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Abstract: A relatively new approach to measure health status is to use non-parametric frontier methods, based on index and production theory. The purpose of this study is to construct and investigate some properties of a non-parametric health status index. The index is based on a non-radial efficiency measure obtained from a non-parametric health characteristics frontier model. The paper includes an empirical application where the health status index is applied to Swedish data from a menopause clinic. The data is collected using the health status profile part of the EuroQol questionnaire. Quality weights are obtained using the time trade-off and visual analogue scale approaches. Correlations between the health status index and quality weights are analysed. The results show that the health status index is significantly correlated both with the rating scale and the time trade-off scores.

Keywords: Health status index, Hormone replacement therapy, Non-parametric frontier models, Rating scale, Russell efficiency measure, Time trade-off.

JEL Classification: I10.

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1. Introduction

Assessing the outcome of health care treatments in terms of benefits for the patient is an important part of health care evaluation studies as well as for policy decisions. Studying changes in benefits in terms of changes in health status is important, both for the patient and the physician, when choosing an optimal treatment strategy. Measuring the effects of a medical treatment is important especially when evaluating different medical treatments of chronic diseases or diseases characterised by a high degree of severity (Guyatt *et al.* (1993)). Further, the majority of medical interventions does primarily affect the health status and not the survival.

The most common approach in contemporary economic evaluation studies is cost-effectiveness analyses where costs are measured in monetary units and effects in non-monetary units. In order to measure the effects of different medical interventions, outcome measures that both incorporate quality and quantity of life are often used. One measure is Quality adjusted life years (QALYs), which takes both these aspects into account. QALYs are calculated by adjusting life years for quality of life in which they are spent. To achieve this the number of years in different health states are multiplied by a quality weight between 0 and 1. There is at least three methods to calculate this weight: the rating scale (RS); the time trade-off (TTO); and the standard gamble (SG). For a presentation of applications and methodological issues in health status measurement see, e.g., Brooks (1991) and Bowling (1995).

A different approach to measure quality of life and health status is to adapt frontier-based methods from index- and production theory (Lovell *et al.* (1992); Roos and Björk (1992)). Lovell *et al.* (1990) use data on what they call resources and functionings to create three indices measuring quality of life, inequality in resources and the ability of individuals to convert resources into functionings (transformation efficiency). The data used in the empirical analysis is extracted from the 1987 Australian Standard of Living Survey. The indices are Malmquist (1953) type indices that are defined in terms of distance functions (Shephard (1970)). The quality of life index and the transformation efficiency index are constructed by output distance functions and the index measuring inequality in resources is constructed by input distance functions. The distance functions are specified as translog functions and are evaluated by econometric techniques (corrected ordinary least squares). A similar method is used in a paper by Roos and Björk (1992), where a non-parametric approach is used to construct quality of life and health status indices. In contrast to Lovell *et al.* (1990), Roos and Björk (1992) examine change in quality of life and change in health status through Malmquist indices. A second difference is that Roos and Björk (1992) evaluate the distance functions by linear programming (LP) techniques in an activity analysis setting. The models of quality of life and health status are applied on data from a sample of 68 patients undergoing a hip-replacement. The patients filled in the Sickness Impact Profile (SIP) before and 6 months after the operation. Data on health attributes and functionings (social interaction, housekeeping, etc.) from the two SIP-questionnaires is then used as ”inputs” and ”outputs”, respectively, to obtain measures on change in quality of life and health status.

In this paper we follow the path of the work in Lovell *et al.* (1990) and Roos and Björk (1992). The purpose of this paper is to construct a health status index, using a non-parametric frontier model based on the Russell output efficiency measure. The aim is further to investigate what properties the index possesses and to apply the proposed index to health status data collected from a menopause clinic treating women suffering from menopausal symptoms.

The paper unfolds as follows: the method is presented in section 2 and 3. In section 2 the theoretical framework is described while the construction of the health status index is viewed in section 3. In section 4 an empirical application is presented. The paper ends with some concluding remarks in section 5.

2. A theoretical framework

The conceptual framework in this study emancipates from the work of Sen (1985) who views commodities in terms of characteristics and functionings, and from Grossman (1972) who views health as a capital good that can be invested in.

Sen proposes that the characteristics of a good are the various desirable properties of the commodities in question. Securing amounts of these commodities gives the owner access to the properties of the commodity. For example, the possession of food gives the individual access to the properties of the food which can be used to satisfy hunger to yield nutrition, to give eating pleasure, to provide support for social meetings. However, we do not know what the individual will be able to do with the characteristics. Functionings on the other hand tells us what a person is able to do, or to be, given the characteristics of the commodity in question. Functionings can for example be: being happy, avoiding premature mortality, being undernourished. The set of all feasible functioning vectors for any person is the capability set, which indicates the opportunity to achieve well-being. A persons' evaluation of a functioning vector is equivalent to that persons' well-being (Sen (1985)).

