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The QALY model wich came in from a general population survey: roughly multiplicative, broadly nonlinear and sometimes contex-dependent

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Este trabajo aplica un método, propuesto inicialmente por Miyamoto (2000), para ajustar los pesos de calidad de vida (o utilidades de los estados de salud) en función de la curvatura de la función de utilidad del tiempo de vida. El procedimiento de ajuste aplicado es robusto ante fenómenos como la propagación del error y el sesgo ocasionado por la transformación de la probabilidad. Los parámetros de curvatura estimados fueron, por lo general, consistentes con la evidencia empírica precedente. Asimismo, el presente estudio también recoge varios contrastes de axiomas clave para el modelo AVAC (Año de Vida Ajustado por la Calidad), válidos tanto para el paradigma de la utilidad esperada como para el paradigma de la utilidad dependiente del orden. Los resultados alcanzados, merced a una encuesta realizada a una gran muestra de población general, sugieren que las preferencias "medianas" de dicha muestra pueden aproximarse razonablemente bien mediante un modelo AVAC multiplicativo, dotado de una función de utilidad potencial del tiempo de vida. Por último, para un número relativamente considerable de estados de salud, hallamos evidencia contraria a la práctica habitual de transferir las utilidades de los estados de salud del contexto de decisión en el que fueron estimadas (p.ej. un contexto de certidumbre) a otro contexto diferente (p.ej. un contexto de incertidumbre).

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Abstract

This paper applies a method, first proposed by Miyamoto (2000), to adjust health state utilities accounting for curvature of the utility function of life duration. Such a method is not susceptible to error propagation and avoids biases due to probability weighting. Group estimates obtained with the new adjustment method were, in general, consistent with previous evidence. Several axiomatic tests of the QALY model under both expected utility and rank-dependent utility were also performed. According to the results obtained from a large general population survey, it seems that a multiplicative QALY model with a power utility function for life duration may be a reasonable approximation to individual true preferences. Finally, we also found that the common practice of freely transferring health state utilities across riskless and risky contexts may be wrong for a significant number of conditions.

Keywords: biases, expected utility, rank-dependent utility, time trade-off, value lottery equivalence

Introduction

This paper is concerned with some biases that may distort both health state utility measurements and their use in subsequent applications. Throughout this manuscript a bias is intended to be as any deviation from the individual true preference. We think that the goal of elicitation methods is to discover such a true (although eventually hidden) preference (Plott, 1996). Otherwise applications based on health state utilities, such as cost-utility analyses, might lead to undesirable decisions. Imagine that an economic evaluation agency prioritizes a health programme instead of other because the former has a cost-utility ratio lower than the latter. Assume that the utilities used as inputs to calculate the ratio did not reflect the societal preferences. The result would be clearly inefficient. The National Health Service would give priority to an intervention which is less preferred by the citizens than other. For this reason it is very important to identify and correct biases.

Within the realm of health state utility measurement, sources of biases are numerous. One main source is that expected utility does not characterize preferences very well. Violations of expected utility provoke that potentially all elicitation methods under risk may lead to biased utilities. Indeed, although the deficiencies of the standard gamble (SG) method have deserved special attention (Llewellyn-Thomas et al., 1982; Bleichrodt, 2001; Oliver, 2003), a similar lack of descriptive validity has been also found for other procedures under risk (Oliver, 2005; Bleichrodt et al., 2007). The key point in all cases is that biases arise as far as it is assumed that the methods can be evaluated under expected utility. However, there is substantial evidence to show that individuals deviate from expected utility. For example, people seem to process probabilities in a non-linear way. This bias is typically called ‘probability weighting’ by both rank-dependent utility theory (Quiggin, 1982) and prospect theory (Tversky and

Kahneman, 1992), currently two of the most popular descriptive alternatives to expected utility. Wakker and Sttigelbout (1995) and Bleichrodt (2002) showed that the SG may lead to utilities biased upwards if people underweight probabilities. Bleichrodt et al. (2007) confirmed these previous theoretical analyses, concluding that other methods under risk might also be affected by probability weighting.

On the other hand, elicitation methods under certainty such as the time trade-off (TTO) do not suffer from probability weighting. Other biases, however, may affect them. The way in which TTO utilities are commonly calculated assumes that the utility function for life duration is linear. There is nevertheless a significant body of evidence showing that the utility function for life years is concave rather than linear (McNeil et al., 1978; Sttiggelbout et al., 1994; Stalmeier et al., 1996; Martin et al., 2000). This evidence would imply that TTO utilities could be biased downwards (Bleichrodt, 2002).

The bias caused by utility curvature does not affect the SG because this method imposes no restriction on the utility function for duration. Bleichrodt et al. (2007), however, showed that there are other methods under risk whose utilities are affected by utility curvature in a similar way as the TTO. Specifically, the method they called 'value lottery equivalence' (VLE) resembles the idea of a TTO framed in terms of risk. As a result of this similarity, VLE utility is in fact the same as that measured by the TTO. Therefore, utility curvature may distort utilities measured through the VLE, an elicitation procedure under risk, in the same way as the TTO method does, a technique framed under certainty. This distortion is produced because the quality adjusted life year (QALY) model is assumed. Such a model requires that the utility of living for a period of time in a health state followed by death can be computed as the product of the time period in the health state and the utility of that state. Thus, the utility function for life duration is assumed to be linear. Hereinafter, when we refer to the QALY model we will mean the linear model.

In this paper we apply a new method to adjust TTO and VLE utilities by taken into account that utility function for life duration is not linear and that individual preferences deviate from expected utility. The procedure was proposed by Miyamoto (2000), and to the best of our knowledge, it has not been used in an empirical study up to now. This method offers a balance between the advantages of parametric and nonparametric measurements of the utility function of life duration, in a similar way as recently Abdellaoui et al. (2008) have measured utility for money outcomes under prospect theory. In both cases elicitations are performed by using a small number of certainty equivalents (CEs). We only require 6 elicitations per health state. In this point the method is very similar to the common procedure used to fit the degree of curvature of the utility function of life years which is also based on CEs (Miyamoto and Eraker, 1985; Stiggelbout et al., 1994; van Osch et al., 2004). One key difference with respect to those studies, is that in our case the CEs are not linked and, hence, not prone to error propagation. Finally, other critical distinction is that we can fully evaluate the CEs under rank-dependent utility without imposing assumptions on the shape of the probability weighting function.

The two health state utility measurement methods used in this study, the TTO and the VLE, allow us to provide more insight in the question whether utilities derived from one context in which health outcomes are taken for certain (intertemporal trade-offs) can be freely applied to a decision context under risk. This is indeed a common practice in both cost-utility and medical decision analysis. As both the TTO and the VLE should lead to the same utility, any difference we observe should be attributed to the different framing of decisions. There is some previous evidence supporting the idea of a unified concept of utility (Wakker, 1994), both for health outcomes (Attema et al., 2007; Stalmeier and Bezembider, 1999) and for money outcomes (Abdellaoui et al., 2007). Notwithstanding, recent evidence (Abellan et al., 2007) suggests caution against routinely assuming that transferability of the same utility across different contexts is justified.

In addition to the new adjustment method presented in this paper, we also report the results from various nonparametric tests of the QALY model. Although previous evidence is contrary to the assumption of linear utility function of life duration, most analyses were based on expected utility. Until now, there are only two tests performed under non-expected utility. Bleichrodt and Pinto (2005) rejected the QALY model under a model consistent with rank-dependent utility, whereas Doctor et al. (2004) found support for the QALY model using a test also valid under prospect theory.

In this paper we test a very general axiom due to Miyamoto (1999), valid under rank-dependent utility, which is necessary for the linear QALY model. One contribution of this paper is that, using a very simple axiomatic condition, we confirm the conclusions previously reached by Bleichrodt and Pinto (2005) . In addition to that, we find strong nonparametric evidence consistent with a power utility function for life years. This is a relevant result since evidence from previous axiomatic tests was negative (Miyamoto and Eraker, 1989), and parametric estimations often do not find differences in goodness of fit between power and exponential models (Bleichrodt and Pinto, 2005; Abdellaoui et al., 2007). Finally, we also test a more general QALY model, in which utility curvature is allowed to change as the severity of the health status varies.

A potential weakness of most previous tests of the QALY model is that empirical studies tipycally employed a small sample-size (around fifty people) and only a few health states (two or three at best). Therefore conclusions have to be specially cautious. For example, Attema and Brouwer (2009) have recently provided further evidence that respondents indeed do not have a linear utility function for life duration. In fact, Attema and Brouwer derived the degree of utility curvature. However, because of only one particular health state (back pain) was considered, Attema and Brouwer recognize (p. 241) that "cannot exclude the possibility that different utility of life duration functions exist for different health states". Consequently, new tests performed with wider samples and health states sets would be highly advisable in order to provide more robust insight on the validity of the QALY model.

As an attempt to overcome potential drawbacks such as those we have just described, all our tests were performed for a large sample (N=656) and variety of health states (18 EQ-5D states). Moreover, unlike the common practice of testing axioms in 'controlled' environments, we surveyed general population. We hope that this large data-base provide more firm insight in the topics we have outlined above.

The structure of the paper is as follows. Section 2 provides background. Section 3 describes the elicitation methods and the tests addressed in this paper. Section 4 describes the survey. Section 5 shows the main results obtained. Section 6 concludes.

