SUPPLEMENTAL INFORMATION FOR "AN APPROACH TO RECONCILING COMPETING ETHICAL PRINCIPLES IN AGGREGATING HETEROGENEOUS HEALTH PREFERENCES"

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This appendix provides more background on societal preference-based measures of HRQL, focusing on the Health Utilities Index Mark 2 (HUI:2) and Mark 3 (HUI:3). As in the main text, we use "HUI" to refer to both the Mark 2 and Mark 3 versions when distinguishing between them is not required. Citations refer to the numbered list at the end of the main text.

Standardized societal preference-based measures of HRQL

The HUI system, along with related generic societal preference-based measures of HRQL (e.g., EuroQol-5D, SF-6D, Quality of Well-Being Scale), defines a *state space* that describes possible states of health. The developers then used an elicitation procedure to assign a number to each state in that space, representing the quality of that health state. These numbers are treated as *utilities*, compactly representing respondents' preferences [4]. The HUI:2 and HUI:3 scoring functions are explicitly estimated using *multi-attribute utility theory* (MAUT) [4, 11, 12, 13]. Other measures use other methods (e.g., regression analysis) to produce their scoring functions.

As an example, a state space might have two attributes: mobility and vision. Health states within it would be represented by a vector $v = (x_{mobility}, x_{vision})$, where $x_{mobility}$ is a level of mobility and x_{vision} is a level of vision. A societal utility (scoring) function, U, for the space would assign a real number, $U(v)$, to each possible vector (i.e., health state) v. One health state is preferred to another if it has a higher $U(v)$. See Figure 1.

Table 1 shows examples of the attributes (e.g., mobility, vision, cognition) used in HUI:2 or HUI:3. HUI:2 has seven attributes, each having three to five levels; HUI:3 has eight attributes, each having five to six levels. Level 1 is best for any attribute. The health state described by the vector of all 1s is the full health state (i.e., the most-able state). Taking into account all of the attributes and the levels of each system, HUI:2 involves a

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seven-dimensional state space with 24,000 unique health states; HUI:3 involves an eight-dimensional state space with 972,000 unique health states.[1] Valuation study participants were asked to compare a tiny fraction of the possible HUI states. The analysis then relied on assumptions about the coherence of their preferences and the interactions between the attributes to generate a utility function for the entire state space.

HUI:2 and HUI:3 use two different methods to aggregate individual utility functions into a societal utility function:

(1) *Mean (overall) utility function.* During the creation of the HUI:2 system, multi-attribute utility functions are estimated for each individual in the sample of participants. These are then averaged to produce an overall societal multi-attribute utility function over the entire state space.

(2) *Person-mean (attribute-based) utility function.* This approach first produces a utility function for each attribute (e.g., mobility, pain), using the mean of the elicited preferences for each level of the attribute. Each of these single-attribute functions is conceptualized as a single-attribute function of a hypothetical individual, the *person-mean,* whose preferences equal the mean of individual preferences within each attribute. These single-attribute functions are then combined (using MAUT methods) to form the overall societal function [4]. HUI:3 uses this method exclusively. HUI:2 uses it in comparison with the mean (overall) utility function method, in order to determine the extent of their disagreement, advocating for the person-mean approach, given its simpler elicitation procedure.

For a simplified example, consider the two-attribute state space, $(mobility, vision)$, and a sample of n people. Assume that each attribute has three levels, creating nine health states. The mean (overall) utility function approach would first elicit each individual's utilities for the three levels of mobility and vision separately, using these values to produce a single-attribute utility function for mobility and for vision for each individual. For each person i, their two single-attribute utility functions would be combined using assumptions from MAUT to produce an overall (multi-attribute) utility function $u_i(x_{mobility}, x_{vision})$. The societal (multi-attribute) utility function is the average of these individual (multi-attribute) utility functions, i.e.,

$$U = \frac{1}{n}\sum_i u_i.$$

[1]The state spaces for HUI:2 and HUI:3 each include an additional state that is not described as a vector of attributes: dead. That is, the state is described by the worst level of each attribute is *not* assumed to be the same as dead. The former is the most-disabled state, sometimes called the "pits."

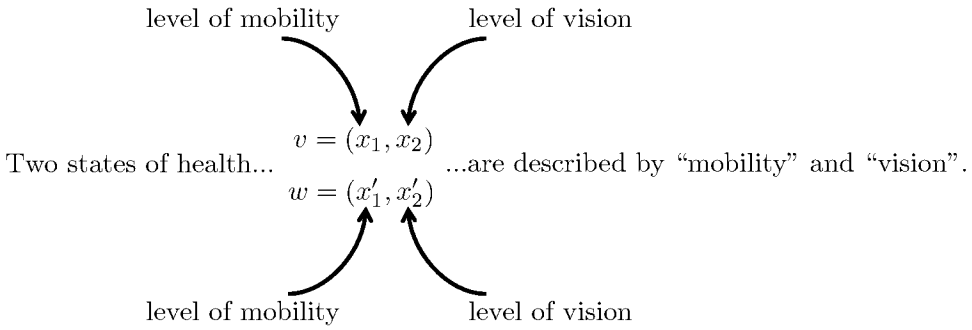
The person-mean (attribute-based) approach would elicit single-attribute utility functions for mobility and for vision from individuals in the sample, but not necessarily both from *every* (or any) individual. The single-attribute functions would then be averaged to produce mean *single*-attribute utility functions for mobility and for vision, $U^{mobility}$ and U^{vision}. The societal multi-attribute utility function combines these two societal single-attribute functions using MAUT modeling assumptions, i.e., $U = f(U^{mobility}, U^{vision})$. See Figure 2.