The model

In this study we look on health capital as represented by health characteristics illustrated by the five health dimensions (attributes) included in the EuroQol questionnaire (see section 4.1 for a description). An individual k is able to choose, to some degree, different health states x_k represented by a health characteristic vector, y_k, through investments in health. This can be accomplished for example by exercise, diet and/or different medical treatments. A health characteristic vector y_k, as summarised into one scalar index value, is defined as the individuals' health status HS_k. The health status index is constructed using the Russell output efficiency measure (see section 3). The health status level of an individual is defined in terms of to what extent each health dimension in the EuroQol questionnaire is fulfilled.

Define the *k:th* individual health state x as $x_k \in \{1,\ 2,\ 3,\ldots,\ H\} = S$ where S is a discrete set of natural numbers that label the health states. The set S contains all the theoretical health states an individual is able to choose. Each health state x_k is represented by a health characteristic vector y_k defined by $y_k = c(x_k)$ where y_k is of dimension M which corresponds to the number of health dimensions in the EuroQol questionnaire. Note that the function $c(x_k)$ depends only on the health state x_k and not on the individual. The health characteristics y_k determines what an individual is able to do or to be, i.e., it gives the functioning vector b_k defined by $b_k = f_k^*(c(x_k))$. A star denotes that the functionings b_k is unobservable due to missing functioning data (the star will be suppressed in the following). Finally, each individual evaluates his/her functionings, and the value of well-being, v_k, is given by the scalar $v_k = h_k\left(f_k\left(c(x_k)\right)\right)$.

Let the set Q_k of feasible functioning vectors for individual k be given by $Q_k = \{b_k : b_k = f_k(c(x_k)), \textit{ for some } f_k \in F_k \textit{ and for some } x_k \in X_k\}$, where $X_k \subseteq S$ is the set of feasible health states the individual is able to choose and F_k is the set of feasible transformation functions that the individual is able to choose. Q_k is called the capability set of individual k and defines what an individual is able to do or to be given that $x_k \in X_k$ and $f_k \in F_k$. Q_k will for example be expanded if new medical drugs become accessible. Further the set V_k of feasible well-being values is defined by $V_k = \{v_k : v_k = v_k(b_k), \textit{ for some } b_k \in Q_k\}$. It is assumed that every individual maximises his/her expected well-being $v_k \in V_k$ by different investments in health, subject to $x_k \in X_k$ and $f_k \in F_k$.

Define the health status HS for individual k as: $HS_k = HS(c(x_k(m_k, g_k)))$, where the health status level depends on m_k, which denotes medical care (for example inpatient care, outpatient care and drugs) and on other factors g_k, such as diet, exercise, the own time of the consumer and individual ability to utilise the specific treatment. When an individual invests in health capital through a medical treatment, the degree of severity in one or several health dimensions will be affected and hopefully improved. The individuals' capability set Q_k has been expanded because of an expanded X_k and the individual is able to choose another health state with a corresponding improved health status level HS_k.

Due to incomplete data, no attempt is made to explain differences in health status from the variables m_k and g_k. The focus of this study will instead be on the health characteristic vector y_k when constructing the health status index HS_k. In the next section it is described how the health status index is constructed.

3. The Health Status Index

A questionnaire consisting of questions on M health characteristics is given to a panel of K patients repeatedly over T time periods. Let y_k^t be a (Mx1) vector of the M health characteristics for patient $k=1, ..., K$ at time $t = 1, ..., T$. The elements in the y_k^t vector are given by the answers of patient k on a discrete scale ranging from 1 to $y_{i,k}^*$, $i = 1,...,M$, at time $t = 1,...,T$.

That is,

$$y_{i,k}^t = \begin{cases} 1 \\ 2 \\ \vdots \\ y_i^* \end{cases}, i = 1,\ldots, M, k = 1,\ldots, K, t = 1,\ldots, T. \qquad (1)$$