2. Background

2.1 Notation and structural assumptions

Let $(Q_1, T_1; Q_2, T_2; \ldots; Q_n, T_n)$ denote a typical health profile that yields health state Q_t for duration T_t. A health profile is reduced to a chronic health outcome if $Q_1 = Q_2 = \ldots = Q_n$. We will denote a chronic health outcome as (Q, T), where Q denotes health state and T life duration, followed by death. The durations T belong to an interval $\Phi = [0, M]$, where M is the maximum life duration, and Ω stands for the set of health states. We also consider binary prospects denoted by $((Q_1, T_1), p; (Q_2, T_2))$, yielding outcome (Q_1, T_1)

with probability p and outcome (Q_2, T_2) with probability $1-p$. If $p = 1$ or $p = 0$ the prospect is riskless, otherwise it is risky.

By $\succeq$ we denote the preference relation meaning "as least as good as" defined over the set of prospects ℓ. Strict preferences are denoted by $\succ$ and indifferences by ~. Preferences over outcomes coincide with preferences over riskless prospects.

Throughout the paper we will assume that risky prospects are rank-ordered. That is, when we write $((Q_1, T_1), p; (Q_2, T_2))$ we assume that $(Q_1, T_1) \succeq (Q_2, T_2)$. This assumption is not a restriction because each prospect can be written in this form by re-ordering the outcomes.

Let Ω^+ be the set of better-than-death health states. A health state Q_1 is *better-than-death* if $(Q_1, T_1) \succeq (Q_1, T_2)$ for every $T_1, T_2 \in \Phi$ such that $T_1 > T_2$. Given a better-than-death state, preference is an increasing function of duration (i.e., people prefer more life years to less). Let Ω^- be the set of worse-than-death health states. A health state Q_2 is *worse-than-death* if $(Q_2, T_1) \succeq (Q_2, T_2)$ for every $T_1, T_2 \in \Phi$ such that $T_1 < T_2$. Given a worse-than-death state, preference is a decreasing function of duration (i.e., people prefer less life years to more).

2.2 Expected utility and rank-dependent utility

Expected utility holds if the utility of any prospect $((Q_1, T_1), p; (Q_2, T_2))$ can be written as

$$pU(Q_1, T_1) + (1-p)U(Q_2, T_2), \tag{1}$$

where U is a real-valued function over outcomes which is unique up to positive affine transformations.

Rank-dependent utility generalizes expected utility by allowing probability weighting. Rank-dependent utility holds if the utility of any prospect $((Q_1, T_1), p; (Q_2, T_2))$ can be written as

$$w(p)U(Q_1,T_1)+(1-w(p))U(Q_2,T_2), \tag{2}$$

where U is a real-valued function over outcomes which is unique up to positive affine transformations and w is a probability weighting function which is increasing and satisfies $w(0) = 0$ and $w(1) = 1$.

Empirical evidence (Gonzalez and Wu, 1999; Abdellaoui, 2000; Bleichrodt and Pinto, 2000) suggests that the probability weighting function is typically 'inverse S-shaped' with a point of inflection, where the function changes from overweighting probabilities, i.e., $w(p) > p$, to underweighting probabilities, i.e., $w(p) < p$, lying around 0.35. Expected utility is the special case of rank-dependent utility when $w(p) = p$.

2.3 QALY models

Under the QALY model the utility of chronic health outcomes in expected utility, rank-dependent utility, and prospect theory is the following

$$U(Q,T)=H(Q)T, \tag{3}$$

where H is the utility of the health state. According to the usual scaling $H(FH) = 1$ and $U(Death) = 0$.

The non-linear QALY model generalizes the QALY model by allowing utility curvature for life duration. The non-linear QALY model may be written in two different forms, either multiplicative or nonmultiplicative. Under the multiplicative QALY model $U(Q, T)= H(Q)L(T)$, where L is the utility function of life duration. This model requires that L is independent on the health state. On the contrary, the non-multiplicative QALY model generalizes the multiplicative one by allowing utility curvature to vary as a function of health state, *i.e.*, $U(Q, T) = H(Q)L(T_Q)$, where T_Q denotes the dependence of T from Q.

We will also consider two possible functional forms for L, the exponential utility function and the power utility function. The exponential family is defined by $L(T_Q) = (e^{\alpha(Q)T} - 1)/(e^{\alpha(Q)} - 1)$ if $\alpha(Q) \neq 0$ and by $L(T) = T$ if $\alpha(Q)=0$. The power specification is defined by $L(T_Q) = T^{\beta(Q)}$. Such functional forms provide two specific non-linear models, the power QALY model and the exponential QALY model. Both models will be multiplicative if L is independent of the health state (*i.e.*, $\alpha(Q)= \alpha$, $\beta(Q)= \beta$, and in consequence $L(T_Q)$ reduces to $L(T)$). Otherwise models will be nonmultiplicative.

Hereinafter we will assume that the utility of health profiles, whatever the QALY model is assumed, can be calculated as the sum over disjoint periods of the utilities of the constituent outcomes (Q, T).

3. Elicitation methods and tests

3.1 Elicitation methods and the adjustment for utility curvature of life duration

In our survey, described in Section 4, we elicited preferences from respondents by means of three methods: the TTO, the VLE, and the CE. The framing of the TTO and the VLE varied depending on the respondent preferred more (less) years to less (more). In the case of the CE, however, the framing was the same irrespective the health state was regarded as better or as worse than death. In what follows, first we analyze TTO and VLE methods under expected utility and rank-dependent utility, and then we analyze CE questions consider non-linear utility of life. This allows for adjusting TTO and VLE utilities for the degree of curvature of the utility function for life duration.

If Q is regarded as better tan death (*i.e.*, $Q \in \Omega^+$) the TTO method asks for the duration T_{TTO} that leads to indifference between the outcome (FH, T_{TTO}) and the outcome *(Q, T)*. On the contrary, if Q is regarded as worse than death (*i.e.*, $Q \in \Omega^-$) the TTO method asks for the duration T^*_{TTO} that leads to indifference between the outcome $(Q, T\text{-}T^*_{TTO}; FH, T^*_{TTO})$ and Death, where *FH* stands for full health.

As the TTO is a method framed in terms of certainty, as long as utility is not context-dependent (*i.e.*, utility remains the same irrespective decisions are framed under risk or under certainty), evaluation of indifferences will be the same regardless we assume expected utility or rank-dependent utility. This means that, for better-than-death states, the TTO is evaluated as $U(FH, T_{TTO}) = U(Q, T)$, and for worse-than-death states $U(Q, T\text{-}T_{TTO^*}; FH, T) = U(Death)$ follows.

If $Q \in \Omega^+$ the VLE method asks for the duration T_{VLE} that leads to indifference between the risky prospect $((FH, T_{VLE}), p; (Death))$ and the risky prospect $((Q, T), p; Death)$. If $Q \in \Omega^-$, then the VLE method asks or the duration T^*_{VLE} that leads to indifference between the risky prospect $((FH, T^*_{VLE}), p; (Death))$ and the risky prospect $((FH, T), p; (Q, T))$.

Indifferences reached through the VLE, when $Q \in \Omega^+$, are evaluated under expected utility as

$$pU\left(FH, T_{VLE}\right) + (1-p)U\left(Death\right) = pU\left(Q, T\right) + (1-p)U\left(Death\right) \tag{4}$$

In case that $Q \in \Omega^-$, indifferences ensured by the VLE are evaluated under expected utility as

$$pU\left(FH, T^*_{VLE}\right) + (1-p)U\left(Death\right) = pU\left(FH, T\right) + (1-p)U\left(Q, T\right) \tag{5}$$

Under rank-dependent utility, probability weights depend on the rank order of the outcomes. This has been made operative by attaching probability weight w to the best outcome of the prospect. Therefore, evaluations under rank-dependent utility will be different depending on Q is considered as better or as worse than death. In the case of questions made by the VLE for $Q \in \Omega^{+}$, as (FH, T_{VLE}) $\succ$ (Q, T) $\succ$ Death, we have

$$w(p)U(FH,T_{VLE})+(1-w(p))U(Death)=w(p)U(Q,T)+(1-w(p))U(Death) \quad (6)$$

In the case of the VLE for $Q \in \Omega^{-}$, then (FH, T) $\succ$ (FH, T^{*}_{VLE}) $\succ$ Death $\succ$ (Q, T), so we have

$$w(p)U(FH,T^{*}_{VLE})+(1-w(p))U(Death)=w(p)U(FH,T)+(1-w(p))U(Q,T) \quad (7)$$

As noted in the Introduction, Miyamoto (2000) proposed a new method to adjust TTO utilities for the bias caused by utility curvature of life duration. We also apply this method to adjust VLE utilities. The procedure consists of two stages. In the first stage the curvature parameter is estimated from a series of CE questions. In the second stage the previous estimate is used to construct health state utilities.

Consider first elicitations of preferences towards life duration by means of a sequence of six independent CE questions. In each of these questions the *CE* method asks for the duration T_{CE} that leads to indifference between the outcome (Q, T_{CE}) and the risky prospect $((Q, T_1), p; (Q, T_2))$. Assume that durations T_1 and T_2 are varied across the six CE questions. In this way we obtain finally six different certainty equivalents T_{CE}.

