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Uncertainty and the under-valuation of services for severe health states in cost utility analyses

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Author names: Jeff Richardson[a]; Angelo Iezzi[a]; Aimee Maxwell[a]

[a]Centre for Health Economics, Level 2, 15 Innovation Walk, Monash University, Clayton Vic 3800 Australia

Corresponding Author: Jeff Richardson; Centre for Health Economics, Monash Business School, Monash University, Vic 3800 Australia

Email: Jeffrey.richardson@monash.edu Ph: +61 3 9905 0754; +Fax: 61 3 9905 8344

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Abstract

Objective: To test the hypothesis that the 'severity effect' – the preference for more than utility maximising expenditure on severe health states – may be the result of, or exacerbated by, the uncertainty associated with the chance of contracting the illness which causes the severe health state.

Methods: Survey respondents were asked to imagine that they will contract one of two illnesses and asked to allocate a budget between two insurance policies, each of which provides services for the treatment of one of the illnesses. A person's final health state varied with the amount of insurance purchased for the illness which occurred and therefore with the level of treatment. The relative cost of the two policies was altered and the selected levels of insurance compared with the levels which would be provided by a health authority which sought to maximise total utility or quality adjusted life years (QALYs) from its own budget.

Results: Respondents selected more than utility maximising insurance for protection against severe health states.

Discussion: A number of psychological factors which affect measurement under uncertainty do not affect utility as currently measured. This difference may explain the present results and also explain the 'severity paradox' that that personal preferences as presently measured imply less expenditure on severe health states than 'social preferences' for the treatment of strangers.

Conclusion: Uncertainty alters preferences. Incorporating these preferences in decision making would result in greater spending on severe health states.

Uncertainty and the under-valuation of services for severe health states in cost utility analyses

1 Introduction

In cost utility analysis (CUA) the unit of benefit is the quality adjusted life year (QALY) which is calculated as life years times the utility of the life years. In welfare theory, utility is the strength of preference for an option when a choice is to be made between options. When the options concern health and medical services individuals commonly face uncertainty: they are usually unsure of the likelihood that they will personally contract an illness. They often have not experienced the outcomes of the possible illnesses and they cannot assess the extent to which, in their personal case, adaptation might occur and mitigate the severity of an outcome. For this reason Kahneman et al. (1) distinguish 'decision' utility – the welfare theoretic concept of preferences before health outcomes are known – from 'experienced' utility, the assessment after they are known, which Kahneman and others recommend as a replacement for decision utility in CUA (2-6). Nevertheless, economic evaluation is still based upon the use of decision utility which permits it to retain the authority of welfare theory.

However the utilities presently used in CUA deviate from the welfare theoretic ideal. They are not assessed by the people who face the choice and the uncertainty of a real decision. Rather they are most commonly estimated using a multi attribute utility instrument (MAUI) whose utility weights were derived from a representative cross section of the population using either a time trade-off (TTO), a rating scale (or VAS: Visual Analogue Scale) or a standard gamble (SG) (7). The first two of these techniques evaluates risk free health states, ie neither risk nor uncertainty affects predicted values. In contrast, SG utilities are obtained 'under risk'. The SG requires respondents to compare a risk free outcome with a gamble between full health and death. The probability which makes the alternatives equally attractive is commonly equated with decision utility as the gamble reveals preferences which take account of a person's attitude towards risk in the form of the life-death gamble. 'SG utility' also gains authority as it is consistent with the appealing behavioural axioms of expected utility theory proposed by Von Neumann and Morgenstern (8). However because of the idiosyncratic and context specific responses to risk and uncertainty the argument that a life-death gamble will indicate people's responses to every risk and uncertainty related situation has been historically controversial (9, 10) and explicitly rejected by Morgenstern who argued that 'as with Von Neumann…I know of no axiomatic system…that specifically incorporates a specific pleasure of gambling' (11 p181).

In sum, the utilities employed in CUA seek to maximise decision utility but do so imperfectly. The context of individuals answering utility surveys differs from the context facing patients at a decision point. Like decision utility the assessment is made by individuals who have not experienced the health state they are evaluating. However the assessment differs from the ideal measurement of decision utility as the individuals have not experienced the uncertainty caused by the unknown likelihood of contracting the illness responsible for the health state. The basis of the present study is the hypothesis that the disutility of this uncertainty increases with the severity of the worst possible outcome. To include this effect in CUA, severe health states would need to be weighted to increase their importance.

This conclusion has also been reached in a significant number of empirical studies reviewed by Shah (12) and Nord and Johansen (13). However these studies are based upon people's social preferences, ie their judgement of how best to allocate resources between other people. They imply what might be called the 'severity paradox'. Severe health states are found to be of greater importance when they are experienced by an unknown person than when they are experienced by the individual whose personal utility is measured. In contrast, the present study is based upon an analysis of personal preferences and does not imply less self concern than concern for anonymous 'others'.

Aims: The aim of this paper is to test the 'uncertainty aversion hypothesis': the hypothesis that aversion to uncertainty results in a personal preference for greater expenditure on severe health states than would be provided by authorities seeking to maximise utility *as presently measured*. The methods used to test the hypothesis are described in section 2 below and results presented in section 3. Section 4 discusses possible reasons for the results.

2 Methods

In sum, the hypothesis was tested by contrasting the insurance decisions of survey respondents with the insurance decisions of a health authority seeking to maximise global utility as utility is currently measured and described above. Survey respondents faced the (hypothetical) certainty of illness A or B but uncertainty concerning which of the two illnesses they would contract. The severity of health states after treatment could be mitigated by the purchase of additional insurance for additional treatment. The study hypothesis was therefore tested by observing whether more than utility maximising insurance was purchased to avoid severe health states. Utility and expected utility maximising insurance were estimated from the assumption that the decision maker assigned an equal probability to the likelihood of each of the two illnesses; an assumption which was tested empirically. The results are subsequently referred to as 'optimal' insurance (A* or B*) and 'optimal' utility (U_A^* or U_B^*) and the results of choices by survey respondents as 'selected insurance' (A or B) and 'selected utility' (U_A or U_B).

The survey: Members of the Australian public enrolled with a panel company, CINT Pty Ltd, were recruited into 12 demographic cohorts until a pre-determined quota was filled. The survey protocol is summarised in Table 1. It had two main components: a budget allocation exercise and the evaluation of the health states used in the allocation exercise. The survey, which was administered by a speaking avatar, is reproduced in Appendix 5. It was approved by the Monash University Human Research Ethics Committee (MUHREC) approval ID: CF15/411 – 2015000201.

Health State Evaluations: Respondents were asked to rate 8 health states using the visual analogue scale (VAS) reproduced in Appendix 5. Four health states were selected from the possible outcomes of each illness and described using abbreviated descriptions from the EQ-5D-5L instrument. The valuations occurred at the beginning of the survey in order to introduce the health states prior to the allocation exercise.

Budget allocation exercise: Respondents were asked to select their preferred mix of insurance A and B as the relative price of the two insurance policies, P_A and P_B, varied. The variation was symmetrical: the final four price ratios P_A:P_B were the reciprocal of the first four ratios. The symmetry was designed to identify the effects of idiosyncratic assumptions about the health states or their likelihood of occurring which would result in an asymmetrical allocation of the budget when the price ratios were inverted. The budget was insufficient to purchase complete insurance for both A and B and additional insurance could not be purchased. Respondents could alter the possible outcomes they faced only by altering the mix of insurance they selected.

The visual aids used to present questions were introduced and explained with a series of images and an illustrative question. An example is given in Box 1. In this, the two scales represent the levels of insurance cover and the cost of the insurance against the two illnesses. In the example the costs of full insurance A and B are $5,000 and $10,000 respectively, ie a combined cost of $15,000 which exceeds the budget of $9,000. An incremental percentile of either insurance could be purchased for 1 percent of its total cost by moving the ‘slider’ beneath the scale. An algorithm adjusted the visual display and constrained total spending so it would be equal to the budget constraint.

Edit criteria: A proportion of respondents to web-based surveys provide arbitrary or minimally considered answers. Consequently pre-determined edit criteria were employed. These are shown in Appendix 2 which also reports results obtained using unedited data.

Optimal insurance: Assuming the two illnesses are equally likely to occur, maximum utility must satisfy equations 1 and 2. MU_A, and MU_B are respectively the marginal utilities from incremental changes in insurance A and B; and P_A, P_B are the corresponding costs of incremental insurance. Bud is the budget.

$$\frac{MU_A}{P_A} = \frac{MU_B}{P_B} \qquad \text{… equation 1}$$

$$\text{Bud} = 0.5\,[P_A.A] + 0.5[P_B.B] \qquad \text{… equation 2}$$

The equations are a special case of the more general rule derived in Appendix 1 that, for the individual and for the population, expected utility and total utility are both maximised by the equalisation of the incremental cost per QALY.

