Estimating (quality-adjusted) life-year losses associated with deaths: with application to COVID-19

DOI:
10.1002/hec.4208

Document Version
Accepted author manuscript

Citation for published version (APA):
Briggs, A., Goldstein, D., Kirwin, E., Meacock, R., Pandya, A., Vanness, D., & Wisløff, T. (2021). Estimating (quality-adjusted) life-year losses associated with deaths: with application to COVID-19. *Health Economics* , *30*(3), 699-707. https://doi.org/10.1002/hec.4208

Published in:
Health Economics

Health Economics

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Journal:	*Health Economics*
Manuscript ID	HEC-20-0352.R1
Wiley - Manuscript type:	Health Economics Letter
Keywords:	quality adjusted life years, QALYs, COVID-19, life tables

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Abstract

Many epidemiological models of the COVID-19 pandemic have focused on preventing deaths. Questions have been raised as to the frailty of those succumbing to the COVID-19 infection. In this paper we employ standard life table methods to illustrate how the potential quality-adjusted life-year (QALY) losses associated with COVID-19 fatalities could be estimated, while adjusting for comorbidities in terms of impact on both mortality and quality of life. Contrary to some suggestions in the media, we find that even relatively elderly patients with high levels of comorbidity can still lose substantial life years and QALYs. The simplicity of the method facilitates straightforward international comparisons as the pandemic evolves. In particular, we compare five different countries and show that differences in the average QALY losses for each COVID-19 fatality is driven mainly by differing age distributions for those dying of the disease.

1. Introduction

As the COVID-19 pandemic has taken hold, many of the epidemiological models informing policy making have focused on deaths prevented as an outcome measure. With the increasing death toll from the COVID-19 pandemic, a number of commentators have speculated as to the health burden of deaths associated with the virus. Emerging evidence suggests that COVID-19-related death rates are higher with increasing age and that people with existing health conditions are particularly vulnerable. This has translated, in some branches of the media, into an argument that 'perhaps these frail victims would have died anyway'.[1]

Within health economics, the Quality Adjusted Life Year (QALY) is an accepted outcome measure that is used to inform health policy. Yet an understanding of the need for conditional life-expectancy calculations or the importance of adjusting for (health-related) quality of life are largely absent from the debate around COVID-19. With this in mind, this short paper seeks to outline a simple-to-use methodology for estimating the likely quality-adjusted life year losses associated with premature death from COVID-19. The approach is based on standard life-table methods, conditioning on age and exploring the potential effect of comorbidities. The aim is to better understand the potential losses associated with deaths that occur at different ages, while adjusting for the presence of comorbidities that could affect both mortality and health-related quality of life. A further aim is to provide an approach that is readily adapted to different geographies based on routinely available aggregate data, thereby facilitating international comparisons.

[1] For example, see: https://thehill.com/homenews/media/491994-bill-oreilly-many-dying-from-coronavirus-were-on-last-legs-anyway (accessed, April 28, 2020).

2. Methods

First the standard approach to estimating life-expectancy is outlined with a focus on conditional life-expectancy having reached a given age. We then demonstrate how this standard approach is easily adapted to adjust separately for both mortality and morbidity effects of comorbidity, to give quality adjusted life-expectancy, before applying discounting to give the potential discounted QALY loss associated with a death at any given age.

2.1 Standard life table approach to estimating life-expectancy

Life tables are produced nationally and show the numbers of people dying in one-year age bands across a population. We start by defining $q(x)$ as the probability of dying between ages x and $x + 1$. From this we can calculate $l(x)$, for a reference population of 100,000, the number surviving to age $x \geq 1$ as:

$$l(x) = 100{,}000 \times \prod_{a=1}^{x} \{1 - q(a)\}$$

where $l(0) = 100{,}000$ by definition.

We now define $L(x)$ as the person-years lived between ages x and $x + 1$ for $x \geq 1$:

$$L(x) = \frac{l(x) + l(x+1)}{2},$$

(assuming a uniform distribution of death during the year) and the total number of person-years lived above age x as:

$$T(x) = \sum_{u=x}^{\omega} L(u)$$

where ω is the upper bound of life-expectancy reported in the life table.

Now we calculate the life expectancy at age x as

$$LE(x) = \frac{T(x)}{l(x)}.$$

2.2 Adjusting for comorbidity, quality of life and time preference

Three steps to adjusting the standard method are outlined below in order to introduce: 1) the mortality impacts of comorbidity on life-expectancy; 2) quality of life adjustment to estimate QALYs; and 3) discounting.