The y_i*:th* vector of characteristics identifies the outcome for the individuals health state in each of the *M* different health characteristics, given the situation the individual is facing. The output vector $y^* = \left(y_1^*,\ldots, y_M^*\right)'$ is defined as the best possible health state for the individual at each point in time. The number of possible health states is given by the product $S = \prod_{i=1}^{M} y_i^*$ (see section 2). The different health states are contained in the *M* dimensional set $P^* = \times_{i=1}^{M} \left\{1,2,\ldots, y_i^*\right\}$. Given this, and the vector y_k^t for the individual, we simply define the health status of the individual in terms of the ”distance” from y_k^t to *y**. One possible measure of this ”distance” is given by the Russell output based efficiency measure $RM_{o,k}^t$ (see Färe *et al.* (1994), p. 116). The measure is in this specific application defined as:

$$RM_{o,k}^t\left(y^t\right) = \max_{\theta}\left\{\frac{1}{M}\sum_{i=1}^{M}\theta_i : \left(\theta_1 y_{1,k}^t,\ldots, \theta_M y_{M,k}^t\right) \in P^*, \theta_i \geq 0 \; i = 1,\ldots, M\right\}, \qquad (2)$$

k =1, ..., K, t = 1, ..., T.

In this specific case the Russell distance measure can easily be calculated directly as follows: For each characteristic dimension *i* the estimate $\hat{\theta}_i$ is obtained as the solution to the equation (suppressing the t index, for simplicity): $\hat{\theta}_i y_{i,k} = y_i^*, i = 1,\ldots, M$. Hence:

$$\hat{\theta} = \left(\frac{y_1^*}{y_{1,k}},\ldots, \frac{y_M^*}{y_{M,k}}\right) = /\text{if } y_i^* = 3 \;\forall i / = 3\left(\frac{1}{y_{1,k}},\ldots, \frac{1}{y_{M,k}}\right). \qquad (3)$$

Given that $y_i^* = 3 \; \forall i$, the Russell measure is thus given by:

$$RM_{o,k}^t = \frac{3}{M}\sum_{i=1}^{M}\frac{1}{y_{i,k}^t}, \; k = 1,...,K \text{ and } t = 1,..., T. \tag{4}$$

The reason for this simplicity is that the Russell measure uses the efficient subset of the output set $P*$ as reference set for the expansion of the vector y_k^t . The efficient subset of $P*$ is defined as (Färe *et al.* (1994), p. 41): $Eff\ P(*) = \{y : y \in P(*), y' \geq y \Rightarrow y' \notin P(*)\} = \{y^*\}$[1].
The ideas are illustrated in *Figure 1* below, where $M = 2$ for illustrative purposes.

The Health Status Index

The health status index, *HS,* is defined as :

$$HS_k^t = 1 / RM_{o,k}^t, \; k = 1,...,K \tag{5}$$

A natural approach is to define the health status index as the inverse of the Russell measure. Since the Russell measure satisfies the following property $\theta_i \geq 1, \forall i \Rightarrow RM_{o,k}^t = \frac{1}{M}\sum_{i=1}^{M}\theta_i \geq 1$, the proposed health status index is normalised in the sense that its range is between zero and one. Since $y_i^t \in \{1,2,\ldots,y_i^*\}$, the normalisation implies that the *HS*-index ranges between $\frac{1}{\frac{1}{M}\sum_{i=1}^{M} y_i^*}$ and 1. If $y_i^* = y^* \;\; \forall i$, as is the case in the empirical application presented in this paper, the range of the *HS*-index is given by the interval $\left[\frac{1}{y^*}, 1\right]$.

[1]The vector inequalities are defined as: $y' \geq y$ if and only if $y'_m \geq y_m \;\; \forall m$ and $y' \neq y$.

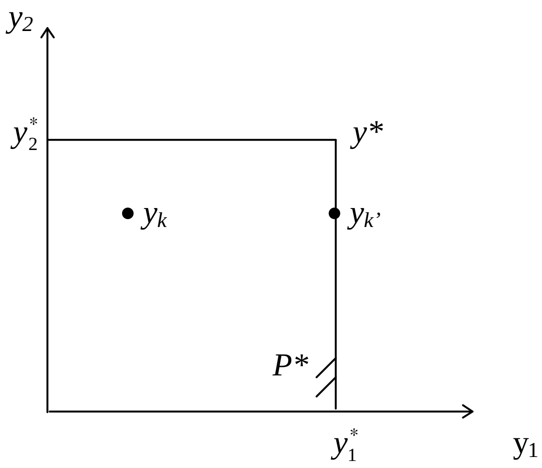

Figure 1: The output set P^* of possible states of nature, where the point y^* defines the best possible state of health in $M = 2$ dimensions.