Equation 2 simplifies to equation 3.

$$A = (2\ \text{Bud} - P_B.B)(1/P_A) \qquad \text{… equation 3}$$

Equations 4 and 5 are linear approximations of the independently determined marginal utilities which will occur after an individual has contracted an illness and received the maximum care permitted by their insurance.

$$MU_A = a_1 + b_1\dot{A} \qquad \text{… equation 4}$$

$$MU_B = a_2 + b_2\dot{B} \qquad \text{… equation 5}$$

$\dot{A} = A/100$; $\dot{B} = B/100$. Therefore $\dot{A}, \dot{B}, MU_A$ and MU_B are measured on a 0.00-1.00 scale. Equations 1-5 simplify to equation 6.

$$B = \left[2b_1 Bud + 100a_1 P_A - 100a_2 . P_A{}^2 / P_B\right] / \left(b_1 P_B + b_2 . P_A{}^2 / P_B\right) \quad \text{… equation 6}$$

Optimal levels of insurance – A* and B* – were estimated for illness A and B using equations 3 and 6 and parameters a_i, b_i from equations 4 and 5. Optimal utilities U_A* and U_B* were calculated from A* and B* respectively and the relationships between the levels of insurance A and B and total utility.

Estimates of equations 4 and 5 were derived from respondents' VAS scores for the health states. These were transformed into an estimated TTO utility using a transformation derived from 3,714 paired observations of TTO and VAS scores, used in the construction of the AQoL-8D (14).

$$(1\text{-TTO}) = (1\text{-VAS})^{1.62}$$

Utilities were estimated for the 8 health states from the respondents' VAS scores and utilities interpolated between these health states for each respondent for each level of insurance (0%-100%) for both illnesses A and B. The interpolation resulted in 101 observations of utility and insurance per respondent, ie one observation per percentile from 0-100 percent cover. Utilities were regressed upon the corresponding level of insurance using a quadratic equation in which the constant was supressed to ensure that utility was 0 (death) in the absence of insurance as shown in the visual aids (see Box 1). Marginal utilities, equations 4 and 5, were derived as the first derivative of these equations. Coefficients from these derived equations were used in equations 3 and 6 to calculate optimal insurance, A* and B*.

In Appendix 3 utilities from the transformation are compared with utilities derived from the transformations employed for the construction of the HUI 2 MAUI (15) and HUI 3 MAUI

(16) (see Table A3.1). Results in section 3 were recalculated using the HUI 3 transformation which differed most from the transformation employed here.

Hypothesis tests: The uncertainty aversion hypothesis implies that selected insurance will result in a smaller difference between outcomes than optimal insurance as severe health states will be mitigated. This may be directly observed. In addition three statistical tests of the study hypothesis were conducted. These are summarised in equations T1-T3 below. In these the more expensive treatment is denoted 'Y' and the less expensive treatment, 'X'. Optimal values are denoted with an asterisk (*). Spending on X and Y are denoted \$X, \$Y.

$$P_X/MU_X = a_1 + b_1 P_Y/MU_Y \quad \text{… T1}$$

$$\$Y/\$Y^* = a_2 + b_2 (P_Y/P_X) \quad \text{… T2}$$

$$U_Y/U_Y^* = a_3 + b_3 (P_Y/P_X) \quad \text{… T3}$$

Test 1: T1 is a direct test of the optimality condition, equation 1. If $a_1=0$, $b_1=1$, then the price or marginal cost per incremental unit of utility is equalised for both options. The uncertainty aversion hypothesis implies that if the price of incremental utility (P_Y/MU_Y) rises and utility after the treatment permitted by insurance, U_Y, falls, then relative to optimal behaviour, people will spend more on insurance, Y, and relatively less on X. Therefore P_X/MU_X will fall as P_Y/MU_Y, rises, ie $b_1<0$.

Test 2, Test 3: As P_Y/P_X rises, the uncertainty aversion hypothesis implies that spending on Y will increase relative to its optimal level to mitigate the effect upon severity of the price induced reduction in Y, ie the ratio Y/Y* will rise. In equation T2 $b_2>0$. As Y/Y* rises the ratio U_Y/U_Y^* also rises and in equation T3, $b_3 > 0$. Equations T1-T3 were estimated using OLS regressions and 3,627 observations (ie 9 observations per person × 403 respondents).

3. Results

The survey was completed by 606 individuals. Editing eliminated 203 respondents. From Table 2 the remaining sample of 403 respondents closely matched the demographic profile of the Australian population, reflecting the use of quota sampling. Reasons for, and the consequences of editing are reported in Appendix 2. From Table A2.1 results with and without data editing differ by a maximum of 4 percent but with a larger standard deviation of estimates when all data are used.

Mean VAS and estimated TTO utilities for the 8 health states are reported in Appendix 4. Maximum and minimum utilities vary by 0.71. The quadratic equations estimated from these and interpolated utility data (n=403×101=40,703) are given in equations 7 and 8 and the derived equations for marginal utilities in equations 7a and 8a.

Mobility

$$U_A = 1.60A - 0.58\,A^2 \qquad \text{… equation 7}$$

$(t=391)\ (t^2=-111)\ n=40,703$

$$MU_A = 1.6 - 1.16A \qquad \text{… equation 7a}$$

Pain

$$U_B = 1.66B - 0.65B^2 \qquad \text{… equation 8}$$

$(t=389)\ (t=-121)\ n=40,703$

$$MU_B = 1.66 - 1.30B \qquad \text{… equation 8a}$$

Coefficients from equations 7a and 8a were used in equations 3 and 6 to calculate the optimal levels of insurance. Corresponding levels of optimal utility were calculated from equations 7 and 8.

Mean values of optimal and selected insurance are reported in Table 3. Optimal insurance A* and B* vary by 87.6 and 83.1 percentage points respectively (column 3, 4), both rising above 100 percent as the equations for optimal expenditure were not constrained. Selected insurance A and B, vary by 58.3 and 59.2 percent respectively (column 1, 2). The difference between optimal and selected insurance in both cases rises to 47 percentage points (column 5, 6). Optimal insurance results in a greater difference between the level of insurance cover for each price ratio in the table. From the final column the percentage of respondents selecting more than optimal insurance rises to 100 percent when relative prices are at their highest and lowest levels.

Figure 1 plots the average levels of selected and optimal insurance. A and A* are on the vertical axis and B and B* on the horizontal axis. Along the diagonal line A=B; A*=B*. To the right of the diagonal P_A varies while P_B is fixed; to the left, P_B varies while P_A is fixed. In both cases the average level of insurance falls as the price rises due to an income effect. In both cases the cheaper insurance is substituted for the more expensive insurance. However the substitution effect is greater with optimal insurance.

Table 4 reports the consequences of these results for utility. Selected utilities U(A) vary by 0.51 from 0.95 to 0.44 (column 1) and U(B)by 0.52 from 0.95 to 0.43 (column 2). Differences between optimal utilities peak at 0.75 (column 8); for selected utilities the maximum difference is 0.26 (column 7). The expected utility from optimal insurance always exceeds the average utility from selected insurance (column 5, 6). In sum, optimal insurance maximises expected utility but selected insurance minimises the difference in possible outcomes.

The final column of Table 4 gives the ratio of selected to optimal utility. It is therefore the severity weights which would be needed to convert optimal to selected utilities. The weights for U(B)* vary from 1.54 with a price ratio P_A/P_B of 0.25 to 0.64 with a price ratio of 4.00; that is, a 16 fold difference in the price ratio alters the severity weight by 1.54/0.64=2.40.

Hypotheses: As hypothesised, from Table 3 there are smaller differences between selected than optimal insurance. Results of the three discriminating tests of the study hypothesis are shown in Table 5 below. In each case the coefficients are significant and have the sign predicted by the uncertainty aversion hypothesis, as outlined above.

4 Discussion

Results are consistent with the study hypothesis: insurance selected by survey participants gave greater cover for severe health states than the insurance which maximised utility. The differences were quantitatively large. From Table 3 the discrepancy between selected and optimal insurance rises to almost 50 percentage points (columns 5, 6). From Table 4 optimal and selected utilities vary by a maximum of 0.75 and 0.26 respectively (column 8 and column 7). The 16 fold variation in relative price results in a severity weight for service B which varies by a factor of 1.54/0.64=2.41 (column 14).

The relation between risk, uncertainty and utility in the literature has been controversial. A longstanding view has been that expected utility theory (EUT) combined with diminishing marginal utility explains risk aversion. In Appendix 1 it is shown that if preferences conformed with EUT then selected insurance would also result in the maximisation of utility which is commonly the objective of CUA. However EUT has been shown to be descriptively unreliable as a general theory (9) and specifically in the health sector (10, 17, 18).

Alternative explanations for these present results do not draw upon EUT. First, they may be attributable to uncertainty or ambiguity aversion. It has been shown that both ambiguity and uncertainty generate anxiety (19), which creates pessimism which may alter subjective probabilities ('probabilistic pessimism' (20, 21). The theory of subjective expected utility may also be modified to include this affect (22). It is therefore possible that an increase in the relative price of insurance increases the subjective assessment of the need for it, and more of the expensive insurance will be purchased to maximise subjective expected utility. This explanation is possible but would imply the implausible revision of subjective probabilities on each of the 8 occasions when the price ratio was varied.

A second explanation draws upon the framework provided by the 'Knowledge Ahead Approach to Risk' proposed by Pope et al. (23). This makes explicit the temporal stages of decision making. These commence with the realisation of the need for a choice and ends when the outcome is experienced. Between these times a diverse range of events and emotions may be triggered which are excluded from atemporal EUT. These include, inter alia, hope, fear, excitement, anxiety and the anticipated regret described in Regret Theory (24). Uncertainty aversion may be explained by an attempt to minimise the negative effects which occur during these pre-outcome periods.