Under expected utility, indifferences with the CE method are evaluated as

$$U(Q,T_{CE})=pU(Q,T_1)+(1-p)U(Q,T_2) \quad (8)$$

Under rank-dependent, if $Q \in \Omega^{+}$, then $T_1 \succ T_2$, and indifferences are evaluated according to

$$U(Q,T_{CE})=w(p)U(Q,T_1)+(1-w(p))U(Q,T_2) \quad (9)$$

On the contrary, if $Q \in \Omega^{-}$, then $T_1 \prec T_2$, and indifferences are evaluated as

$$U\left(Q,T_{CE}\right)=\left(1-w\left(1-p\right)\right)U\left(Q,T_{1}\right)+w\left(1-p\right)U\left(Q,T_{2}\right) \tag{10}$$

Consider now the power nonmultiplicative QALY model, in such a way $U(Q, T) = H(Q)\, T^{\beta(Q)}$. This model and Equation (8) imply that

$$T_{CE}=\left(pT_{1}^{\beta(Q)_{EU}}+\left(1-p\right)T_{2}^{\beta(Q)_{EU}}\right)^{1/\beta(Q)_{EU}} \tag{11}$$

Parameter $\beta(Q)_{EU}$ is then estimated at individual level by nonlinear regression. If now assume the validity of rank-dependent utility, we have two different equations as the health state is regarded, respectively, as better or as worse than death:

$$T_{CE}=\left[w\left(p\right)T_{1}^{\beta(Q)_{RDU}}+\left(1-w\left(p\right)\right)T_{2}^{\beta(Q)_{RDU}}\right]^{1/\beta(Q)_{RDU}} \tag{12}$$

$$T_{CE}=\left[\left(1-w\left(1-p\right)\right)T_{1}^{\beta(Q)_{RDU}}+w\left(1-p\right)T_{2}^{\beta(Q)_{RDU}}\right]^{1/\beta(Q)_{RDU}} \tag{13}$$

As before, these equations can be solved by nonlinear regression for estimates of $\beta(Q)_{RDU}$ and w. It is well worth noting that with this procedure we do not need to estimate the whole probability weighting function, but only its value for one particular probability value p. Since it is convenient to use easily perceived values of probability (Bleichrodt and Schmidt, 2002) we fixed $p = 0.5$ in our measurements.

If the probability weighting function corresponds to a typical inverse S-shaped, in such a way that probabilities above 0.35 are underweighted, Equation 12 with $w(p) = w(0.5)$, implies that $\beta(Q)_{RDU} > \beta(Q)_{EU}$. On the contrary, the same inverse S-shaped predicts for Equation 13 with $w(p) = w(0.5)$ that $\beta(Q)_{RDU} < \beta(Q)_{EU}$. The fact that power coefficients estimates differ under the two utility theories, is a consequence from that under rank-dependent utility risk attitude is not longer only reflected by the curvature of the utility function of life duration (Wakker and Stiggelbout, 1995). If $w(0.5) < 0.5$, then the subject is underweighting the probability of the best outcome (*i.e.*, he/she is behaving as a pessimistic), thus allowing the concavity of the utility function of life duration to be lower than under expected utility[1]. Indeed as Abdellaoui et al. (2008) showed if underweighting of probability is strong enough then risk aversion can co-exist with linear or even convex utility.

Once $\beta(Q)_{EU}$ and $\beta(Q)_{RDU}$ have been estimated, TTO utilities can be adjusted accordingly. The same can be done for VLE utilities, but now, if rank-dependent utility is assumed, the estimate of $w(0.5)$ is required as well.

The different expressions for $H(Q)$ under three alternative paradigms (*i.e*, combinations of utility theory and QALY model) are shown in Table 1. The first row of the table shows the expression for $H(Q)$ under expected utility and the QALY model (assuming linearity in the utility function of life years). When validity of the nonmultiplicative power QALY model is assumed, we obtain the other two cases displayed in the table. The three combinations are referred in the table as 'EU-linear', 'EU-power', and 'RDU-power' for short. The multiplicative case follows from assuming that $\beta(Q)= \beta$ for any Q, and hence it is not displayed in the table. For the sake of brevity, Table 1 does not provide the expressions for the exponential specification either.

[Insert Table 1 about here]

As it is well-known, the TTO for worse-than-death states produces negative utilities which have not a lower bound. Such "raw" utilities are commonly rescaled (e.g., Dolan, 1997) in such a way that health state utilities lie between –1 and +1. The expressions depicted in Table 1 for the TTO have been scaled in that way. On the contrary, the VLE for worse-than-death states leads directly to utilities ranging between –1 and +1. This is an interesting property of the VLE method, since the scale

[1] Note that concavity (convexity) requires that the value for β is different depending on the utility function for life duration is strictly increasing or strictly decreasing. This implies that if $Q \in \Omega^+$ then concavity (convexity) requires that $\beta < 1$ ($\beta > 1$). On the contrary, if $Q \in \Omega^-$, then concavity (convexity) requires that $\beta > 1$ ($\beta < 1$).

transformation employed with the TTO produces bounded values but, as it has been recognized (Patrick et al., 1994), such rescaled valuations are no longer “true” cardinal utilities.

3.2 Axiomatic tests

It is apparent that expressions displayed in Table 1 for the TTO and the VLE are coincidental for better-than-death states. This identity is derived from the fact that the TTO is a monotonic transformation of the VLE. The VLE assigns the same probability p to the most desirable outcome in the two risky prospects which are compared. If $p = 1$ then the TTO arises. In consequence, unless the framing matters, the utility for a given better-than-death state should be the same in the two methods, since the answers to questions asked by both methods should indeed be the same. Therefore, the comparison between TTO and VLE utilities serves as a test of the assumption of transferability of utility across riskless and risky contexts. Written in a formal way:

Test 1: Transferability: utility is transferable across the TTO and the VLE if

$(FH, T_{TTO}) \sim (Q, T)$ then $((FH, T_{VLE}), p; (Death)) \sim ((Q, T), p; Death)$.

This test is a specification of a more general preference requirement known as ‘stochastic dominance’, *i.e.*, if $p > q$ and $(Q_1, T_1) \succ (Q_2, T_2)$ then $((Q_1, T_1), p; (Q_2, T_2)) \succ ((Q_1, T_1), q; (Q_2, T_2))$.

The same test cannot be performed for worse-than-death states, since the TTO method in that case is not a monotonic transformation of the VLE (i.e., we cannot derive the TTO from the VLE increasing the probability of the most desirable outcome).

The assumption of linear utility of life duration is the key assumption of the QALY model. Miyamoto (1999) showed that a condition called ‘constant proportional coverage’ implies the QALY model under expected utility and rank-dependent utility. Doctor et al. (2004) showed that the same condition can serve to characterize the QALY model under prospect theory. The reader is referred to Doctor et al.'s article to know such condition.

Miyamoto (1999) defined a 50/50 certainty equivalent as the duration T_{CE} for which the decision-maker is indifferent between the outcome (Q, T_{CE}) and the risky prospect $((Q, T_1), 0.5; (Q, T_2))$. Miyamoto also showed that, instead of constant proportional coverage, the following condition based on 50/50 certainty equivalent questions (which is our second test) can be also used to characterize the QALY model:

Test 2: Linearity. 50/50 certainty equivalents cover a constant proportion of the lottery range if

$(Q,T_1) \sim ((Q,T_2),0.5;(Q,T_3))$ *and* $(Q,T_1') \sim ((Q,T_2'),0.5;(Q,T_3'))$ *then* $(T_1 - T_3)/(T_2 - T_3) = (T_1' - T_2')/(T_2' - T_3')$.

The proportions described in Test 2 correspond to a general form which can be written as $(CE - Low)/(High - Low)$, where *Low* stands for the lower duration in the risky prospect (*e.g.*, T_3) and *High* stands for the higher duration (*e.g.*, T_2). This type of proportion was called a 'proportional match' (PM) by Miyamoto and Eraker (1988). From now on, we will refer to them by using such a term.

The same 50/50 certainty equivalents involved in Test 2 can be used to test the validity of the multiplicative QALY model. Miyamoto (1999) provided the following condition to get that:

Test 3: Multiplicativity. 50/50 certainty equivalents are invariant under same valence changes in health state if

$(Q_1, T) \sim ((Q_1, T), 0.5; (Q_1, T))$ *iff* $(Q_2, T) \sim ((Q_2, T), 0.5; (Q_2, T))$.

As Miyamoto (1999) argues our Test 3 is incompatible with a QALY model that permits changes in utility curvature. Therefore, if Test 3 is falsified, then a non-multiplicative QALY model is required.

Finally, we will consider other two conditions, which serve to discriminate between an exponential and a power specification for the utility function of life duration. As it is well known (Keeney and Raiffa, 1976) the former is characterized if constant risk posture is satisfied, whereas the latter requires constant proportional risk posture. Such conditions constitute our tests 4 and 5.

Test 4: Exponential utility function. Preferences for risky prospects over health outcomes satisfy constant risk posture if

$$(Q,T_1)\succeq((Q,T_2),0.5;(Q,T_3)) \text{ iff } (Q,T_1+t)\succeq((Q,T_2+t),0.5;(Q,T_3+t))$$

Test 5: Power utility function. Preferences for risky prospects over health outcomes satisfy constant proportional risk posture if

$$(Q,T_1)\succeq((Q,T_2),0.5;(Q,T_3)) \text{ iff } (Q,T_1\times t)\succeq((Q,T_2\times t),0.5;(Q,T_3\times t))$$

The CE questions we used in the survey are of type 50/50 (i.e., p = 0.5), just which is required to perform tests 2 and 3. Constant risk posture and constant proportional risk posture do not require necessarily that $p = 0.5$, but only that p is the same across the indifferences. In our case $p = 0.5$ in order to be able to test the four tests together and to make easy the estimation of the utility curvature for life duration.

A restriction that non-expected utility imposes to use the conditions described above for testing the QALY model, is that such conditions have to be applied in a separate way to better and worse than death states. This constraint is a consequence that the rank-order of the outcomes varies as a function of that the health state is better or worse than death (see Equations 9-10).

4. Survey

4.1 Subjects

The sample included 720 adult people living in the Autonomous Community of Andalusia. Age and gender quotas were imposed to ensure that the sample was representative of the Spanish general population. The sample was split into nine balanced subsamples (N=80 each), maintaining representativeness inside them. The survey was conducted over a period of three months (October-December of 2008) and all the interviews took place in Sevilla.