A comment on alternative approaches may be in place here: The reason why we choose to define the health status index in terms of the Russell output based efficiency measure and not in terms of the output distance functions - as has been done in other work in the area of health status and quality of life measures (see for example Roos and Björk (1992)) - is that the latter approach, with the use of discrete categorical questionnaire data, easily leads to degenerate results in connection with the non-parametric method we use to calculate the efficiency measures. Specifically, defining the health status index in terms of the output distance function implies that the health status would be assessed as the best (or $HS=1$) as soon as a respondent has given a best response *on any* of the M health characteristics (see Appendix 1 for a formal proof of this). In *Figure 1* this is illustrated by the point $y_{k'}$ which gives an output distance function equal to one. The Russell measure, on the other hand, indicates a slack in the second dimension. Hence, a health status index defined in terms of the output distance function is clearly unsatisfactory and motivates the non radial approach taken in this paper.

Properties of the health status index

We derive some properties of the *HS*-index by considering derivatives of the measure. Note that this is not strictly valid since the index as it is defined depend on discrete arguments. Since the main interest is in the signs, rather than the exact magnitudes, of the relevant properties the derivative approach can be motivated.

The central derivative is the following:

$$\frac{\partial}{\partial y_i} HS = \frac{HS^2}{M} \frac{y_i^*}{y_i^2} > 0, \; i = 1,\ldots,M \qquad (6)$$

This derivative reveals that the change in the health status depends on four variables: *1)* The health state, *HS*, from where the change in y_i has occurred. *2)* The number of dimensions included in the index, *M*. *3)* The maximum level of the *i:th* characteristics, y_i^*, and *4)* the level of the *i:th* dimension from where the change has occurred.

Based on these remarks it is relevant to study the following two derivatives as well:

$$\frac{\partial}{\partial y_i} HS\Big|_{HS=HS''} \geq \frac{\partial}{\partial y_i} HS\Big|_{HS=HS'}, \; i = 1,\ldots,M, \qquad (7)$$

when $HS'' \geq HS'$. The change in *HS* caused by a change in y_i increases with *HS*. That is, the change in *HS* caused by a change in y_i is not independent of the levels of all the other dimensions y_j, $j \neq i$.

$$\frac{\partial^2}{\partial y_i^2} HS = 2\frac{HS^2 y_i^*}{My_i^2}\left(\frac{HSy_i^* - My_i}{My_i^2}\right), \; i = 1,\ldots,M. \qquad (8)$$

From (8) we see that $\partial^2 HS / \partial y_i^2 \begin{Bmatrix} \leq \\ \geq \end{Bmatrix} 0$ if $HS \begin{Bmatrix} \leq \\ \geq \end{Bmatrix} My_i / y_i^*$. Since $0 \leq HS \leq 1$, $\partial^2 HS / \partial y_i^2 < 0$ if and only if $M > y_i^* / y_i$. Hence, if the number of characteristics, *M*, included in the questionnaire is greater than the maximum level of each characteristics, y_i^*, the *HS* index is an increasing concave function in each of the *M* dimensions. This reveals that the concavity/convexity property of the *HS* index is questionnaire dependent since the questionnaire design determines the property.

A health status change index

The *HS*-index is defined as the one period (inverted, non-radial) distance to the best possible state of the *M* health attributes as defined by y^*. Given that we have *HS* indices from two periods, we can define an index of the change in the health status as:

$$HSCH_k^{t,t+1} = \frac{HS_k^{t+1}}{HS_k^t} = \frac{RM_{o,k}^t}{RM_{o,k}^{t+1}}, \; k = 1,...,K \tag{9}$$

In Appendix 2 some common index-tests are performed on the *HSCH*-index.[2]

Interpretation: If $HSCH = 1$, the distance from y^t to y^* is the same as that of y^{t+1} to y^*, and the conclusion is that the health status is unchanged. On the other hand, if $HSCH<1$, the distance from y^{t+1} to y^* is larger than the distance from y^t to y^*. Hence, the conclusion is that the health status has decreased. Analogously, if $HSCH>1$, the health status has increased.

4. Empirical Application

4.1 Data

Hormone replacement therapy (HRT) reduces the menopausal symptoms which about 80 percent of all women experiences in the age of 50. Results from Daly *et al.* (1993) indicate that menopausal symptoms may have a large impact on quality of life and health status of a woman.

In order to estimate the impact of menopausal symptoms on quality of life and health status a form was consecutively administered to 65 women recruited from a menopause clinic at Södertälje hospital. All women were, after their consultation with the physician, interviewed by two nurses during the period February 1995, to October 1995. The criterion for eligibility was that the woman should be between 45 and 60 years, and that she had been treated with HRT for at least a period of 1 month.