Finally, results are consistent with the behaviour described by prospect theory (25) which has recently been used to explain decision making in the health domain (17, 18). The theory proposes that when people face risk and uncertainty they do not assess health state utilities directly but losses and gains which are perceived as deviations from a reference point. Psychologically, losses are of greater importance ('loss aversion') with some estimates suggesting that they are twice as important as objectively equivalent gains (26). In the present study the reference point is likely to be an equal division of the budget with possible gains and losses determined by the selection of more or less insurance. Loss aversion implies a preference for increased insurance when the loss may be greatest, ie when the most severe health state may occur.

Each of the explanations support the argument for using severity weights which, from Table 4, vary by a factor of 1.94/0.64=2.4. By comparison, the maximum severity weights derived from ‘social preferences’ in two recent studies were 3.6 (13) and 2.0 (27). The similarity with the present results may not be coincidental. The motivations for allocative decisions made from a social perspective remains speculative. However one possibility is that they are a reflection of personal preferences. This is supported by experimental and neurological evidence which is summarised by Kameda et al. (28) in the following way:

> ‘People’s allocative decisions for others are closely related to economic decisions for oneself at behavioral, cognitive and neural levels…participants’ distributive choices closely matched their risk preferences… The results provide convergent evidence that social distribution for others is psychologically linked to risky decision making for self.’ (p11817).

This suggests that individuals evaluating a health state from a ‘social perspective’ imagine that they are in the health state and transfer their personal preferences to others. The large literature on reciprocal altruism and reciprocity further suggests that individuals would seek treatment for others that they would expect to receive themselves (29-31).

This explanation of social preferences also lends weight to the third explanation of the study results above. The first two imply an alteration or addition to the variables in the pre-outcome period – pessimism induced changes in subjective probabilities or the importance of anxiety, fear or anticipated regret. These pre-outcome emotions are less likely to affect decisions made from a social perspective if people focus upon outcomes, not pre-outcome effects. In contrast, prospect theory suggests that information is processed in a way which does not rely upon private psychological factors. Both a potential patient and a third party have access to the same relevant data and process it in the same way. This would resolve the ‘severity paradox' that the importance assigned to a severe health state is greater when it is assessed from a social than from a personal perspective.

The present study was based upon a number of assumptions. First, survey respondents were assumed to treat illnesses A and B as being equally likely. In principle, the differences between the two illnesses or some unobserved factor may have affected this judgement. For example, it has been shown that subjective probabilities may be affected by personal preferences (32) or by a particular event such as experiencing one of the health states used in the survey (33). However results support the assumption. The same level of insurance A and B was selected when the price of both types of insurance was the same. This indicated a similar level of concern with respect to the likelihood of the illness occurring. The inverting of the price ratios in subsequent questions permitted a further test of the assumption. From Table 3 the level of insurance A purchased at any price ratio was very similar to the level of insurance B purchased when the price ratio was inverted. This implies the implicit use of similar subjective probabilities that the illness will occur.

A second assumption was that utilities are satisfactorily measured by the TTO. With the exception of the SF-6D the major MAU instruments employed to estimate QALYs derive their parameters from the TTO, a VAS or the transformation of a VAS (7). The utilities employed in the present study to derive optimal values are therefore similar to those used in the construction of QALYs in the mainstream literature and the objective of the present study was to compare results using these utilities with choices selected by respondents.

The SF-6D could be seen as an exception as it derives importance weights from the standard gamble which some authors argue is the only scaling instrument to measure decision utility (34, 35). As noted earlier the distinction is contentious (36). Of greater relevance here the SF-6D assigns higher, not lower utilities to severe health states than any other major MAU instrument except for the 15D: that is, the use of the standard gamble – at least in the SF-6D – gives lesser not greater importance to severe health states (37).

A third caveat to the present study is that optimal values were derived from a particular transformation which converted VAS scores into TTO utilities. Three different transformations are compared in Appendix 3 and study results re-estimated using the transformation employed to obtain utilities for the HUI 3 MAU instrument which differed most from the transformation used in the present study. The HUI 3 utilities inflated low VAS scores (see Tables A3.3 and Figure A3.1). This mitigated but did not fundamentally alter the study results.

Finally, results were derived from a severely edited sample. Nevertheless it closely matched the composition of the Australian population. The percentage in each age cohort differed from the national profile by an average of 1.6 and a maximum of 3.2 percentage points (Table 2). The sample was also atypical consisting of people enrolled in a panel company. There are, however, no clear reasons why this would affect their attitude to the importance of severe health states.

5. Conclusions

Evidence presented here supports the hypothesis that uncertainty will result in a ‘severity effect’, a personal preference for greater spending on severe health states than would occur if a health authority allocates its budget to maximise QALYs or total utility as presently measured. Incorporating these preferences in decision making would therefore result in greater funding of services for severe health states.

The similarity of the implied severity weights found here and in the literature suggest that the social preferences measured in these latter studies may, in part or whole, be the projection of personal preferences which are affected by decision rules and psychological traits which present methods for measuring utility exclude. While this hypothesis requires further research the present results add to the case for increased expenditure on services which mitigate the most severe outcomes.

Table 1 The Survey Protocol

A	**Introduction and the visual aids** • Introduction to a VAS and the Visual Aid • Introduction to the illnesses • Rating 8 health states (4 per illness) on a VAS **Introduction to the budget allocation exercises** • 3 numerical examples									
B	**The Allocation Exercise**									
	Question	1	2	3	4	5	6	7	8	9
	Price of insurance									
	A ($000)	5	5	5	5	5	7.5	10	12.5	15
	B ($000)	5	7.5	10	12.5	15	5	5	5	5
	Budget ($000)	9	9	9	9	9	9	9	9	9
C	**Personal questions** • Age, gender, education									

Table 2 Survey respondents by age, gender and educational status

	Age (%)						Education (%)			Total
	18-24	25-34	35-44	45-54	55-64	65+	HS	Trade	Uni	
Male	5.5	7.4	7.9	9.4	7.2	8.4	14.6	13.9	17.4	185
Female	8.2	8.7	10.2	10.2	7.4	9.4	15.1	19.1	19.9	218
Total	13.6	16.1	18.1	19.6	14.6	17.9	29.8	33.0	37.2	403
Aust (1)	11.0	19.3	18.2	17.5	15.0	19.0				

(1) Percent of Australian population above age 18 in ABS estimated resident population (ABS 2015)

Table 3 Selected[(1)] versus Optimal Insurance

Price (Marginal cost) of insurance per percentile		% Insurance						Difference				% respondents where A>A*
		Selected[(2)]				Optimal[(3)]		Selected-Optimal		Selected	Optimal	
		1		2		3	4	5	6	7	8	9
A	B	A	sd	B	sd	A*	B*	A-A*	B-B*	B-A[(2)]	B*-A*	
200	50	31.5	7.5	53.8	30.2	19.7	101.3	11.8	-47.5	-22.3	-81.6	100.00
150	50	42.2	9.52	53.5	27.6	25.3	95.0	13.9	-41.6	-11.3	-69.7	94.0
100	50	58.1	10.6	63.8	21.1	46.5	86.9	11.6	-23.1	-5.7	-2.04	87.8
75	50	70.7	10.7	74.0	16.1	64.1	83.8	6.6	-9.8	-3.3	19.7	71.5
50	50	90.8	7.5	89.2	7.5	92.7	87.3	-1.9	1.9	1.6	5.4	38.5
50	75	79.1	14.5	67.2	9.3	88.2	61.2	-9.1	6.0	11.9	27.0	31.0
50	100	70.3	16.9	54.9	8.4	91.3	44.4	21.0	10.5	15.4	46.9	9.9
50	150	60.2	25.7	39.9	8.6	100.2	26.6	-39.8	10.5	20.3	73.6	9.9
50	200	60.1	27.9	30.0	7.0	107.3	18.2	-46.9	11.8	30.1	89.1	0.0
Maximum difference		58.3		59.2		87.6	83.1					

[(1)] n=403; [(2)] Survey results; [(3)] estimated from optimality equations

Table 4 Utility from Selected[1] *vs* Optimal Insurance

Price ratio	Mean Utility*				Average (EU)		Differences in utility		Ratio P/MU				Severity weight	
	Selected[2]		Optimal[3]		Selected[2]	Optimal[3]	Selected [2]	Optimal[3]	Selected[2]		Optimal[3]		Ratio[4] (U/U*)	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
P_A/P_B	U(A)	U(B)	U(A)*	U(B)*	[U(A)+ (B)]/2	[U(A)*+ U(B)*]/2	U(A)-U(B)	U(A)*- U(B)*	A	B	A*	B*	A[1]	B
4.00	0.44	0.64	0.29	1.00	0.54	0.65	-0.20	-0.71	0.13	0.05	0.15	0.15	1.52	0.64
3.00	0.56	0.65	0.40	0.98	0.61	0.69	-0.09	-0.58	0.14	0.05	0.12	0.12	1.40	0.66
2.00	0.72	0.76	0.61	0.94	0.74	0.78	-0.04	-0.33	0.11	0.06	0.10	0.10	1.18	0.81
1.50	0.82	0.85	0.78	0.93	0.84	0.85	-0.03	-0.15	0.10	0.07	0.09	0.09	1.05	0.91
1.00	0.95	0.95	0.97	0.95	0.95	0.96	0.00	0.02	0.10	0.10	0.10	0.10	0.98	1.00
0.67	0.88	0.81	0.94	0.77	0.84	0.86	0.07	0.18	0.08	0.10	0.09	0.09	0.94	1.05
0.50	0.81	0.71	0.96	0.61	0.76	0.78	0.10	0.35	0.07	0.11	0.10	0.09	0.84	1.16
0.33	0.71	0.55	1.00	0.39	0.63	0.70	0.15	0.61	0.06	0.13	0.13	0.11	0.71	1.41
0.25	0.70	0.43	1.03	0.28	0.57	0.65	0.26	0.75	0.06	0.16	0.15	0.15	0.68	1.54

(1) n=403; (2) Survey results; (3) estimated from optimality equations; (4) Ratio of utility from selected to optimal insurance

Table 5 Test results

	Regression	t	R^2	n[1]
Test 1	$P_X/MU_X = 0.18 - 0.79\ (P_Y/MU_Y)$	-80.7	0.64	3,627
Test 2	$\$Y/\$Y^* = 0.6 + 0.29\ (P_Y/P_X)$	77.4	0.62	3,627
Test 3	$U_Y/U_Y^* = 0.68 + 0.23\ (P_Y/P_X)$	74.8	0.61	3,627

*denotes an optimal value

(1) 3,627 = 9 allocations per respondent × 403 respondents

Box 1 Visual aid for questions

Think about your life in the health states described on the 2 scales.