4.2 Procedure

The survey consisted of a computer assisted questionnaire. All the interviews were run on laptop computers. Responses were collected in personal interview sessions. Average time per interview was about 20 minutes.

The questionnaire was organized in five sections. Sections 1, 3, and 5 were identical for all the respondents. Nevertheless, order in which sections 2 and 4 were presented to subjects varied at random from one interview to another. Such sections contained the questions required to measure health state utilities with the TTO and the VLE. Hence, some respondents first answered TTO questions (section 2) and then VLE questions (section 4), whereas for the remaining respondents the order was reversed. The duration used as stimulus in both methods (*i.e.*, T in Table 1) was 10 years. Appendix 1 provides some illustrations of the questions.

Section 1 described the 18 EQ-5D health states (Table 2) for which preferences were elicited. This set of health states provides enough variability to encompass a wide range of conditions. Each of the nine subsamples valued two health states, anonymously labelled as X and W, respectively. They were assigned in such a way that health state X was always logically better than state W. Respondents were asked to score both health states by a visual analogue scale (VAS). This task was only included in order to help people to familiarize with the health states.

[Insert Table 2 about here]

Section 3 administered the six unchained CE questions required to account for utility curvature of the utility function for life years and also for testing QALY models. The prospects for which we determined the certainty equivalents are displayed in Table 3. Section 5 collected some sociodemographic characteristics (gender, age, educational level, income level, etc.) from subjects.

[Insert Table 3 about here]

The three methods applied (TTO, VLE, and CE) elicited preferences through a sequence of choices. The use of choice-based mechanisms in order to find the respondent's indifference value is supported by two basic reasons. First, individual's choices are the primitive of utility theory, being the basis of decision theory. Second, prior research by Bostic et al. (1990) showed that a choice-based procedure was more consistent with simple choices than matching-based procedures. Both reasons support the determination of indifferences through choices, as it is indeed done in many health state utility measurements (Lener et al., 1998). Besides, choice-based procedures are commonly implemented in a 'transparent' way, that is, respondents are aware that the aim of the whole sequence of choices is to produce indifference. However, as Fischer et al. (1999) showed, the more transparent the choice-based procedure is the larger the discrepancy with respect to simple choices is. The discrepancy vanished when the aim of the choice-based procedure remained 'hidden' to subjects, as indeed occurred with the choice-based procedure used by Bostic et al. (1990). Braga and Starmer (2005) argued in similar terms in favour of using opaque choice-based procedures in order to avoid preference reversals in cost-benefit analysis.

Previous discussion motivated that we used a non-transparent choice-based procedure. Specifically, we used the parameter estimation by sequential testing (PEST) procedure to elicit preferences (Luce, 2000). This routine inserts filler questions generated at random, forcing the respondent to evaluate each choice "as if" it was independent from the rest of the sequence, and only converges to an indifferent point when the responses become consistent (for details, see Appendix 2). To the best of our knowledge, the only study related to the topic of this paper in which the PEST has been applied, was the experiment conducted by Bleichrodt et al. (2005).

4.3 Analysis

We classified the respondents according to different criteria. First of all, for a given health state, we identified those subjects who regarded it as better than death. In the same way, we also identified those subjects who assessed the same health state as worse than death. Henceforth, we will use the expressions better-than-death subjects and worse-than-death subjects for referring to these two groups of respondents.

Afterwards, we classified both better and worse than death subjects according to their attitudes towards risk. For better-than-death subjects, in order to account for response error, we classified a subject as risk averse (risk seeking) if the certainty equivalent in at least 4 out of 6 CE questions was lower (higher) than the expected value of the risky prospect. For worse-than-death subjects, the classification of a subject as risk averse (risk seeking) was the same except that now the certainty equivalent had to be higher (lower) than the expected value of the prospect. Risk neutrality required in both cases that the certainty equivalent was equal to the expected value of the prospect.

Finally, estimates for the curvature coefficient of the utility function of life duration obtained through nonlinear least squares served to classify the respondents according to the shape (concave, convex, linear) of such a utility function. This was only done under rank-dependent utility, since under expected utility there is a one-to-one relationship between risk attitude and shape of the utility function. For the power function, this classification implies that a subject was classified as concave (convex, linear) for better-than-death health states if the corresponding power estimate was less than 0.95 (was greater than 1.05, was between 0.95 and 1.05). Worse-than-death subjects were classified in the opposite way: concave (convex) utility required that the power coefficient was larger than 1.05 (was less than 0.95). Health state utilities were computed for each subject according to the formulas shown in Table 1.

QALY assumptions were tested by using two different non-parametric tests, namely, the Wilcoxon signed-rank test and the Friedman test. A significance level of 10% was used in all cases..

The nonparametric Wilcoxon signed-rank test served to test for significance of differences between responses given to the TTO and the VLE for a given health state, within each subsample. This was the way in which the assumption of transferability (Test 1) was tested. As noted in Section 3, the test was restricted to better-than-death states.

The nonparametric Friedman test was used to test for significance of differences among the proportional matches based on the twelve certainty equivalents that each respondent provided. In such a way we checked whether the QALY model is linear (Test 2). Notice that in this test we did not separate health state X from health state W because linear utility function for life duration implies that preferences for life duration are independent from severity of the health state. The test was performed, on the one hand, with those respondents who regarded both state X and state W as better than death and, on the other, with those respondents who considered states X and W as worse than death.

The assumption of multiplicativity (Test 3) was examined at the individual level. The nonparametric Wilcoxon signed-rank test was used to test for significance of differences between the six certainty equivalents elicited for health state X and the six ones elicited for state W for each respondent. Next we computed the percentage of subjects for which we could not reject the null hypothesis of equality between CEs. All these comparisons were performed separating respondents who regarded both health states as better than death from those who regarded the states as worse than death.

Note that the outcomes included in Table 3 allow for testing the functional form of the utility of life duration (Tests 4 and 5). For example, since outcomes of prospect 3 follow from adding two years to outcomes of prospect 2, and outcomes in the latter follow from adding the same amount to outcomes belonging to prospect 1, two tests of constant risk posture (Test 4) result. Prospects 1 and 3, 4 and 5, and also 5 and 6, can be also compared in a similar way. In short, we have five tests of constant risk posture per health state as a result of comparing the following proportional matches: PM1 vs PM2, PM2 vs PM3, PM1 vs PM3, PM4 vs PM5, and PM5 vs PM6, where the subscript denotes the prospect concerned according to numeration used in Table 3. Constant proportional risk posture (Test 5) was tested by comparing the following proportional matches for each health state: PM1 vs PM4, PM3 vs PM6, and PM2 vs PM5. Again, we performed the tests keeping apart people who regarded a health state as better than death from those who regarded the same state as worse than death.

5. Results

5.1 Sample

Observations from 656 subjects were finally used in the data analysis. Sixty four individuals were excluded because of various types of inconsistencies. Firstly, thirty-four participants assigned higher valuations to the health state W than to the state X (remember that all pairs of health states can be logically rank ordered). Six out of those thirty-four were inconsistent in their VAS valuations, thirteen in the TTO responses and the fifteen remaining in the VLE task. On the other hand, thirty individuals who had regarded one of the health states as worse than death with one of the methods applied (TTO, VLE, and CE), considered the same state as better than death with another method. This type of 'preference reversal' occurred between TTO and VLE for thirteen individuals, and between CE and one of the two mentioned for the other seventeen subjects. The main characteristics of the final sample are shown in Table 4. The representativeness of the sample was hardly affected as a result of the exclusions.

[Insert Table 4 about here]

5.2 Risk attitude towards life years in better and worse than death health states

Table 5 classifies the respondents in terms of their risk attitude. As it was expected, there were quite a lot more respondents regarding health state W (the more serious condition) as worse than death (315) than those who considered health state X as less preferred to death (8). Only four of the X states (*i.e.,* 11113, 11131, 13212, and 11312) contained some worse-than-death subject, with a maximum of 3 worse-than-death subjects for state 13212. On the contrary, all the W states included some worse-than-death respondent (the minimum was 3 subjects for health state 13311).

[Insert Table 5 about here]

Table 5 shows a twofold pattern of risk attitudes. Better-than-death respondents mostly exhibited risk aversion (concave utility under expected utility), whereas worse-than-death subjects behaved as risk seekers (convex utility under expected utility). The only exception to this rule occurs with the health state 32223, for which the reverse pattern is found. It is interesting to notice that this twofold pattern resembles previous evidence in the domain of money, where various studies (Fishburn and Kochenberger, 1979, Pennings and Smidts, 2003) have found concave utility for positive outcomes (or gains) and convex utility for negative outcomes (or losses), under expected utility. This similarity could suggest that the zero duration (or the death) may act as a threshold, thus making that the same life duration is perceived as a positive duration (a gain) or a negative duration (a loss) according to the severity of the health state. It has to be emphasized that this phenomenon of 'sign-dependence' should be viewed as an indication of a multiplicative relationship between duration and health status (Miyamoto, 1999) rather than as an expression of some type of 'maximum endurable time' (Sutherland et al., 1982). Maximum endurable time is an example of non-monotonic preferences for life duration, which is different from the coexistence of better and worse than death health states.