The form included the EuroQol questionnaire and a time trade-off question. The EuroQol questionnaire is a non-disease-specific instrument for valuing quality of life and it contains

[2] For further reading see Färe *et al.* (1994) and Russell (1985).

two parts: a health status profile and a visual analogue scale (VAS). The health status profile covers five health dimensions (health characteristics): Mobility, Self-care, Usual activities, Pain/discomfort, and Anxiety/depression. Each health dimension is divided into three degrees of severity. The five health dimensions in the health status profile defines a health state and the health status profile consists of 243 (3^5) theoretical health states. Scores on the VAS, or equivalently, the rating scale (RS), range (after normalising) from 0 (death) to 1 (full health). When combining health states with the VAS it is possible to assign quality weights to each health state. Each woman was at first asked to answer the health status profile part of the EuroQol questionnaire based on the experienced health status before initiated HRT, i.e., her health status at least one month ago. Then she was told to answer the same question but based on her present health status, after at least one month of HRT. The data is described in *Table 1*.

Table 1: The percentage and (frequency) of respondents answering 1 (severe symptoms), 2 (mild symptoms) or 3 (no symptoms) according to the five health dimensions in the EuroQol questionnaire, before and after initiated HRT, N=65.

	Before						***After***					
Dim	*1*		*2*		*3*		*1*		*2*		*3*	
1	0	(0)	0	(0)	100	(65)	0	(0)	1.5	(1)	98.5	(64)
2	0	(0)	0	(0)	100	(65)	0	(0)	0	(0)	100	(65)
3	1.5	(1)	9.2	(6)	89.2	(58)	0	(0)	4.6	(3)	95.4	(62)
4	30.8	(20)	60	(39)	9.2	(6)	3.1	(2)	23.1	(15)	73.8	(48)
5	23.1	(15)	40	(26)	36.9	(24)	1.5	(1)	24.6	(16)	73.8	(48)

Each woman was then asked to indicate her experienced health status before initiated HRT and her present health status, on the VAS. The two health states were then evaluated using the time trade-off method. The first time trade-off question was formulated as: ”Suppose that you would experience the symptoms you had before the HRT was initiated for 30 years. Indicate on the scale below how many years in full health followed by death which is equivalent to 30 years with the experienced symptoms followed by death.” This question was then repeated for her present health state. The data on *RS* and *TTO* is given in *Table 2* below.

Table 2: Quality weight values before (RS_t,TTO_t) and after (RS_{t+1}, TTO_{t+1}) treatment and change in quality weight values (RS_{t+1}/RS_t, TTO_{t+1}/TTO_t). N=65.

	Max	Min	Mean	Median	St.dev.
RS_t	1.00	0.03	0.45	0.40	0.24
RS_{t+1}	1.00	0.20	0.84	0.90	0.15
RS_{t+1}/RS_t	0.39	0.27	2.92	1.94	3.41
TTO_t	1.00	0.03	0.67	0.67	0.26
TTO_{t+1}	1.00	0.27	0.94	1.00	0.14
TTO_{t+1}/TTO_t	30.00	0.83	2.28	1.36	3.83

4.2 Empirical results

Using data from the EuroQol questionnaire we estimate the health status index for each individual as described in section 2.2. This gives estimates of health status before (HS_0) and after (HS_1) treatment for each individual. The changes in health status are computed using the ratio of the indices mentioned above. Those results are summarised in *Table 3*. Correlation between the health status index and *TTO* and *RS*, respectively, are analysed by the ordinary (Pearson) correlation coefficient and the Spearman rank correlation coefficient. The Spearman rank correlation coefficient ranges between -1 and 1, where values close to 1 indicate a strong monotonic relationship between two variables. Our null hypotheses are that the correlation's between HS_t and RS_t, TTO_t, respectively, ($t = 0,1$) and between *HSCH* and RS_{t+1}/RS_t, TTO_{t+1}/TTO_t, respectively, are equal to zero[3]. These are tested against the hypothesis that the correlation's are larger than one. The Spearman rank correlation's are shown in *Table 4* and the Pearson correlation's are shown in *Table 5*.

Table 3: Health status index before (HS_0) and after (HS_1) treatment and change in health status (*HSCH*). N = 65.

	Max *1*	Min *2*	Mean *3*	Median *4*	St. dev. *5*	# = 1 *6*	# >1 *7*	# <1 *8*
HS_0	1.000	0.526	0.777	0.833	0.138	4	0	61
HS_1	1.000	0.526	0.944	1.000	0.091	41	0	24
HSCH	1.900	0.842	1.248	1.200	0.235	9	54	2

Columns one and two in table 3 show the maximum and minimum values, respectively. The health status index ranges between 0.526 and 1 both before and after treatment. Column six shows that only four individuals are assigned full health status before treatment, whereas 41 individuals reach full health status after the treatment. Mean health status was 0.78 before treatment and 0.94 after treatment.