Illness A affects walking (mobility) and washing and dressing (self-care). Other parts of your health have no problem. The cost of a complete cure is $5,000.

Illness B causes mental health problems and pain. The cost of insurance guaranteeing a full cure is also $10,000.

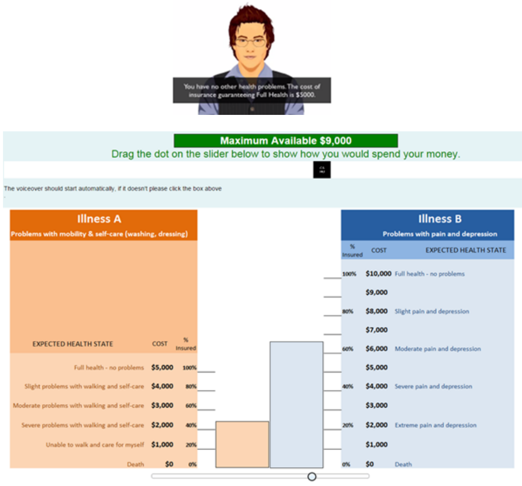


Figure 1 Optimal *vs* selected insurance

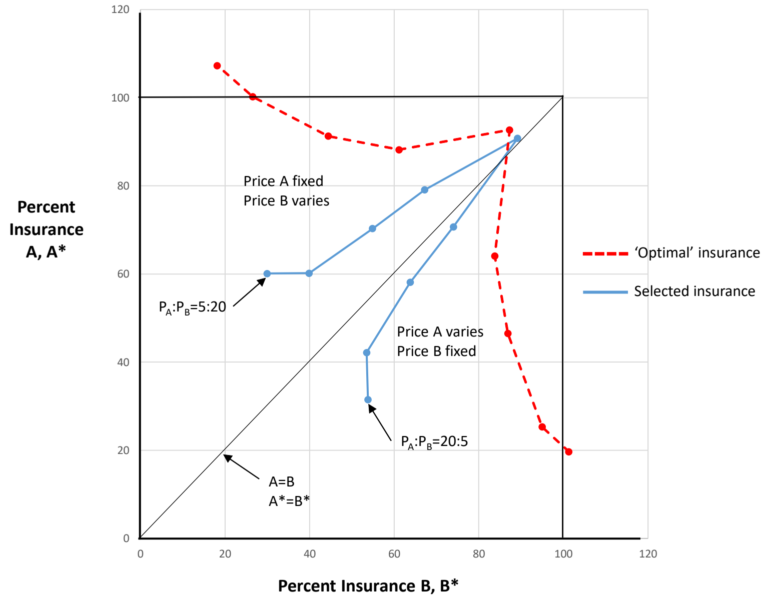
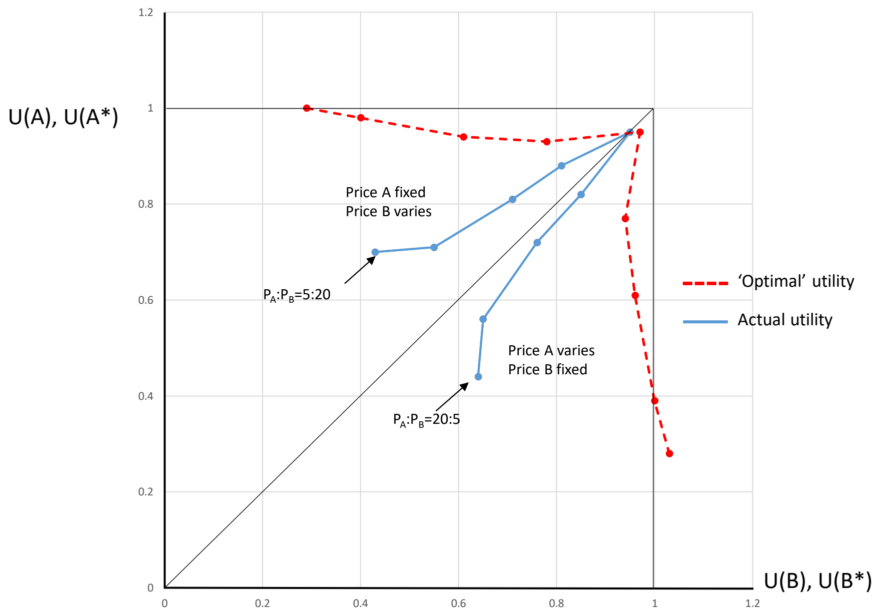


Figure 2 Optimal and realised utility after illness as prices change



Appendix 1 Optimal insurance derived from expected utility theory and health maximising insurance

The expected utility (EU) from purchasing A and B percent insurance against two illnesses is given by equation A.1 and the budget constraint by equation A.2.

$$EU = p_1 U(A) + p_2 U(B) \qquad \text{… equation A.1}$$

$$Bud = [P_A.A] + [P_B.B] \qquad \text{… equation A.2}$$

where p_1, p_2 are the probabilities of the two illnesses which, after maximum treatment permitted by their insurance, yields utilities with present values of U_A and U_B respectively. Incremental insurance can be purchased at prices P_A and P_B which are proportional to expected treatment costs. 'Bud' is the available budget. From equation (1) the percent insurance A and B must satisfy equation A3.

$$\frac{d(EU)}{dA} = 0 = p_1 \cdot \frac{\partial U}{\partial A} + p_2 \cdot \frac{\partial U}{\partial B} \cdot \frac{\partial B}{\partial A} \qquad \text{… equation A.3}$$

From equation A.2 $\qquad B = \{Bud - P_A.A\} / P_B$

$$\frac{\partial B}{\partial A} = -(P_A / P_B)$$

Substituting in A.3 and defining MU

as the marginal benefit of insurance, ie $\qquad \frac{\partial U}{\partial A} = MU_A, \ \frac{\partial U}{\partial B} = MU_B$

$$0 = p_1.MU_A - p_2.MU_B (P_A / P_B)$$

$$\frac{p_1.MU_A}{P_A} = \frac{p_2.MU_B}{P_B} \qquad \text{… equation A.4}$$

As MU is equal to the marginal utility from improved health times the duration of the benefit, it is equal to the incremental QALY gain. Equation A.4 therefore states that EU is maximised when the expected QALY gained per dollar cost is equalised. At the level of the population the standard error of the expected benefit becomes trivially small and the expected benefit may be replaced by the average (incremental) benefit. Equation A.4 becomes equation A.5

$$\frac{M.(BenA)}{P_A} = \frac{M(BenB)}{P_B} \qquad \text{…equation A.5}$$

where M.Ben(A), M.Ben(B) the marginal benefits of A and B respectively are measured as QALYs.

Equation A.5 is the familiar rule for maximising population health. Its derivation here indicates that it may be justified by the argument that it is a necessary consequence of the individual seeking to maximise expected utility.

If an individual has privileged information indicating that their risk differs from p_1 and p_2 their optimal allocation of resources will differ. In the present study respondents were informed that they will definitely contract one of two illnesses but they are not provided with their probabilities. Faced with uncertainty the default assumption is to assume $p_1=p_2=0.5$. Equation A.4 reduces to equation A.6 which is also, therefore, the necessary condition, given these probabilities, for maximising population health. It is reproduced as equation 1 in the main text.

$$\frac{MU_A}{P_A} = \frac{MU_B}{P_B} \qquad \text{… equation A.6}$$

Appendix 2 Editing and its effect

The reasons for deleting cases and the numbers deleted were as follows:

Reason	**Number**
The same VAS score was given for all health states, or The rank order of VAS scores did not follow the sequence ‘no problem’, ‘slight’, ‘extreme’ problem	138
The numbers (1-4) were given as responses to the health states on the 100 point VAS scale	49
The purchase of insurance never changed with its price	16
Total errors/deletions	203*

Table A2.1 reports the average level of selected insurance with the inclusion and exclusion of deleted cases.