5.3 Axiomatic tests

The assumption of transferability (Test 1) holds for eleven of the eighteen states. That is, for these health states, the hypothesis of equality in the responses given to the TTO and the VLE methods cannot be rejected. Nevertheless, there are seven states (more than one third) for which TTO and VLE valuations significantly differ (Wilcoxon signed-rank test, $p < 0.0001$). Most of these health states (6 out of 7) could be labeled as 'moderate' or 'severe', according to the classification that Dolan (1997) coined when modeling the EQ-5D system. Thus, although transferability seems to be an acceptable assumption for the majority of health states used in this study, this does not hold for a significant percentage (around 39%) of the selection. This evidence suggests that the common practice of using TTO utilities to make decisions under risk is not probably right in all the cases.

As noted in Section 3.1, under rank-dependent utility assumptions it is necessary to distinguish between better-than-death and worse-than-death health states because probability weights are dependent on the rank order of the outcomes. Therefore we have to set apart both domains, Ω^+ and Ω^-, in order to test QALY assumptions. As there were only eight respondents who regarded both health state X and health state W as worse than death[2], we opted for omitted them from the tests of linearity (Test 2) and multiplicativity (Test 3) assumptions. Since the tests of constant (Tests 4) and proportional risk posture (Test 5) were performed at health state level we had not to restrict our attention to subjects who regarded X and W together as better or as worse than death health states. We only removed from these tests the same eight respondents as before.

The non parametric Friedman test rejects the assumption of linearity for the utility function of life in five out of nine subsamples displayed in Table 2 (groups 1, 2, 3, 4, and 7). This encompasses almost 75% of better-than-death subjects (249/341). Hence we find a broad rejection to the assumption of linear utility for life years under both expected utility and rank-dependent utility. Conversely, multiplicativity (Test 3) is strongly supported at individual level. Wilcoxon signed-rank tests suggest that the null hypothesis (equal distributions of CEs for X and for W) cannot be rejected for the 91.40% of the better-than-death respondents (319/341). This finding is consistent with the idea noted in Section 5.2 about that better and worse than death health states are examples of diagnostic of a multiplicative QALY model.

[2] These subjects are the eight respondents that valued states type X 11113, 11131, 13212, and 11312 as worse than death. The same subjects regarded the corresponding states type W 32223, 23232, 33333, and 33323 in the same way.

Finally, we found that proportional risk posture clearly outperformed constant risk posture. Overall, the proportional risk posture assumption is not rejected in 68 out of 81 possible comparisons (83.95%) of the PMs, with percentages for better-than-death and worse-than-death subjects of 85.19% and 81.48%, respectively. On the contrary, we only found support to the hypothesis of constant risk attitude in 62 out of 135 possible comparisons (45.93%). In this case, percentages were 44.44% for better-than-death subjects and 48.89% for worse-than-death subjects. Therefore, we found strong nonparametric evidence consistent with a power specification for the utility function of life years. Thus, we will assume in the following this functional form in order to account for utility curvature of life duration in the calculations of health state utilities.

5.4 Health state utilities under expected utility and linear QALY model

Table 6 shows median utilities for the 18 health states obtained under the same three paradigms which were previously considered in Table 1, *i.e.*, expected utility and linear QALY model (EU-linear), expected utility and power QALY model (EU-power), and rank-dependent utility and power QALY model (RDU-power).

[Insert Table 6 about here]

The inspection of the results for ‘EU-linear’ reveals that the highest median value corresponds to the EQ-5D health state 11112 (H_{TTO}=0.9167 and H_{VLE}=0.9083). The worst valued state is the ‘pits state’ (33333), with median utilities of –0.3333 for VLE and –0.8125 for TTO method. It is noticeable that there are no logical inconsistencies between median values. That is, considering the 73 pairs of health states which can be logically compared one to each other (e.g., 11112 *vs* 11113), the logically better state has been valued higher than the logically worse one, for both TTO and VLE methods. Differences arise, however, when both type of utilities are compared within each health state. We found significant differences for the half of the health states. Most the differences concern states type W (all of them except for state 22222 and state 32223). States type X 12111 and 13212 have to be added to the seven remaining states type W. Notice, however, that this comparison is done for the whole sample, without distinguishing between better and worse than death subjects. When such distinction is made, we obtain for better-than-death subjects the same results that we found when the assumption of transferability was tested.

5.5 Health state utilities under expected utility and power QALY model

We assumed a power specification to calculate health state utilities by relaxing the assumption of linear utility function for life duration. Two power coefficients were estimated for each subject, one for each of the health states (X and W) they assessed. In the case of EU-power, the overall median estimate for the power coefficient was 0.638. At health state level, all the median estimates were below 1, except for health state 32223 whose estimate was significantly above the unity. Median estimate for better-than-death subjects was of 0.61, whereas the one for worse-than-death subjects was of 0.747. These estimates predict concavity and convexity respectively, since they are using in different domains (positive the first, negative the second) of the utility plane. Therefore, in agreement with previous evidence assuming expected utility (*e.g.*, Stiggelbout et al., 1994) we find strong support for concave utility of life duration in the domain of better-than-death health states. The finding of a mean estimate predicting convexity for worse-than-death subjects is consistent with the results described previously in Table 5. The calculation of health state utilities assuming individual estimates for the power utility function of life years yielded a new set of values for TTO and VLE, as it can be seen in column 'EU- power' in Table 6.

Most of the new TTO utilities significantly differ from those calculated under 'EU-linear'. Only for health states 32223, 32313, and 33323 differences remained non-significant. A similar finding arises for VLE utilities, sharing the three previous states plus health state 23232. It is apparent then that, under expected utility, the largest discrepancies between linear and power utilities emerged for mild and moderate health states above all. When TTO and VLE utilities are compared, once they have been adjusted by utility curvature, we found a very similar result that that was obtained under 'EU-linear'. Discrepancies hold for the same health states as for 'EU-linear' except for states 11133 and 33323 for which now there is no significant difference.

5.6 Shape of the utility function of life duration and probability weights

Table 7 shows the classification of the subjects based on the individual power coefficients estimated under rank-dependent utility. The dominant pattern was concave utility for better-than-death subjects and convex utility for worse-than-death subjects. Hence, the general pattern remains the same as it was under expected utility.

[Insert Table 7 about here]

However, if Table 7 is compared with Table 5 we then obtain some indication that the equivalence between risk aversion and concave utility under rank-dependent is not so straightforward as under expected utility was. For health states type X, the proportion of better-than-death respondents with convex and mixed utility was significantly higher than that for risk lovers and risk neutrals subjects in Table 5 (31.4% *vs* 12.81%). There was also a minor variation in health state W, but it was not significant. For worse-than-death respondents, the number of subjects with convex and linear utility was also larger than under expected utility (in the case of the health state

W). As only eight respondents regarded state X as worse than death, the comparison between the two tables does not reveal any relevant change.

The different proportions found under each utility theory, may in principle be attributed to the fact that under rank-dependent utility the probability weight reflects part of the risk attitude that under expected utility is completely encapsulated in the utility function. The impact of probability weighting, however, is not enough powerful as to reverse the modal pattern from expected utility to rank-dependent utility, except for one of the health states. In the case of state 32223, a reversion of preferences occurs, in the sense that although better-than-death (worse-than-death) subjects are risk seekers (risk averse) they have concave (convex) utility under rank-dependent utility. To the best of our knowledge, this is the first time that the coexistence of risk seeking (risk aversion) and concave (convex) utility has been found for health outcomes. Abdellaoui et al. (2008) recently reported similar evidence with money outcomes.

Overall median estimate for the power coefficient under rank-dependent utility (β_{RDU}) is 0.784, with median *w(0.5)* equals to 0.444. Therefore, although our data do not provide information on the whole probability weighting function, but only for the specific probability value of $p=0.5$, our overall estimate for *w(0.5)* is consistent with an inverse S-shaped probability weighting function, in a similar way that Abdellaoui et al. (2008) found for money outcomes. Median estimates of β_{RDU} for better-than-death and for worse-than-death subjects were respectively 0.786 and 0.782. Both median estimates exceed those obtained under expected utility, above all the former.

Since the probability weights are dependent on the rank order of outcomes, it is interesting to realise how median estimates for *w(0.5)* behave when better and worse than death subjects are separated. Remember (Section 3.1) that underweighting of $p=0.5$ leads to a different prediction on the relationship between β_{EU} and β_{RDU}

according to the assessment of the health state as better or worse than death. When attention is restricted to better-than-death subjects, we found that the median estimate for *w(0.5)* was 0.43. Hence, in broad terms, it seems that because of the underweighting of *p=0.5*, the analysis of data under expected utility leads to overestimate the concavity of the utility function for life duration ($\beta_{EU}=0.61 < \beta_{RDU} = 0.786$). This lower concavity under non-expected utility is broadly consistent with the findings reported by Bleichrodt and Pinto (2005).

The picture was rather different for worse-than-death subjects. In this case, there was hardly evidence of probability transformation of *p=0.5* in terms of the median estimate. Notwithstanding, this aggregate finding hides substantial variability at individual level, as it is usual in empirical exercises in which group estimates are calculated as a median or average of the subjects' estimates. In this study, variability means that we found some less of one-third of worse-than-death respondents whose probability weight was above 0.5, whereas the contrary, *i.e.*, $w(0.5)<0.5$, can be held roughly for the half of the sample. The net effect of these opposite forces is that the median transformation of *p=0.5* is approximately linear. For this reason, the median power coefficient estimated under rank-dependent for worse-than-death subjects is much closer to that obtained under expected utility ($\beta_{EU}=0.747$ and $\beta_{RDU} = 0.782$).

The previous finding apparently contradicts the assumption of an inverse S-shaped probability weighting function with a point lying between 0.3 and 0.4 for which the function changes from overweighting probabilities to underweighting probabilities. To test the robustness of this result, and taking into account that there were less worse-than-death subjects than better-than-death subjects, we recalculated the median estimate for *w(0.5)* only for those health states in which there had forty or more worse-than-death respondents (*i.e.*, states 23232, 32223, 32313, 33323, and 33333). The resulting estimate (0.47) suggested small but significant underweighting (*p*=0.03), being coherent with the typical form of the probability weighting function. This finding suggests that in those health states in which there were less worse-than-death subjects, there was overweighting of probability.