Thus, although the methods differ, both *average* individual preferences in order to produce a societal aggregate, with one averaging over the multi-attribute utility functions and the other averaging over single-attribute functions.

For more background on societal preference-based HRQL measurement, including the HUI systems and others, see [3, Chapter 7].

TABLE 1. Example attributes and descriptions of their levels from HUI:2 and HUI:3 [11, 13].

Attribute	Level	Description
Sensation (HUI:2)	1	Able to see, hear, and speak normally for age.
	2	Requires equipment to see or hear or speak.
	3	Sees, hears, or speaks with limitations even with equipment.
	4	Blind, deaf, or mute.
Mobility (HUI:2)	1	Able to walk, bend, lift, jump, and run normally for age.
	2	Walks, bends, lifts, jumps, or runs with some limitations but does not require help.
	3	Requires mechanical equipment (such as canes, crutches, braces, or wheelchair) to walk or get around independently.
	4	Requires the help of another person to walk or get around and requires mechanical equipment as well.
	5	Unable to control or use arms and legs.
Speech (HUI:3)	1	Able to be understood completely when speaking with strangers or friends.
	2	Able to be understood partially when speaking with strangers but able to be understood completely when speaking with people who know me well.
	3	Able to be understood partially when speaking with strangers or people who know me well.
	4	Unable to be understood when speaking with strangers but able to be understood partially by people who know me well.
	5	Unable to be understood when speaking to other people (or unable to speak at all).
Cognition (HUI:3)	1	Able to remember most things, think clearly and solve day to day problems.
	2	Able to remember most things, but have a little difficulty when trying to think and solve day to day problems.
	3	Somewhat forgetful, but able to think clearly and solve day to day problems.
	4	Somewhat forgetful, and have a little difficulty when trying to think or solve day to day problems.
	5	Very forgetful, and have great difficulty when trying to think or solve day to day problems.
	6	Unable to remember anything at all, and unable to think or solve day to day problems.



A societal utility function U assigns a number to every health state:

$U(v) > U(w) \Rightarrow$ the health state represented by v has better quality of life than that represented by w.
$U(v) < U(w) \Rightarrow$ the health state represented by v has worse quality of life than that represented by w.
$U(v) = U(w) \Rightarrow$ the health state represented by v has equal quality of life to that represented by w.

U allows **comparisons** between all health states than can be described as a vector $(x_{mobility}, x_{vision})$.

FIGURE 1. An example health-related quality of life measurement system.

There are 9 health states $(x_{mobility}, x_{vision})$ describable in the system:

$$\begin{array}{ccc} (1,1) & (1,2) & (1,3) \\ (2,1) & (2,2) & (2,3) \\ (3,1) & (3,2) & (3,3) \end{array}$$

Goal: Build a societal utility function U that assigns a number to each state.

The mean (overall) utility function approach

Elicit single-attribute functions for both attributes from each of the n individuals in the sample:

$$\{u_1^m(x_{mobility}), u_2^m(x_{mobility}), \ldots, u_n^m(x_{mobility})\},$$
$$\{u_1^v(x_{vision}), u_2^v(x_{vision}), \ldots, u_n^v(x_{vision})\}.$$

Use these to produce a multi-attribute utility function for each individual:

$$u_i(x_{mobility}, x_{vision}) = f_i(u_i^m(x_{mobility}), u_i^v(x_{vision})),$$

where f_i is determined by MAUT [4]. The societal utility function U is their average:

$$U = \frac{1}{n}\sum_{i=1}^{n} u_i.$$

The person-mean (attribute-based) function approach

Elicit k $(k \leq n)$ single-attribute functions for mobility.

Elicit j $(j \leq n)$ single-attribute functions for vision.

Create societal **single**-attribute utility functions for both mobility and vision:

$$U^{mobility} = \frac{1}{k}\sum_{i=1}^{k} u_i^m$$
$$U^{vision} = \frac{1}{j}\sum_{i=1}^{j} u_i^v.$$

Define U to be a function of the two societal single-attribute functions:

$$U = f(U^{mobility}, U^{vision}),$$

where f is determined by MAUT [4].

FIGURE 2. A simplified example explaining the two preference aggregation approaches used in the HUI systems.