Table A2.1 Insurance Selected With and Without Data Editing

Marginal or unit cost (P)		Ratio	% Insurance selected								Ratio of insurance	
			A				B				Edited sample A /Full sample A	Edited sample B /Full sample B
P_A ($000)	P_B ($000)	P_A/P_B	Edited sample	sd	Full sample	sd	Edited sample	sd	Full sample	sd		
0.2	0.05	4.00	31.5	7.5	31.4	8	53.8	30.2	54.4	31.7	1.00	0.99
0.15	0.05	3.00	42.2	9.52	41.6	9.8	53.5	27.6	55.5	29.2	1.01	0.96
0.1	0.05	2.00	58.1	10.6	58	12.4	63.8	21.1	64	24.5	1.00	1.00
0.075	0.05	1.50	70.7	10.7	71	12.5	74	16.1	73.5	18.8	1.00	1.01
0.05	0.05	1.00	90.8	7.5	90.3	7.8	89.2	7.5	89.7	7.8	1.01	0.99
0.05	0.075	0.67	79.1	14.5	77.5	18.1	67.2	9.3	68.4	12.1	1.02	0.98
0.05	0.1	0.50	70.3	16.9	67.7	23	54.9	8.4	56.2	11.5	1.04	0.98
0.05	0.15	0.33	60.2	25.7	60.6	28.1	39.9	8.6	39.8	9.4	0.99	1.00
0.05	0.2	0.25	60.1	27.9	60.7	29.4	30	7	29.8	7.4	0.99	1.01

Appendix 3 Alternative Transformations of VAS values into TTO utilities

The transformation from VAS values to TTO utility used a relationship derived during the construction of the AQoL-8D utility algorithm (14). A total of 162 health states describing the 8 dimensions of the AQoL-8D were evaluated during an interview using both a VAS and a TTO. The sample of 670 individuals interviewed included 323 patients undergoing treatment and 347 demographically representative members of the Australian public. On average each was asked to rate 5.5 health states giving a total 3,714 observations or an average of 23 observations per health state. The 162 average results were used to estimate a number of regression models. The most successful of these was equation A3.1 below.

$$U = 1-(1-V)^{1.62} \qquad \text{…equation A3.1}$$

By comparison, in the construction of the HUI 2 Torrance et al. (15) used 4 points derived from average data to fit the transformation function A 3.2.

$$U = 1-(1-V)^{2.29} \qquad \text{…equation A3.2}$$

where U was estimated using a standard gamble and V employed a VAS.

For the construction of HUI 3 Feeny et al. (16) employed three marker states between death and full health. Two functions were estimated, one for those where the worst health state was worse than death and one for where it was better than death. His selected transformation for the former, larger group is given by A3.3.

$$U = VAS^{0.559} \qquad \text{…equation A3.3}$$

where U was measured as a standard gamble and VAS on a ‘feeling thermometer’.

The difference in predicted utilities from these functions is illustrated below in the Table A3.1. They imply similar results but with a greater concentration of utilities using the

Torrance formula at the top of the scale and a greater inflation of utilities using the Feeny formula at the bottom of the scale. Differences may be explained, to an unknown extent, by the different survey methodologies employed and by the use of a standard gamble rather than the time trade-off as in the estimation of AQoL-8D utilities.

Re-estimating optimal outcomes

The procedures described in the methods section were reapplied to obtain utility and marginal utilities for the two illnesses based upon equation A3.3 which was used to derive 'SG utilities' for the HUI 3. As described 101 pairs of observations (VAS, SG) were obtained for both illness A and illness B for each individual. The SG utilities were regressed upon the level of insurance A or B (n=101×403=40,703). In Table A3.2 resulting utility functions are contrasted with the 'TTO utility functions' used in the main study. Optimal insurance calculated from equation 8 and 10 using parameters from the SG based marginal utility functions are contrasted with those obtained using the TTO based utility functions in Table A3.3. Optimal insurance and optimal utilities are plotted in Figures A3.1 and A3.2.

Table A3.1 Estimated utilities using three transformations

VAS	0.0	0.1	0.2	0.4	0.6	0.8	0.9	1.0
HUI 2[(1)]	0.0	0.21	0.40	0.69	0.88	0.97	0.99	1.0
HUI 3[(2)]	0.0	0.28	0.41	0.60	0.75	0.88	0.94	1.0
AQoL-8D[(3)]	0.0	0.16	0.30	0.56	0.77	0.93	0.98	1.0

(1) Torrance et al 1996; (2) Feeny et al 2002; (3) Richardson et al (2014)

Table A3.2 TTO and SG based utility functions (n=40,703)

Utility	Regression
TTO (A)	$1.60A-0.58A^2$; $t_A=391$ $t_{A^2}=-111$
SG (A)	$1.82A-0.87A^2$; $t_A=525$;$t_{A^2}=-193$
TTO (B)	$1.66B-0.65B^2$; $t_B=389$ $t_{B^2}=-121$
SG (B)	$1.87B-0.92B^2$; $t_B=512$; $t_{B^2}=-197$

Differences between optimal and selected utilities remain significant, but are mitigated by the use of the HUI 3 transformation. Arithmetically, this mitigation is attributable to the greater inflation of low VAS scores by the HUI 3 formula. The HUI 2 transformation produces utilities between AQoL-8D and HUI 3. Results from the use of this formula would therefore lie between the two results reported here.

Table A3.3 SG based results

	Unit cost (P)		Optimal insurance		Difference	Optimal utility		Selected utility		Optimal – selected	
	P_A	P_B	A*	B*	A*-B*	A*	B*	A	B	U(A)*-U(B)*	U(A)-U(B)
5	0.05	0.2	84.94	23.77	61.17	0.92	0.39	0.78	0.47	0.53	0.31
4	0.05	0.15	81.49	32.84	48.65	0.91	0.51	0.78	0.59	0.36	0.19
3	0.05	0.1	78.56	50.72	27.84	0.90	0.71	0.85	0.74	0.19	0.11
2	0.05	0.075	80.52	66.32	14.20	0.91	0.83	0.90	0.83	0.08	0.07
1	0.05	0.05	91.68	88.32	3.35	0.94	0.93	0.94	0.93	0.01	0.01
6	0.075	0.05	68.01	77.99	-9.98	0.84	0.90	0.85	0.87	-0.06	-0.02
7	0.1	0.05	51.84	76.32	-24.48	0.71	0.89	0.76	0.81	-0.18	-0.05
8	0.15	0.05	33.65	79.05	-45.40	0.51	0.90	0.61	0.72	-0.39	-0.11
9	0.2	0.05	24.38	82.49	-58.11	0.39	0.91	0.49	0.73	-0.52	-0.24

Figure A3.1 Optimal insurance derived from TTO and SG based transformations

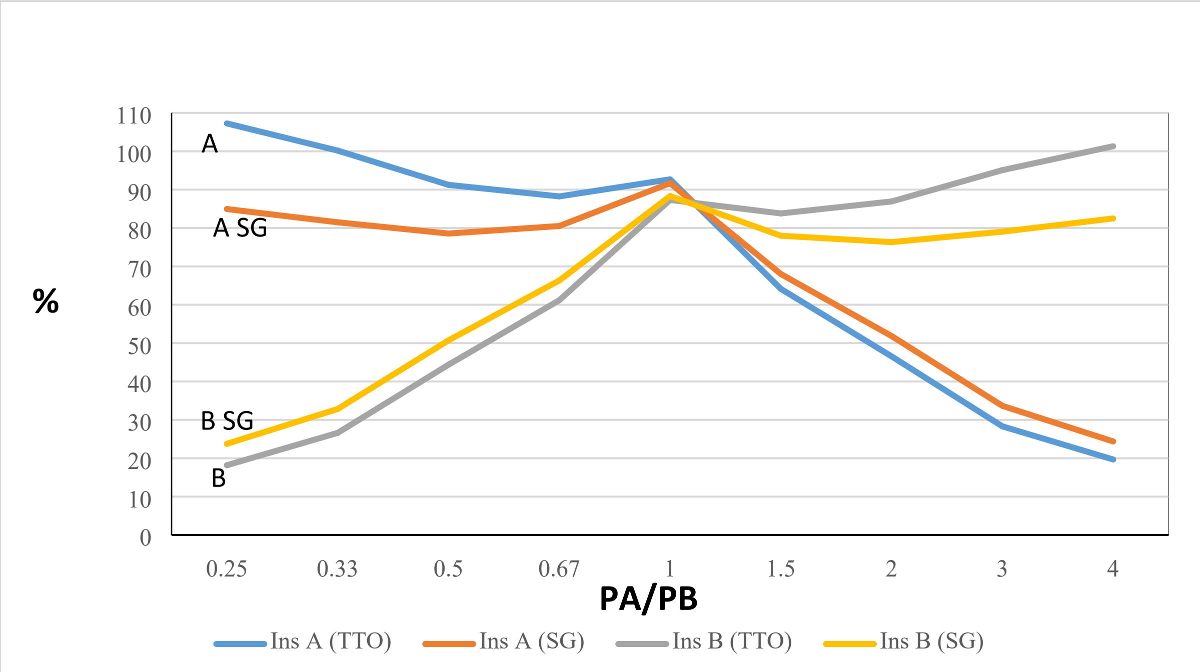
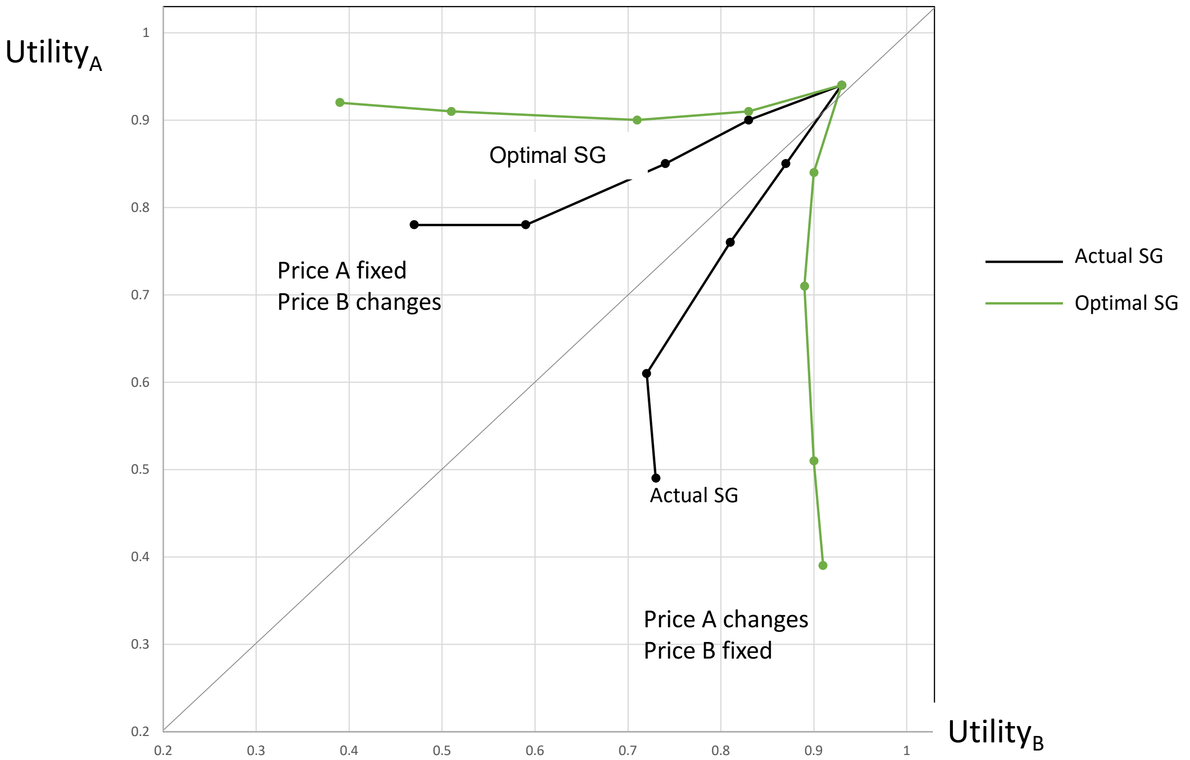