5.7 Health state utilities under rank-dependent utility and power QALY model

The health state utilities estimated under 'RDU-power' are also shown in Table 6. Median values are for the most part significantly different from those obtained under expected utility, but the ranking of the health states remains widely unchanged. The pattern previously described for expected utility is now intensified under rank-dependent utility: the difference between linear and power utilities is significant for all the health states except for the state 32313 (for TTO utilities) and the state 23232 (for VLE utilities). The picture hardly changes when TTO utilities calculated under 'EU-power' and 'RDU-power' paradigms are compared each other. There are only two states for which no significant difference is found (32313 and 33323) for the TTO method. The same can be stated for VLE utilities: we cannot reject the hypothesis of null differences for three health states (23232, 32223, and 32313). When both elicitation methods are directly compared, we find that the number of health states for which there are significant differences falls from nine to seven, with respect to 'EU-power' and 'EU-linear'. Such health states are the following: 12111, 13212, 13311, 23232, 32211, 33323, and 33333.

6. Discussion

We set five main objectives in the introduction of this manuscript. First of them was the aim of applying a new method to account for curvature of the utility function of life duration in order to adjust health state utilities. Bleichrodt and Pinto (2006) stated that the utility function for life years "can generally be approximated to a reasonable degree by performing five to six preference measurements". The method employed in the study reported in this paper, and first proposed by Miyamoto (2000), used six certainty equivalence questions to get that "reasonable approximation". Such a procedure has the advantages of not being susceptible to error propagation, and to avoid biases due to probability weighting, one of the main deviations from expected utility.

Group estimates obtained with the new adjustment method were, in general, consistent with previous evidence, since that better-than-death subjects (those with an increasing utility function of duration) exhibited concave utility for both expected utility and rank-dependent utility, the two theories considered in this paper. As it was expected, the estimate for the power coefficient was significantly higher for rank-dependent utility than for expected utility. This finding confirms previous parametric estimations performed by Bleichrodt and Pinto (2005) under rank-dependent utility. In fact, the median estimate obtained in the present study was very similar to those estimated by them. Apart from that, although the procedure applied is not intended to estimate the probability weighting function, the median estimate for probability $p=0.5$ is broadly consistent with an inverse S-shaped probability weighting function.

The second aim of this paper was to provide evidence on the validity of a common practice in economic evaluation of health programmes, consisting in freely transferring utilities derived from a riskless context to a decision context under risk. This is indeed an assumption underlying a so extensively used multiattribute system as the EQ-5D is. The assumption of transferability has been tested before (Bleichrodt and Johannesson, 1997; Abellan et al., 2007) by using the time trade-off and the standard gamble methods. Both studies provided some evidence against the validity of transferability. Other studies, employing different elicitation methods (*e.g.*, Stalmeier and Bezembinder, 1999) have found evidence supporting the idea of a 'unified' concept of utility. The test reported in this paper is, in some respect, more demanding than the previous ones. We used an elicitation method framed in terms of risk (called value lottery equivalence) which is a monotonic transformation of the time trade-off. As the framing of the time trade-off and the framing of the value lottery equivalence are similar, discrepancies between the indifference responses elicited by the two methods are more troublesome than those which could be obtained between the time trade-off and the standard gamble. Our data show that transferability was violated for seven out of eighteen possible health states. This finding suggests that, although transferability may work in many cases, it may be also violated by a significant number of people. Thus, our results claim cautious in transferring utilities across riskless and risky contexts.

The three last issues focused on in this paper concerning the validity of three assumptions of the QALY model. Our findings are straightforward for the three tests we performed. Linearity of the utility function for life duration is firmly rejected by testing a very simple axiomatic condition, not previously tested yet. Hence, this finding adds to the previous one due to Bleichrodt and Pinto (2005) by using a different test and a quite a lot larger sample than they used. Therefore, hope for the linear QALY model only remains in the realm of prospect theory (Doctor et al., 2004). On the contrary, the property of multiplicativity (that is, that utility curvature is independent on the severity of the health status) is widely supported by our data. It has to be noted, however, that we only performed within-subject tests of multiplicativity. Hence, we cannot discard that differences may exist among curvature parameters estimated from different samples. Finally, we found strong support to a power specification for the utility function of life duration. Previous evidence (Miyamoto and Eraker, 1989) by testing the same assumption as ours (proportional risk posture) was negative, which may be related to the scarce sample size used.

The fact that this study has been based on a large survey of general population permits to provide of more robustness some previous findings. This is the case of our results in favour of multiplicativity and against linearity. At the same time, we think that our database provides insight in topics where previous investigations have failed. This is the case of our substantial support to a power utility function in opposition to an exponential utility function.

Obviously, as always happens, this study has some limitations. Probably the most important drawback is that we have only considered rank-dependent utility as an alternative to expected utility. This implies that the estimation of the curvature parameter of the utility function for life years has only accounted for probability weighting, but not for loss aversion. Previous empirical evidence (Bleichrodt et al., 2007) seems to suggest that loss aversion is a driver of biases for some risky methods, such as the certainty equivalence and the standard gamble. It is less clear, however, if a method involving two prospects such as the value lottery equivalence may be affected by loss aversion. Any way, we think that is preferable to correct some biases, even though other possible remain active, rather than to trust in that, for example, upwards and downwards biases offset.

Appendix 1. Some illustrations from the questionnaire.

Figure 1. Descriptive card for 32313 health state

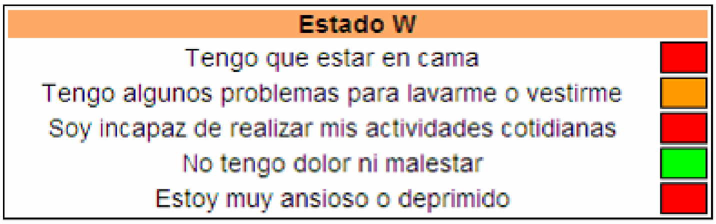


Figure 2. Visual analogue scale (after scoring the health states).

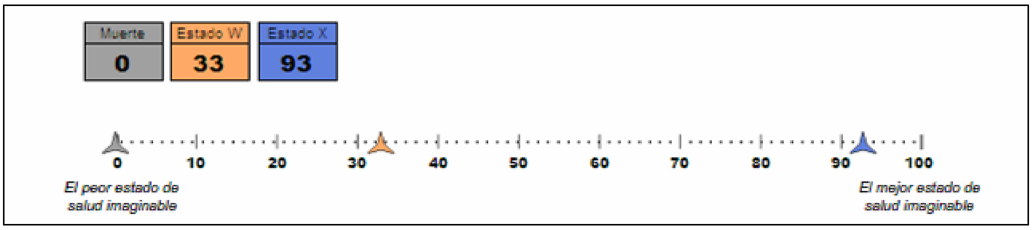


Figure 3. An example of *value lottery equivalence* (VLE) questions.

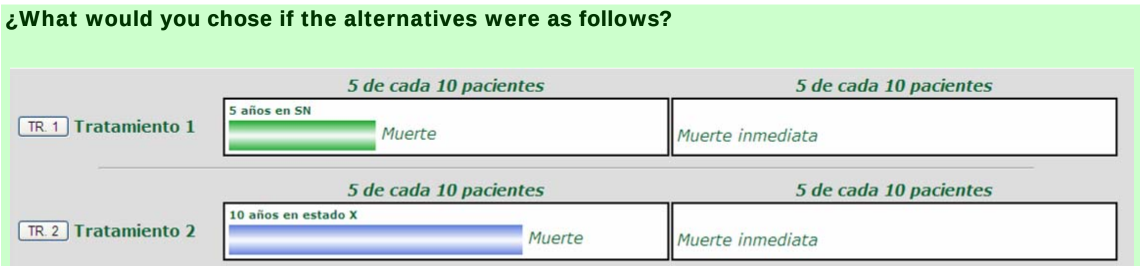


Figure 4.An example of *time trade-off* (TTO) questions.

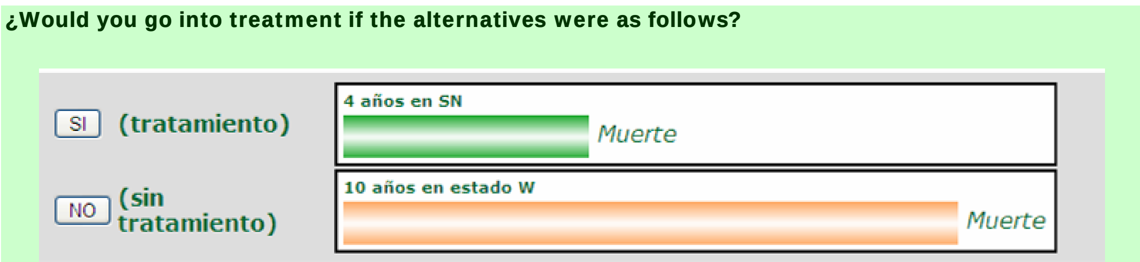
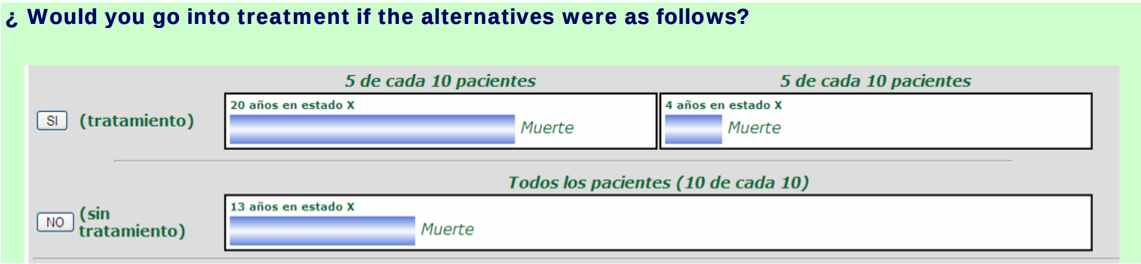


Figure 5. An example of *certainty equivalent* (CE) questions.