Life tables implicitly capture the average comorbidity burden by age. However, those most at risk of COVID-19 death, have pre-existing comorbidities that put them at increased risk of death compared to the average for their age group. In epidemiology, the standardized mortality ratio (SMR) summarizes how a given comorbidity can increase the risk of dying. However, applying SMR directly to the probability of death within a period would risk the probability exceeding one, especially for older ages. We therefore estimate the underlying instantaneous death rate, $d(x) = -ln\{1 - q(x)\}$, that corresponds to the per period death probability, $q(x)$, and apply an SMR parameter to this underlying rate to represent the impact of pre-existing comorbidity. This gives the equation for the reference population surviving to age x, $1 \leq x < \omega$ to give:

$$l_s(x) = 100{,}000 \times \prod_{a=1}^{x} e^{-d(a).SMR}$$

with $L_s(x)$ the average of $l_s(x)$ and $l_s(x+1)$ as previously defined.

Next, we adjust for health-related quality of life in two ways. Standard population norm tables have been published for EQ-5D tariff values that can be used to adjust life-years to give QALYs for many different jurisdictions (Janssen B & Szende A, 2014). These tables give the population average quality of life tariff as a function of age x, $Q(x)$. In order to adjust for the specific impact of pre-existing comorbidity on quality of life, an additional parameter, qCM is defined. Multiplying $L(x)$ by $Q(x)$ and qCM allows the calculation of quality-adjusted $T(x)$ and dividing by $l_s(x)$ gives the quality-adjusted life-expectancy (QALE) at age x:

$$QALE(x) = \frac{\sum_{u=x}^{\omega} L_s(u).Q(u).qCM.}{l_s(x)}$$

The final step in providing an estimate of QALYs lost associated with a premature death at age x is to apply a discount rate r to account for the relative value of life years experienced in the future relative to the present:

$$dQALY(x) = \frac{\sum_{u=x}^{\omega} L(u).Q(u).qCM.(1+r)^{-(u-x)}}{l_s(x)}.$$

Note that the adaptation to the standard life table method uses two separate parameters to represent comorbidity. The *SMR* parameter acts only on mortality, and the qCM parameter acts only on health-related quality of life – therefore these contribute to separate dimensions of the QALY calculation. It is also important to note that the quality adjustment for comorbidity relates to an adjustment for existing co-morbidity that is assumed to remain for the rest of a subject's life. The adjustment is not intended to capture the quality of life impacts of the COVID-19 infection itself.

3. Results

Based on standard life tables published by the UK Office of National Statistics, Table 1 presents the conditional life-expectancy (LE), quality-adjusted life-expectancy (QALE) and discounted QALY (dQALY) by three levels of pre-existing comorbidity (represented by the combination of SMR and reduction on population quality of life for the remainder of life). In addition, the Table includes the relative frequency distribution of age at death for all subjects dying of COVID-19 in the UK to 9 July 2020. These relative frequencies can be used as weights to give the average loss associated with a COVID-19 death in the UK.

Comparable life tables, age distributions at death, and quality of life norms (Xie et al., 2016; Szende A, Janssen B & Cabases J, 2014, Norwegian Medicines Agency, 2018) have been assembled for US, Canada, Norway and Israel (the countries represented by the author team) and the equivalent tables for Table 1 for each of these countries are shown in the appendix. Table 2 summarises the different country results for the scenario of a SMR of 2 and a reduction of 20% on remaining life-expectancy. Overall conditional life-expectancy is broadly comparable across the countries represented in Table 2. However, the differences in weighted mean loss of (quality-adjusted) life-years and discounted QALYs is more marked and is strongly influenced by different patterns in the age distribution at death (see Figure 1) and to a lesser extent differences in the quality of life norms and institutional discount rates for each jurisdiction.

In terms of the method itself, Table 1 can be used to show the sensitivity of the calculations to the various elements. For example, the weighted mean results per death in the final row show that life-expectancy without any mortality or quality of life adjustment is 10.94 years for those dying of COVID-19 in the UK, which reduces to 9.13 (83%) and 7.99 (73%) with SMRs of 1.5 and 2 respectively. Adjusting for quality of life background norms reduces this figure by 2.8 years to 8.14 (74%) with the comorbidity adjustments at 90% and 80% as stated. From this we can infer that both morbidity and mortality effects are important, but that the estimates are reduced to a greater extent by the impact of comorbidities on the SMR than the pure QOL burden of comorbidities and that the impact of background norms is more substantial to the estimated QALY than the part due to morbidity.