Highest improvement in health status was 90% and the lowest value was 0.84, i.e., a worsened change in health status by approximately 16%. As column 8 shows, only two individuals experienced a decline in health status, whereas 54 individuals improved their health status, while the health status was unchanged in 9 cases. Accordingly, the average change in health status was positive and equal to 1.25. We note that both HS_0 and HS_1 are skewed to the left, which reflects the truncation from above at unity for the health status index. Since there are more cases with full health (HS = 1) after the treatment, the skewness is more pronounced after the treatment. The change in health status (*HSCH*), which is only bounded from below by zero, is skewed to the right.

Table 4: Spearman rank correlation coefficients. p-values in parenthesis.

	HS_0		HS_1		*HSCH*
	1		*2*		*3*
RS_0	0.345	RS_1	0.581	RS_1 / RS_0	0.392
	(0.002)		(0.000)		(0.001)
TTO_0	0.266	TTO_1	0.563	TTO_1 / TTO_0	0.295
	(0.016)		(0.000)		(0.008)

Column *1* shows that the rank correlation is positive between the health status index and *RS* and *TTO* both before and after initiated HRT. The two correlation coefficients are both significant at a 5% significance level. The correlation's are positive and significant also after the treatment as seen in column *2*. The rank correlation coefficients between the change measures are also positive and significant.

Table 5: Pearson correlation coefficients. p-values in parenthesis.

	HS_0		HS_1		*HSCH*
RS_0	0.353	RS_1	0.724	RS_1 / RS_0	0.234
	(0.002)		(0.000)		(0.030)
TTO_0	0.318	TTO_1	0.646	TTO_1 / TTO_0	0.167
	(0.005)		(0.000)		(0.092)

[3] Ratios of RS and TTO are used because the *HSCH* index is a ratio of *HS* indices.

The correlation is again positive between *HS* and *RS* as well as between *HS* and *TTO*. The same result also holds for the correlation between *HSCH* and change in *RS* and *TTO*, respectively. All correlations in table 5 are significant at the 5% level, except for the correlation between *HSCH* and change in *TTO*.

5. Concluding Remarks

In this exploratory study we look on health capital as represented by health characteristics defined by the five health dimensions in the EuroQol questionnaire. The health status index is constructed from a simple non-parametric frontier model where the health status is defined in terms of the ”distance” to the best possible health state. The health status index is defined in terms of the Russell output based efficiency measure which is a non radial measure contrary to the earlier used distance function. The reason for not using a radial measure is that the distance function approach, with discrete questionnaire data, can lead to degenerate results when assessing the health status. Further, an index reflecting change in health status is also derived. The health status change index is defined in terms of ratios of health status indices from two time periods.

The method is applied to data from a Swedish study of hormone replacement therapy. Data from 65 respondents is used to construct the health status index and a health status-change index for each individual. For each individual information on quality weights is also collected using rating scale and TTO. The results show that the presented health status index is significantly correlated both with the rating scale and the time trade-off score. This holds both for the ordinary (Pearson) correlation, as well as for the Spearman rank correlation coefficient.

Some of the properties of the health status index should be further commented : The change in *HS* caused by a change in y_i is the same for all dimensions. No distinction is thus made as to whether the health characteristics actually have different effects on the individuals’ health status. If the change in *HS* caused by a change in y_i is not the same for all the dimensions, information is needed on the relative importance of the different dimensions, i.e. what weights do individuals assign the different health characteristics. A modified health status index should account for the fact that different health characteristics representing a health state may have different importance for the individually assessed level of health. Furthermore, the change in *HS* caused by a change in y_i increases with *HS*. That is, the change in *HS* caused by a change in y_i is not independent of the levels of all the other dimensions y_j, $j \neq i$.

Finally, the concavity/convexity property of the *HS* index is questionnaire dependent. By choosing a specific design of the questionnaire, in terms of the number of characteristic dimensions included and the maximum level measured in each dimension, the researcher can choose the desired concavity or convexity property. The questionnaire design used in the empirical part of this paper implies that the *HS* index is an increasing, concave function of each of the *M* dimensions. For example, a certain increase in the health characteristic anxiety/depression, results in a greater increase in the health status for an individual suffering from severe anxiety/depression compared with an individual only suffering from mild anxiety/depression. The health status index thus possesses decreasing marginal health of each health characteristic.

The constructed health status index could also be used as an explanatory variable when predicting TTO and/or RS scores. This can be used to produce predictions of the change in the TTO and/or the RS given only observations of the *M* health characteristics before and after a medical treatment.