Appendix 2. The PEST procedure

Let *t* the attribute used in each elicitation method to yield indifference. Then the PEST procedure is intended to be a set of rules for searching such indifference. The value of *t* changes, according to the sequence described bellow, depending on the individual's responses, until a six months interval was enclosed. Then, the subject is asked to specify the precise amount of months that makes her indifferent between both prospects (treated vs. not treated, or treatment 1 vs. treatment 2).

The rules of the procedure in our study were slightly different for TTO and VLE, by one side, and CE, on the other side. In the first two cases, the rules were:

1. The initial value for *t* (i.e. the first stimulus) was randomly selected from the rank of possible values.
2. After the first individual's response, the value of *t* increases (decreases) by 1 year ("initial step").
3. A second choice in the same way (i.e. the respondent choses "Treatment 2" or "No treatment" twice consecutively) causes the same increase (decrease) in the amount of years offered.
4. Once the individual has made four choices in the same way, the rate of increase (decrease) doubles ("double step"), as far as the boundaries were not exceded; in that case, a new value for *t* is set, one year away from the limit.
5. Whenever the individual changes her election (i.e. switches from "Treatment 1" to "Treatment 2"), the increase (decrease) splits by two.
6. The third choice in the same way may lead to an increase (decrease) of the same or double amount than the previous one, depending on which was the last change: if that was preceded by an increase in the amount of the "step", this amount remains unchanged; in other case, the "step" doubles.
7. Every two choices, the subject faces a value of *t* completely random, unrelated to the followed sequence. The objective is to make the procedure less transparent to the individuals, so they cannot notice that they are "led" along a convergence path.

For the CE, the procedure was slightly modified to shorten the time spent in the task, and thus prevent the individuals fatigue or strain (remember that each respondent had to fulfil 12 CE tasks, six with each health state). Only the rule number 2 was changed, and the change consisted in setting the "initial step" in two years, instead of only one year.

References

Abdellaoui M (2000). Parameter-free elicitation of utilities and probability weighting functions. Management Science 46, 1497–1512.

Abdellaoui M, Bleichrodt H, L'Haridon O (2008). A tractable method to measure utility and loss aversion under prospect theory. Journal of Risk and Uncertainty 36, 245-266.

Abdellaoui, M., Barrios C., Wakker P. P. (2007). Reconciling introspective utility with revealed preference: Experimental arguments based on prospect theory. Journal of Econometrics 138, 356-378.

Abellan-Perpinan, J.M., Bleichrodt, H., Pinto, J.L. (2007). Testing the predictive validity of the time trade-off and the standard gamble. Working paper, CENTRA, E2007/14.

Attema AE, Brouwer WBF (2009). The correction of TTO-scores for utility curvature using a risk-free utility elicitation method. Journal of Health Economics 28, 234-243.

Attema, A.E., Bleichrodt, H.,Wakker, P.P. (2007).Measuring the utility of life duration in a risk-free versus a risky situation.Working paper, Erasmus University Rotterdam.

Bleichrodt H, Abellan-Perpiñan JM, Pinto JL, Mendez I. (2007) Resolving Inconsistencies in Utility Measurement under Risk: Tests of Generalizations of Expected Utility. Management Science; 53: 469-482.

Bleichrodt H, Doctor J, Stolk E (2005). A nonoparametric elicitation on the equity-efficiency trade-off in cost-utility analysis. Journal of Health Economics 24, 655-678.

Bleichrodt H, Johannesson M. The Validity of QALYs: An Empirical Test of Constant Proportional Tradeoff and Utility Independence. Medical Decision Making 1997; 17: 21-32.

Bleichrodt H, Pinto JL (2006). Conceptual Foundations for Health Utility Measurement.

In Jones A (ed.). The Elgar Companion to Health Economics. Edward Elgar Publishing Limited.

Bleichrodt H, Pinto JL. (2000) A Parameter-Free Elicitation of the Probability Weighting Function in Medical Decision Analysis. Management Science,46:1485-1496.

Bleichrodt H, Pinto JL. The Validity of QALYs under Nonexpected Utility. The Economic Journal 2005,115: 533-550.

Bleichrodt H. (2002) A new explanation for the difference between time trade-off utilities and standard gamble utilities. Health Economics; 11: 447-456.

Bleichrodt, H. (2001). Probability weighting in choice under risk: an empirical test. Journal of Risk and Uncertainty, 23, 185-198.

Bleichrodt, H. and Johannesson, M. (1997). The Validity of QALYs: An Empirical Test of Constant Proportional Tradeoff and Utility Independence. Medical Decision Making, 17, 21-32.

Bleichrodt, H. and Schmidt, U. (2002). A context-dependent model of the gambling effect. Management Science, 48, 802-812.

Bostic, R., Hernstein, R. J. and Luce, R. D. (1990). The effect on the preference reversal phenomenon of using choice indifferences. Journal of Economic Behavior and Organization 13, 193-212.

Braga J, Starmer C (2005). Preference anomalies, preference elicitation and the discovered preference hypothesis. Environmental and Resource Economics 32, 55-89.

Doctor JN, Bleichrodt H, Miyamoto J, Temkin N, Dikmen S. (2004) A New and More Robust Test of QALYs. Journal of Health Economics; 353-367.

Dolan P. (1997) Modelling valuations for EuroQol health states. Medical Care; 35: 1095-1108.

Fischer, G. W., Carmon, Z., Ariely, D., and Zauberman, G. (1999). Goal-based

Construction of Preferences: Task Goals and the Prominence Effect. Management Science, 45, 1057-1075.

Gonzalez R, Wu G (1999). On the shape of the probability weighting function. Cognitive Psychology 38, 129-166.

Keeney, R. and Raiffa, H. (1976). Decisions with multiple objectives. New York, Wiley.

Lener LA, Cher DJ, Goldstein MK, Bergen MR, Garber A (1998). The effect of search procedures on utility elicitations. Medical Decision Making 18, 76-83.

Llewellyn-Thomas, H. A., Sutherland, H. J., Tibshirani, R., Ciampi, A., Till, J. E. and Boyd, N.F. (1982). The Measurement of Patients' Values in Medicine. Medical Decision Making, 2, 449-462.

Luce RD. (2000) Utility of Gains and Losses: Measurement-Theoretical and Experimental Approaches. New Jersey: Lawrence Erlbaum Associates, Inc.,.

Martin, A.J., Glasziou, P.P., Simes, R.J., Lumley, T. (2000). A comparison of standard gamble, time trade-off, and adjusted time trade-off scores. International Journal of Technology Assessment in Health Care 16 (1), 137–147.

McNeil, B. J., Weichselbaum R., and Pauker S. G. (1978). Fallacy of five-year survival in lung cancer. New England Journal of Medicine, 299, 1397-1401.

Miyamoto JM, Eraker SA. (1988) A multiplicative model of the utility of survival duration and health quality. Journal of Experimental Psychology: General; 117: 3-20.

Miyamoto JM, Eraker SA. (1985) Parameter Estimates for a QALY Utility Model. Medical Decision Making, 5: 191-213.

Miyamoto JM. (1999) Quality-adjusted life years (QALY) utility models under expected utility and rank-dependent utility assumptions. Journal of Mathematical Psychology; 43: 201-237.

Miyamoto JM. (2000) Utility assessment under expected utility and rank-dependent utility assumptions. En: Chapman GB, Sonnenberg FA (eds). Decision Making in Health Care, Cambridge University Press: Cambridge.

Miyamoto, J. M. (2000). Utility assessment under expected utility and rank dependent utility assumptions. In G. B. Chapman and F. Sonnenberg. Decision making in health care: Theory, psychology, and applications. New York: Cambridge University Press, 65-109.

Miyamoto, J. M. and Eraker, S. A (1985). Parameter Estimates for a QALY Utility Model. Medical Decision Making, 5, 191-213.

Miyamoto, J. M. and Eraker, S. A. (1989). Parametric Models of the Utility of Survival Duration: Tests of Axioms in a Generic Utility Framework. Organizational Behavior and Human Decision Processes, 44, 166-202.

Oliver A (2005). Testing the internal consistency of the lottery equivalents method using health outcomes. Health Economics 14, 149-159.

Oliver, A. (2003). The internal consistency of the standard gamble: tests after adjusting for prospect theory. Journal of Health Economics, 22, 659-674.

Plott, C. P. (1996). Rational individual behavior in markets and social choice processes. Arrow, K. J. Colombatto, E. Perlman, M. and Schmidt, C. eds. (1996) The Rational Foundations of Economic Behavior: Proceedings of the IEA Conference Held in Turin, Italy. St Martin's Press, New York, 225–250.

Quiggin J. (1981) Risk perception and risk aversion among Australian farmers. Australian Journal of Agriculture Economics; 25: 160–169.

Stalmeier, P. F. M., Bezembinder T. G. G., and Unic I. J. (1996). Proportional Heuristics in Time Trade Off and Conjoint Measurements. Medical Decision Making, 16, 36-44.