Figure A3.2 Realised and optimal utility derived from SG based transformations



Appendix 4 VAS and TTO utilities

Table A4.1 Mean VAS and estimated TTO utilities for the 8 health states

	Illness A: Problems with mobility and self-care				**Illness B: Problems with pain and depression**			
	VAS		**TTO**		**VAS**		**TTO**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Full health	1.00		1.00		1.00		1.00	
Slight	0.8264	0.1003	0.9319	0.0635	0.8204	0.1096	0.9271	0.0745
Moderate	0.6113	0.1006	0.7765	0.0911	0.6238	0.1249	0.7837	0.1157
Severe	0.3411	0.1073	0.4846	0.1318	0.384	0.1386	0.5323	0.1628
Extreme	0.1644	0.0939	0.2478	0.1328	0.1378	0.084	0.2098	0.1201
Death	0.00	0.00	0.00		0.00		0.00	

Appendix 5 Transcript of the Avatar text and visual aids

Hi, this is a letter from the chief investigator, Professor Jeff Richardson
Thanks for participating in this research project. This survey is part of a larger research program at the Centre for Health Economics at Monash University and is not connected with any political or commercial interest.

Please read the Participation Information which follows.
If you agree to participate click the 'I agree' button at the end.

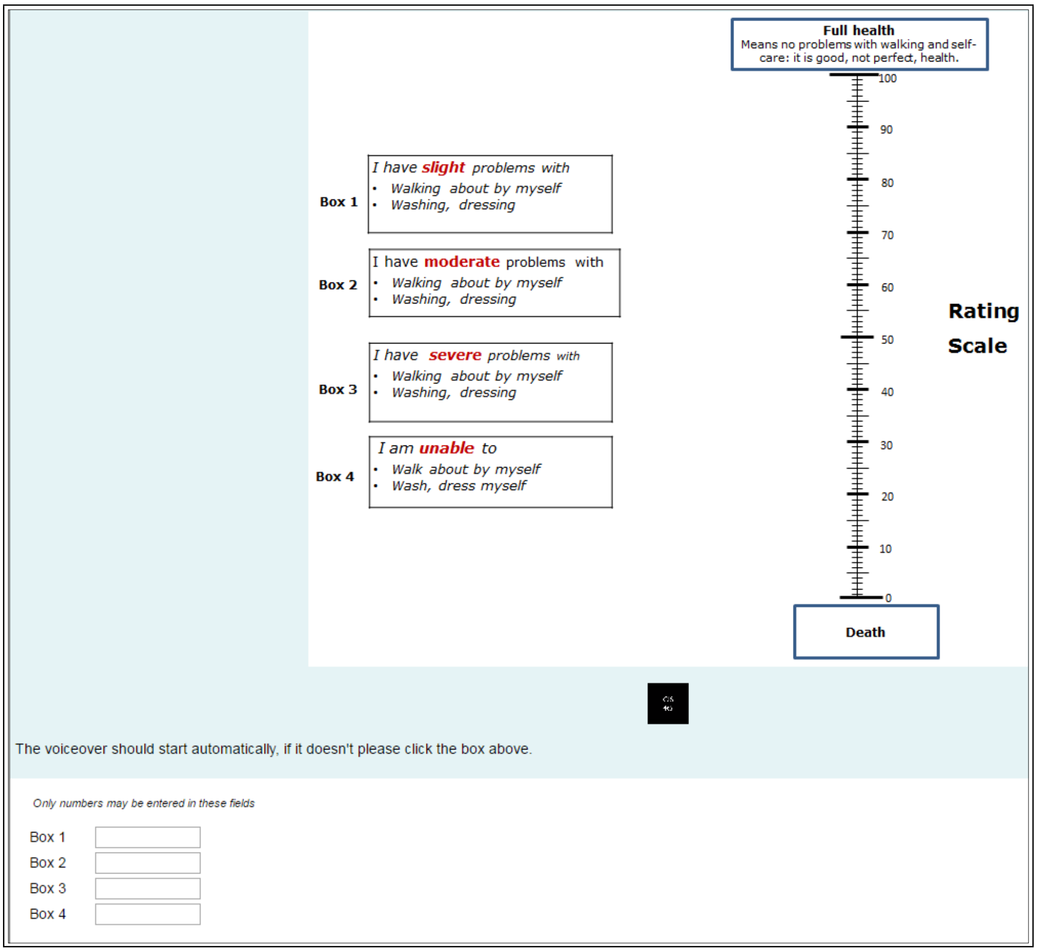
The questions we'll ask you concern the allocation of Medicare's budget. The questions don't deal directly with Medicare. They are artificial and designed to help us understand the type of health services which should be insured by Medicare
It is important that you think carefully about them as the outcome of the study will depend upon your answers.
Also please read the 'INTRODUCTION TO THE QUESTIONS' very carefully – re-read them if necessary to ensure you understand the task before answering the questions.

Thanks for your careful assistance. Your answers will help us understand the sort of services people would like Medicare to insure.
Press NEXT to continue.

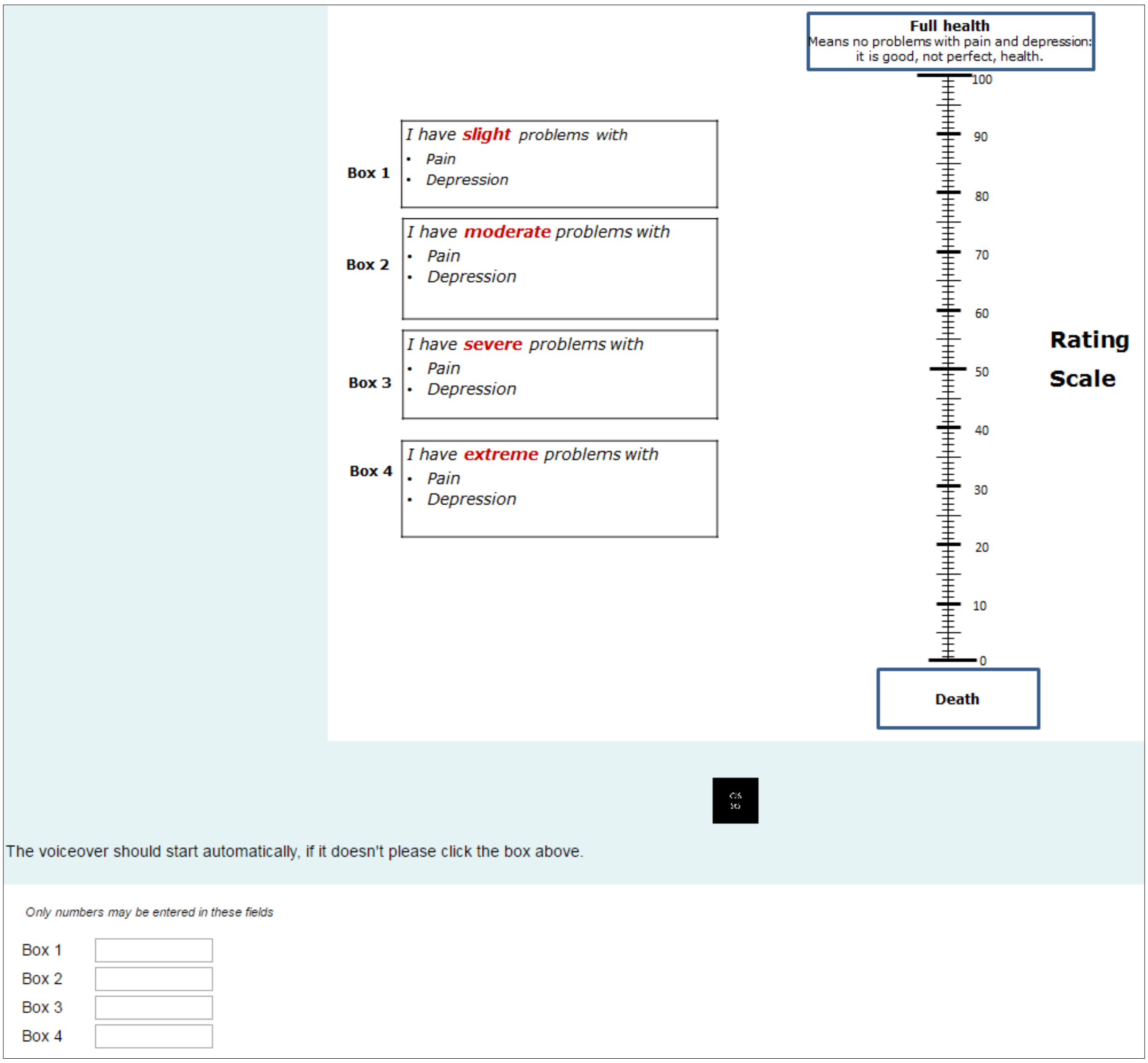
Now rate the 4 health states on the screen. They are about mobility and self care. The levels of severity range from slight to moderate to severe and to extreme (unable to).
Think carefully about them and use the scale to indicate how good or bad you feel they are.