In conclusion, this paper explores the possibility of developing a health status index based on information only on health characteristics. The health status index is derived from a non-parametric frontier model based on a non radial efficiency measure adopted from production theory. Future research remains to be done in order to modify and develop measures of health status that reflects individual preferences. One approach is to develop the characteristic/functioning approach described in section 2. Furthermore, it seems relevant to consider the weights individuals assign different health characteristics in the determining the health status index.

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Appendix 1

Motivation for using the Russell output based measure of efficiency instead of the output distance function in defining the health status index in this specific application

In earlier work where measures of health status and quality of life measures have been measured by similar methods - see Roos & Björk (1992), and Lovell *et al.* (1990) - the indices have been defined in terms of distance functions. The output distance function is defined by

$$D_{o,k}^{t}\left(y_{k}^{t},x\right)=inf\left\{\theta : \frac{y_{k}^{t}}{\theta} \in P^{*}(x)\right\}.$$

This function involves radial scaling of the outputs and uses the isoquant of the output set as reference set for the scaling of the outputs. The problem that introduces in this situation, with the isoquant of hypothetical output set P*(x) as reference set, is that it is enough that a person given a maximum answer in on arbitrary dimension of the health characteristics for the health status measure to indicate a best state of health!

To see this, assume that the health status index is defined in terms of the output distance function as $HS_{k}^{\prime t} = D_{o,k}^{t}$, and the health status change index measure is given similarly as:

$$HSCH_{k}^{\prime t,t+1} = \frac{HS_{k}^{\prime t+1}}{HS_{k}^{\prime t}} = \frac{D_{o,k}^{t+1}}{D_{o,k}^{t}} .$$

Proposition:
If $y_{i,k}^{t} = y_{i}^{*}$, for some *i = 1, ..., M*, then the distance function is given by $D_{o,k}^{t} = 1$, and the individuals health status, as measured by *HS*', indicates a full health status since *HS*'=1. (I.e., if the *k:th* individual is assumed to enjoy the best possible state of health in *at least* one dimension of the M dimensions that are measured, the health status index indicates a ”full” health.)

Proof:
Assume that the converse holds, i.e. assume that $D_{o,k}^{t} < 1$. This leads to a contradiction since $\frac{y_{k}^{t}}{D_{o,k}^{t}} \notin P^{*}(x) = \times_{i=1}^{M}\left[0,y_{i}^{*}\right]$. Specifically, $y_{i}^{*} < \frac{y_{i,k}^{t}}{D_{o,k}^{t}} \notin \left[0,y_{i}^{*}\right]$ for some *i*. If on the other hand $D_{o,k}^{t} > 1$, the radially rescaled vector $\frac{y_{k}^{t}}{D_{o,k}^{t}} \in P^{*}\left(x\right)$ but $\frac{y_{k}^{t}}{D_{o,k}^{t}} \notin Isoq\,P^{*}\left(x\right)$. Hence the only remaining possibility is that $D_{o,k}^{t} = 1$, in which case $\frac{y_{k}^{t}}{D_{o,k}^{t}} = y_{k}^{t} \in Isoq\,P^{*}\left(x\right)$.

Q.E.D.

This motivates the use of the Russell measure in the definition of the health status and health status change indices.

Appendix 2

The index of health status change, given by: $HSCH_k^{t,t+1} = \frac{HS_k^{t+1}}{HS_k^t} = \frac{RM_o^{k,t}}{RM_o^{k,t}}$, fulfils the following index tests:

P.1. (Dimensionality) Homogeneity of degree 0 in y^t and y^{t+1} :

$$HSCH\left(\lambda y^t, \lambda y^{t+1}\right) = HSCH\left(y^t, y^{t+1}\right), \ \lambda>0$$

Proof: $$HSCH\left(\lambda y^t, \lambda y^{t+1}\right) = \frac{\frac{y^*}{M}\sum_{i=1}^{M}\frac{1}{\lambda y_i^t}}{\frac{y^*}{M}\sum_{i=1}^{M}\frac{1}{\lambda y_i^{t+1}}} = \frac{\frac{1}{\lambda}\sum_{i=1}^{M}\frac{1}{y_i^t}}{\frac{1}{\lambda}\sum_{i=1}^{M}\frac{1}{y_i^{t+1}}} = HSCH\left(y^t, y^{t+1}\right)$$

P.2. Homogeneity of degree +1 in y^{t+1}: $HSCH\left(y^t, \lambda y^{t+1}\right) = \lambda \cdot HSCH\left(y^t, y^{t+1}\right)$, $\lambda>0$