Stalmeier, P.F. and Bezembinder, T. G. (1999). The discrepancy between risky and riskless utilities: a matter of framing?. Medical Decision Making 19(4), 435-447.

Stiggelbout, A. M., Kiebert, G. M., Kievit, J., Leer, J. W. H., Stoter, G. and de Haes, J. C. J. M. (1994). Utility Assessment in Cancer Patients: Adjustment of Time Tradeoff Scores for the Utility of Life Years and Comparison with Standard Gamble Scores. Medical Decision Making, 14, 82-90.

Sutherland, H. J., Llewellyn-Thomas, H., Boyd, N. F. and Till, J. E. (1982). Attitudes towards quality of survival: The concept of "maximum endurable time". Medical Decision Making, 2, 299-309.

Torrance GW. (1986) Measurement of health-state utilities for economic appraisal: A review. Journal of Health Economics; 5: 1-30.

Tversky A, Kahneman D. (1992) Advances in prospect theory: Cumulative representation of uncertainty. Journal of Risk and Uncertainty, 5:297-323.

van Osch, S. M. C., Wakker P. P., van den Hout W. B., Stiggelbout A. M. (2004). Correcting biases in standard gamble and time tradeoff utilities. Medical Decision Making 24, 511-517.

Wakker P, Stiggelbout A. (1995) Explaining distorsions in utility elicitation through the rank-dependent model for risky choices. Medical Decision Making; 15: 180-186.

Wakker, P. (1994). Separating marginal utility and probabilistic risk aversion. Theory and Decision, 36, 1-44.

Table 1. Utilities under expected utility and rank-dependent utility

	TTO		VLE	
	Q^+	Q^-	Q^+	Q^-
EU-linear	$\frac{T_{TTO}}{T}$	$-\frac{T^*_{TTO}}{T}$	$\frac{T_{VLE}}{T}$	$\frac{T^*_{VLE}}{T}-1$
EU-power	$\left(\frac{T_{TTO}}{T}\right)^{\beta(Q)_{EU}}$	$-\left(\frac{T^*_{TTO}}{T}\right)^{\beta(Q)_{EU}}$	$\left(\frac{T_{VLE}}{T}\right)^{\beta(Q)_{EU}}$	$\left(\frac{T^*_{VLE}}{T}\right)^{\beta(Q)_{EU}}-1$
RDU-power	$\left(\frac{T_{TTO}}{T}\right)^{\beta(Q)_{RDU}}$	$-\left(\frac{T^*_{TTO}}{T}\right)^{\beta(Q)_{RDU}}$	$\left(\frac{T_{VLE}}{T}\right)^{\beta(Q)_{RDU}}$	$\frac{w(0.5)\left[\left(T^*_{VLE}\right)^{\beta(Q)_{RDU}}-\left(T\right)^{\beta(Q)_{RDU}}\right]}{\left[1-w(0.5)\right]T^{\beta(Q)_{RDU}}}$

Note: Q^+ and Q^- stand for better-than-death and worse-than-death heath states, respectively

Table 2. Health states directly valued

Group (subsample)	X state	W state
1	11112	32313
2	11113	32223
3	11121	11133
4	11131	23232
5	11211	13311
6	13212	33333
7	12111	32211
8	21111	22222
9	11312	33323

Table 3. Outcomes of the reference lottery in the six CE questions

T_1	8	10	12	16	20	24
T_2	0	2	4	0	4	8

Table 4. Characteristics of the sample

	N=656	%
Gender		
Female	331	50.38
Male	325	49.47
Age (years)		
18 to 29	149	22.71
30 to 41	184	28.05
42 to 53	142	21.65
54 to 65	105	16.01
More tan 65	76	11.59
Marital status		
Single	255	38.87
Married or coupled	331	50.46
Separated, divorced, widow	70	10.67
Number of children (mean)	0.71	
Educational level		
No studies	22	3.35
Primary	156	23.78
Secondary	319	48.63
Higher	159	24.24
Income level (euros)		
Up to 900	41	6.25
901 to 1500	215	32.77
1501 to 2000	219	33.38
2001 to 3000	134	20.43
More than 3000	47	7.16
Smoker (%)	34.60	
Private medical insurance (%)	20.88	
Self-assessed health condition (EQ-5D)		
11111	466	71.04
11121	69	10.52
11122	30	4.57
Other	92	14.02

Table 5. Classification of respondents in terms of risk attitude towards life years for better and worse than death health states. Number of subjects (% over N=656)

				State X					
				Better than death (BTD)			Worse than death (WTD)		
State X	BTD	WTD	N_X	Risk averse	Risk seeking	Mixed	Risk averse	Risk seeking	Mixed
11112	74	0	74	64	4	6	0	0	0
11113	73	1	74	62	4	7	0	0	1
11121	74	0	74	67	2	5	0	0	0
11131	71	2	73	65	1	5	0	1	1
11211	75	0	75	64	3	8	0	0	0
11312	67	2	69	54	2	11	0	2	0
12111	75	0	75	69	3	3	0	0	0
13212	69	3	72	59	3	7	1	1	1
21111	70	0	70	60	1	9	0	0	0
N_X	648 (98.78)	8 (1.22)	656 (100)	564 (85.98)	23 (3.51)	61 (9.3)	1 (0.15)	4 (0.61)	3 (0.46)
				State W					
				Better than death (BTD)			Worse than death (WTD)		
State W	BTD	WTD	N_W	Risk averse	Risk seeking	Mixed	Risk averse	Risk seeking	Mixed
11133	65	9	74	54	5	6	2	6	1
13311	72	3	75	59	4	9	0	3	0
22222	58	12	70	50	2	6	0	11	1
23232	19	54	73	11	6	2	13	30	11
32211	63	12	75	52	5	6	0	12	0
32223	22	52	74	3	19	0	28	17	7
32313	33	41	74	28	5	0	7	33	1
33323	5	64	69	4	1	0	22	33	9
33333	4	68	72	2	0	2	7	53	8
N_W	341 (51.98)	315 (48.02)	656 (100)	263 (40.09)	47 (7.16)	31 (4.73)	79 (12)	198 (30.18)	38 (5.79)

Table 6. Health states utilities (median values)

State	N	TTO utilities			VLE utilities		
		EU-linear	*EU-power*	*RDU-power*	*EU-linear*	*EU-power*	*RDU-power*
11112	74	0,9167	0,9523	0,9322	0,9083	0,9499	0,9238
11211	75	0,8667	0,9229	0,8996	0,8667	0,9169	0,8877
11121	74	0,8625	0,9139	0,8940	0,8333	0,9120	0,8772
21111	70	0,8333	0,9150	0,8679	0,8333	0,9130	0,8637
12111	75	0,7833	0,8782	0,8420	0,8583	0,9175	0,8985
11113	74	0,6417	0,7549	0,6791	0,6500	0,7643	0,7126
11131	73	0,5917	0,7480	0,6439	0,5583	0,6815	0,6098
11312	69	0,4667	0,6180	0,5380	0,5083	0,6304	0,5574
13212	72	0,3417	0,4792	0,4014	0,3125	0,4770	0,3580
13311	75	0,4333	0,5729	0,5010	0,3750	0,4833	0,4172
11133	74	0,2958	0,4525	0,3650	0,2333	0,4399	0,3773
22222	70	0,1083	0,2065	0,1355	0,1333	0,2416	0,1839
23232	73	-0,1417	-0,1475	-0,2846	0,0167	-0,0859	-0,3104
32211	75	0,2250	0,4039	0,3315	0,2083	0,4039	0,3148
32223	74	-0,1250	-0,0473	-0,1726	-0,0333	-0,0217	-0,2060
32313	74	-0,0333	-0,0346	-0,0466	0,0292	-0,0111	-0,0679
33323	69	-0,5583	-0,6467	-0,6878	-0,3167	-0,5514	-0,2219
33333	72	-0,8125	-0,8597	-0,8533	-0,3333	-0,6508	-0,4575

Table 7. Classification of respondents in terms of the shape of utility function for better and worse than death health states. Number of subjects (% over N=656)

				State X					
				Better than death (BTD)			Worse than death (WTD)		
State X	BTD	WTD	N	Concave	Convex	Mixed	Concave	Convex	Mixed
11112	74	0	74	52	10	12	0	0	0
11113	73	1	74	44	16	13	0	0	1
11121	74	0	74	59	5	10	0	0	0
11131	71	2	73	43	12	16	0	2	0
11211	75	0	75	50	12	13	0	0	0
11312	67	2	69	46	8	13	0	1	1
12111	75	0	75	52	10	13	0	0	0
13212	69	3	72	50	8	11	1	2	0
21111	70	0	70	46	9	15	0	0	0
N_X	648 (98.78)	8 (1.22)	656 (100)	442 (67.38)	90 (13.72)	116 (17.68)	1 (0.15)	5 (0.76)	2 (0.3)
				State W					
				Better than death (BTD)			Worse than death (WTD)		
State W	BTD	WTD	N	Concave	Convex	Mixed	Concave	Convex	Mixed
11133	65	9	74	51	6	8	2	5	2
13311	72	3	75	49	12	11	1	2	0
22222	58	12	70	43	8	7	0	10	2
23232	19	54	73	18	0	1	0	50	4
32211	63	12	75	43	8	12	1	9	2
32223	22	52	74	11	3	8	9	33	10
32313	33	41	74	23	3	7	0	32	9
33323	5	64	69	5	0	0	5	50	9
33333	4	68	72	2	0	2	12	46	10
N_W	341 (51.98)	315 (48.02)	656 (100)	245 (37.35)	40 (6.1)	56 (8.54)	30 (4.57)	237 (36.13)	48 (7.32)