On our scale 'Full Health' does not mean perfect health but 'no problems with moving about by yourself and self care: it is good, not perfect health'.

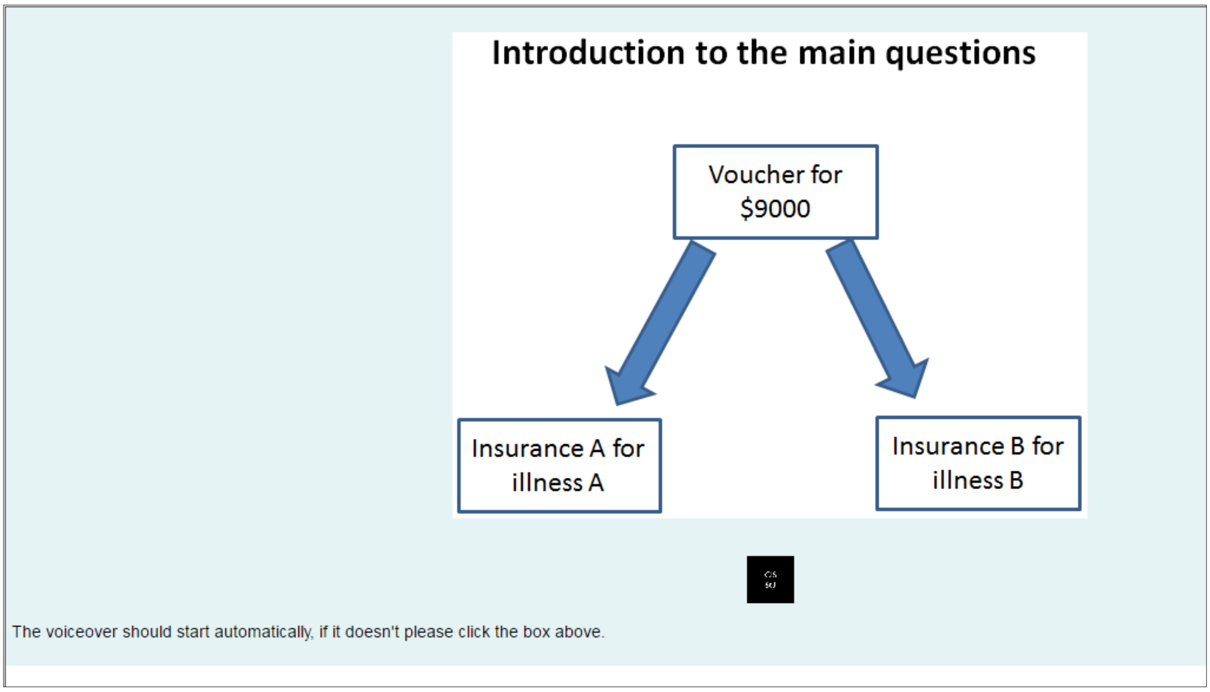
Last and most importantly, you should imagine what it would be like if you were in the health states described. We want to know how strongly you would feel about it. There are no right and wrong answers. The scores tells us how you personally would feel in those health states.
Now enter the numbers corresponding to your ratings of the 4 health states.



Now we'll ask you to rate another 4 health states. These vary the levels of severity of pain and depression from slight problems to extreme problems.
Again please think carefully about them before you use the scale to indicate how good or bad you feel they are and enter your answers in the boxes below.



Thanks.
Now we'll explain the second type of question.

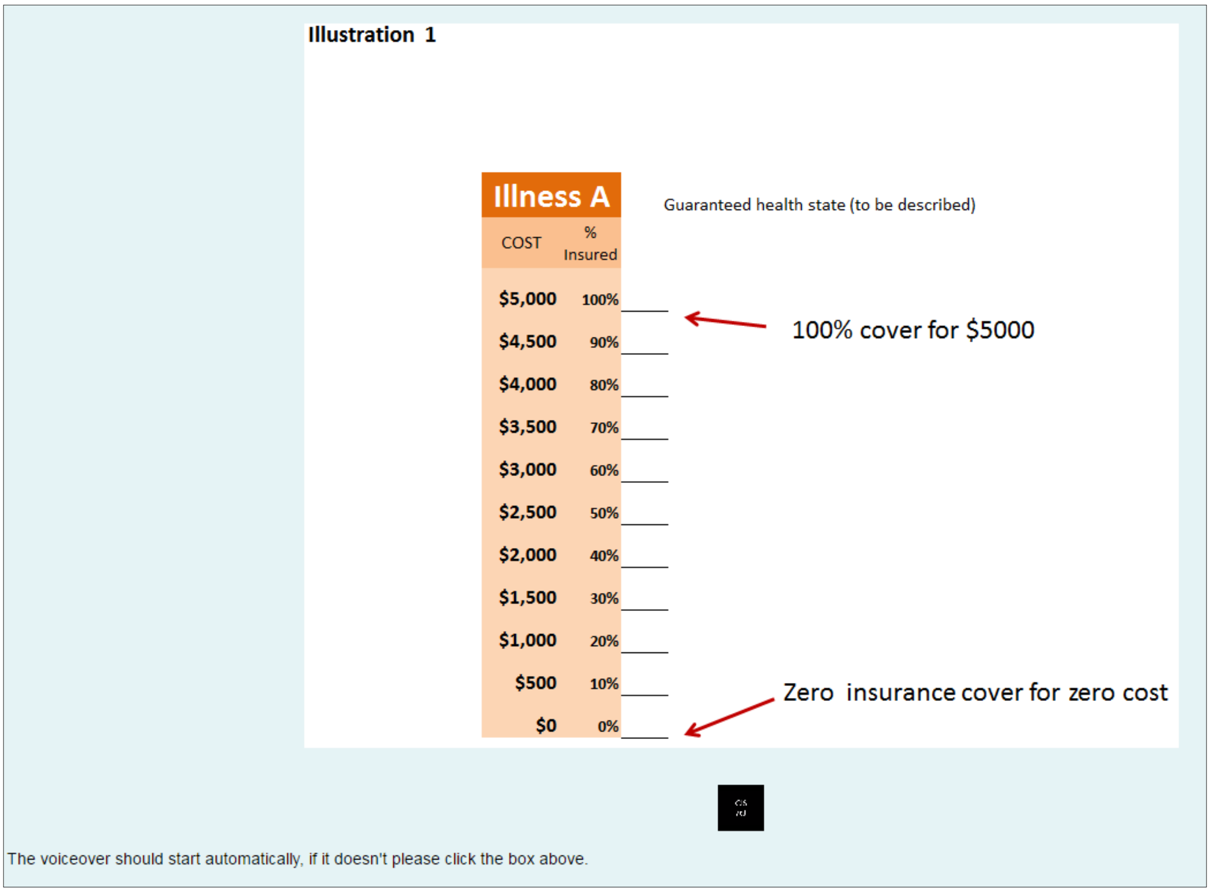


Imagine that the government has scrapped Medicare and replaced it with a scheme which gives people a voucher for $9000. This is so important for this survey I am going to repeat it: imagine that the government has scrapped Medicare and replaced it with a scheme which gives people a voucher for $9000.

You can use the $9000 to buy insurance cover against 2 illnesses which we'll call illness A and illness B. You can vary how much insurance A and insurance B you buy so long as you don't spend more than $9000. <u>You cannot buy extra insurance with your own money.</u>
<u>Please imagine that in the near future you will definitely have either Illness A or Illness B.</u> BUT YOU DO NOT KNOW WHICH ILLNESS IT WILL BE.
Imagine that each level of insurance will buy enough services to guarantee you a particular quality of life.

