however, that a forward looking research strategy will be most fruitful. Theoretically founded future empirical studies can potentially shed much more lights on the relevance of person trade-offs estimates in connection with QALY-based methods for decision aid in program evaluation.

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