Proof: $$HSCH\left(y^t, \lambda y^{t+1}\right) = \frac{\frac{y^*}{M}\sum_{i=1}^{M}\frac{1}{y_i^t}}{\frac{y^*}{M}\sum_{i=1}^{M}\frac{1}{\lambda y_i^{t+1}}} = \frac{1}{\frac{1}{\lambda}}\frac{\sum_{i=1}^{M}\frac{1}{y_i^t}}{\sum_{i=1}^{M}\frac{1}{y_i^{t+1}}} = \lambda \cdot HSCH\left(y^t, y^{t+1}\right)$$

P.3. Homogeneity of degree -1 in y^t : $HSCH\left(\mu y^t, y^{t+1}\right) = \frac{1}{\mu} \cdot HSCH\left(y^t, y^{t+1}\right)$, $\mu>0$

Proof: $$HSCH\left(\mu y^t, y^{t+1}\right) = \frac{\frac{y*}{M}\sum_{i=1}^{M}\frac{1}{\mu y_i^t}}{\frac{y*}{M}\sum_{i=1}^{M}\frac{1}{y_i^{t+1}}} = \frac{1}{\mu}\frac{\sum_{i=1}^{M}\frac{1}{y_i^t}}{\sum_{i=1}^{M}\frac{1}{y_i^{t+1}}} = \frac{1}{\mu} \cdot HSCH\left(y^t, y^{t+1}\right)$$

P.4. The index has a bounded range: $HSCH^{t,t+1} = \frac{HS^{t+1}}{HS^t} \in \left[\frac{1}{y^*}, y^*\right]$

Proof: a) maximum value of *HSCH* when: $y_i^{t+1} = \max_i\{y_i\} = y^* \ \forall i$

$y_i^t = \min_i\{y_i\} = 1 \ \forall i$

The minimum value of y_i is set to unity without loss of generality, follows from proposition *P.1.*)

$$HSCH^{max} = \frac{\frac{y^*}{M}\sum_{i=1}^{M}\frac{1}{y_i^t}}{\frac{y^*}{M}\sum_{i=1}^{M}\frac{1}{y_i^{t+1}}} = \frac{\sum_{i=1}^{M}\frac{1}{y^{min}}}{\sum_{i=1}^{M}\frac{1}{y*}} = \frac{M}{M\frac{1}{y^*}} = y^*$$

b) minimum value of *HSCH* when: $y_i^t = \max_i\{y_i\} = y^* \ \forall i$

$y_i^{t+1} = \min_i\{y_i\} = 1 \ \forall i$

$$HSCH^{min} = \frac{\frac{y^*}{M}\sum_{i=1}^{M}\frac{1}{y_i^t}}{\frac{y^*}{M}\sum_{i=1}^{M}\frac{1}{y_i^{t+1}}} = \frac{\sum_{i=1}^{M}\frac{1}{y^*}}{\sum_{i=1}^{M}\frac{1}{y^{\min}}} = \frac{M\frac{1}{y^*}}{M} = \frac{1}{y^*}$$

P.5. Transitivity: $HSCH\left(y^t, y^{t+2}\right) = HSCH\left(y^t, y^{t+1}\right) \cdot HSCH\left(y^{t+1}, y^{t+2}\right)$

Proof:

$$HSCH\left(y^t, y^{t+1}\right) \cdot HSCH\left(y^{t+1}, y^{t+2}\right) = \frac{\frac{y^*}{M}\sum_{i=1}^{M}\frac{1}{y_i^t}}{\frac{y^*}{M}\sum_{i=1}^{M}\frac{1}{y_i^{t+1}}} \cdot \frac{\frac{y^*}{M}\sum_{i=1}^{M}\frac{1}{y_i^{t+1}}}{\frac{y^*}{M}\sum_{i=1}^{M}\frac{1}{y_i^{t+2}}} = \frac{\frac{y^*}{M}\sum_{i=1}^{M}\frac{1}{y_i^t}}{\frac{y^*}{M}\sum_{i=1}^{M}\frac{1}{y_i^{t+2}}} = HSCH\left(y^{t+1}, y^{t+2}\right)$$

P.6. Time reversal: $HSCH\left(y^t, y^{t+1}\right) \cdot HSCH\left(y^{t+1}, y^t\right) = 1$

Proof: $HSCH\left(y^t, y^{t+1}\right) \cdot HSCH\left(y^{t+1}, y^t\right) = \frac{\frac{y^*}{M}\sum_{i=1}^{M}\frac{1}{y_i^t}}{\frac{y^*}{M}\sum_{i=1}^{M}\frac{1}{y_i^{t+1}}} \cdot \frac{\frac{y^*}{M}\sum_{i=1}^{M}\frac{1}{y_i^{t+1}}}{\frac{y^*}{M}\sum_{i=1}^{M}\frac{1}{y_i^t}} = 1$