You can vary how much insurance A and insurance B you buy so long as you don't spend more $9000. The more insurance you buy against illness B, the higher your quality of life if you get illness B.

Some of the questions we'll be asking you below will be very hard. If you spend more on insurance against one illness you will receive more services if you need them and your quality of life will be higher; but you will have less money left over to buy the other type of insurance and your quality of life will be lower if you get the second illness.
Press NEXT to continue.

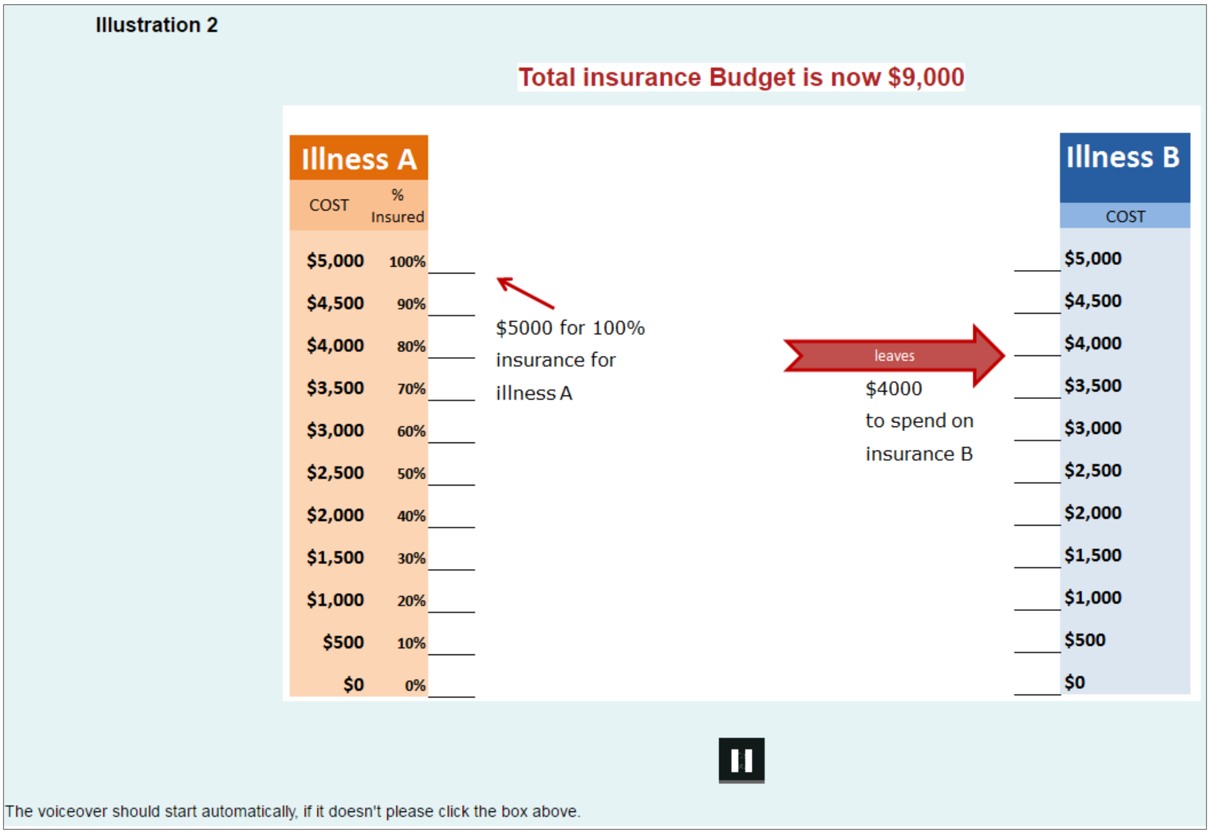


The scale at the left represents different levels of insurance cover against illness A and the cost of the insurance. The scale varies from no insurance cover for no cost to 100% cover for $5000. More insurance will result in better health and a better quality of life but it will leave you with less money to buy insurance against illness B.

Press NEXT to continue.

For example, with a total insurance budget of $9000, if you choose to spend $5000 for 100% insurance for illness A, you will have only $4000 for insurance against illness B.

Press NEXT to continue.



Before you make your final choice it is very important that you check what this means for your health in the columns marked 'Expected health state'.

For Example: You may consider choice 1: spending $5000 on insurance for illness A which leaves $4000 to spend on insurance for illness B.

This would leave you with a slight occasional headache if you got illness A and severe difficulty with walking if you got illness B.

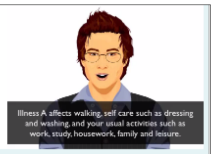
Thinking about this, you might decide to change your mind and buy more insurance B and less insurance A. You might think choice 2 is a better split: the maximum $5000 for B and $4000 for A. The change means that you would have a migraine each week if you got illness A but only slight difficulty running if you got illness B.

Illustration 3

Illness A – Headaches: EXPECTED HEALTH STATE	COST	% Insured	% Insured	COST	Illness B – Moving around: EXPECTED HEALTH STATE
Choice 1: Slight headache occasionally	$5,000	100%	100%	$5,000	Choice 2: Slight difficulty walking
↓	$4,500	90%	90%	$4,500	↑
Choice 2: Migraine each week	$4,000	80%	80%	$4,000	Choice 1: Severe difficulty walking
	$3,500	70%	70%	$3,500	
	$3,000	60%	60%	$3,000	
	$2,500	50%	50%	$2,500	
	$2,000	40%	40%	$2,000	
	$1,500	30%	30%	$1,500	
	$1,000	20%	20%	$1,000	
	$500	10%	10%	$500	
	$0	0%	0%	$0	

The voiceover should start automatically, if it doesn't please click the box above

Press NEXT to continue.



Illness A – Problems with mobility & self-care (washing, dressing): EXPECTED HEALTH STATE	COST	% Insured	% Insured	COST	Illness B – Problems with pain and depression: EXPECTED HEALTH STATE
Full health - no problems	$5,000	100%	100%	$5,000	Full health - no problems
Slight problems with walking and self-care	$4,000	80%	80%	$4,000	Slight pain and depression
Moderate problems with walking and self-care	$3,000	60%	60%	$3,000	Moderate pain and depression
Severe problems with walking and self-care	$2,000	40%	40%	$2,000	Severe pain and depression
Unable to walk and care for myself	$1,000	20%	20%	$1,000	Extreme pain and depression
Death	$0	0%	0%	$0	Death

This example combines all the information you need to make a decision.

Illness A affects walking and moving about by yourself and self care such as dressing and washing yourself. 100% cover will ensure no problems; 60% cover will result in moderate problems in these areas if you develop this illness.
Illness B causes pain and depression. 60% cover will result in moderate problems with pain and depression if you develop this illness.
Remember, it is important before you make your choice to check on each scale what your expected health state will be when you buy insurance and how you would feel if you were in this health state.

In this example full insurance costs $5000 for each disease.
So you would have to make a choice. Complete insurance for both illnesses will cost $5000 + $5000 , a total of $10,000. But your voucher is only for $9000 and you cannot buy extra insurance with your own money.

For each question following we'll ask you to indicate how much you would spend on Insurance A and how much on Insurance B. Remember the maximum you can spend is $9000.

If you'd like to hear this explanation again, you can click on my picture at the top right.

Qn 1

This is the same as the last example.

Illness A affects walking and self-care such as dressing and washing. You have no other health problems. The cost of insurance guaranteeing Full Health is $5000.

Illness B causes pain and mental health problems. You have no other physical health problems. The cost of insurance guaranteeing Full Health is also $5000.

Please slide the button on the slider bar below the pictures to indicate how much you would spend to insure against illness A and illness B.

You can slide the button to any position as long as you stay within both your budget and the maximum amounts for each insurance.

As you move the button, columns for insurance A and insurance B will rise or lower depending on how you choose to split your money. You do not have to split your budget, you may give it all to one insurance if it is within the maximum for that insurance.

In the following questions we'll be increasing the cost of insurance. You'll not be able to buy as much insurance and you will be forced to make some very hard decisions about living in some very poor health states. Please persevere. Part of what we want to know is the type of choices you make when these choices get really tough.

Qn 2

The cost of full insurance for illness B now costs $7500 and $5000 for illness A.

Please divide your $9000 voucher between the two types of insurance using the button on the slider bar at the bottom of the page.

Qn 3

Full insurance for illness B now costs $10,000 and $5000 for illness A.

Please divide your $9000 voucher between the two types of insurance using the slider button.

Qn 4

Full insurance for illness B now costs $15,000 and $5000 for illness A.

Please divide your $9000 voucher between the two types of insurance.

Qn 5

Full insurance for illness B now costs $20,000 and $5000 for illness A.

Please divide your $9000 voucher between the two types of insurance.

Qn 6

Now the maximum cost of insurance to cover against Illness B is $5000.

Full insurance for illness A costs $7500.

Please divide your $9000 voucher between the two types of insurance.

Qn 7

(voice)**Full insurance for illness A now costs $10000 and $5000 for illness B.**

Please divide your $9000 voucher between the two types of insurance.

Qn 8

The cost of 100% insurance for illness A now costs $15000 and $5000 for illness B.

Please divide your $9000 voucher between the two types of insurance.

Qn 9

Great, this is the last question of this kind.

Full insurance for illness A now costs $20000 and $5000 for illness B.

Please divide your $9000 voucher between the two types of insurance.

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