Figure 2 shows the burden (for the total population and by million) for each of the five countries using the weighted estimates of burden by case and assuming an SMR of 1.5 and quality of life reduction of 10% to allow for comorbidity (see Table 2). This shows clearly how the impact of the pandemic is greater in UK and the US due to the higher number of deaths. Of course, once the greater population of the US, at over 330M, is taken into account – the absolute burden is highest in the US with approximately 810,000 discounted QALYs and 1.5M undiscounted life-years lost by the end of July 2020.

4. Discussion

Although evidence suggests that those dying from COVID-19 in the first wave of the pandemic are predominantly elderly and with comorbidities, we show that there is, nevertheless, substantial loss of (quality-adjusted) life expectancy associated with these deaths. The methods we use are straightforward to apply and are based on standard actuarial life-table analysis. Similar methods have been used before – for example, Meacock and colleagues (2014) employed a similar measure to estimate QALY gains associated with reducing hospital deaths in their evaluation of pay for performance incentives. Our approach extends the standard approaches to allow for comorbidities, which is pertinent to the current COVID-19 crisis, but is generally applicable to any disease that results in loss of life.

One limitation of our work is that the SMR and discount on remaining quality of life are not empirically estimated. However, the accompanying spreadsheet tool allows the user to vary these components to their specific circumstance and as data emerge on the exact nature of comorbidities among COVID-19 victims these can be easily incorporated. By way of illustration, ischaemic heart disease and diabetes both have SMRs close to 1.5 and a recent study found that the average number of comorbidities in a COVID-19 population was two (Hanlon et al, 2020). This motivated our choice to present illustrative results for SMRs of 1.5 and 2. Similarly, one study that compared the health-related quality of life of people with and without five common chronic conditions found that the quality of life reduced from 92% for hypertension to 80% for stroke (Jai et al 2013). This suggests our values of 10-20% reduction in quality of life due to comorbidity are reasonable.

One issue to bear in mind is that the use of life tables to estimate life-expectancy includes the background rate of comorbidity in the population and therefore the older age groups have a greater background comorbidity rate. This may explain why SMRs among older age groups for the same condition attenuate. Similarly, the population norm quality of life data employed incorporates the background rates of comorbidity on quality of life but the additional quality of life effects of those comorbidities have still to be estimated.

Other limitations are due to the availability of routine data internationally. Our method estimates dQALYs for males and females together. As combined life tables are not consistently published internationally, our method combines life tables as a primary step, assuming that gender balance is equivalent in birth cohorts, as $l(0) = 100{,}000$ for both males and females. The validity of this assumption varies internationally. Second, the distribution of deaths by age group is likely to change as the COVID-19 pandemic continues and is subject to many sources of measurement bias, which vary by jurisdiction. Finally, there are methodological differences in most international quality of life estimates although there have been some efforts to standardise international comparisons (Szende A, Janssen B & Cabases J, 2014).

Despite these limitations, we contend that the relative simplicity of the method has particular advantage in the fast-moving situation of COVID-19 where the situation is evolving rapidly. The use of life tables as the backbone of the approach allows for easy adaptation to different settings and facilitates international comparisons. The accompanying spreadsheet tool, available from <url to be added>, will allow users to not only add data suitable to their own jurisdiction but also to explore the impact of alternative assumptions regarding SMR and quality of life impacts of comorbidities.

A recent working paper contribution by Bassett and colleagues (2020) has shown how life-year measures can be employed to examine racial/ethnic disparities in the burden of COVID-19. They used undiscounted life-years lost before the age of 65 and concluded that more potential years of life were lost by African Americans and Latinos than whites, even though the white population is 3-4 fold larger. Although the outcome they used was specific to their research question relating to disparities particularly in younger age groups, the total life years lost was widely reported in the media as being of the order of 138,000. Our analysis shows that this misses the huge burden that falls on older age groups.

In conclusion, despite QALYs being a widely used outcome measure within the health economics and health services research community, wider policy-making audiences and lay media have been slow to proceed beyond lives-saved as the COVID-19 pandemic has evolved. We illustrate that, with minor modifications, standard methods using routinely reported aggregate statistics can be used to more accurately estimate the true burden of COVID-19 deaths, while contributing to more efficient policy making.

5. References

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Table 1
Life expectancy (LE), quality adjusted life expectancy (QALE) and discounted QALYs (dQALY) as a function of age and SMR, United Kingdom

		SMR=1 | qCM=1 | r=0.035			SMR=1.5 | qCM=0.9 | r=0.035			SMR=2 | qCM=0.8 | r=0.035		
Age	Age at death	LE	QALE	dQALY	LE	QALE	dQALY	LE	QALE	dQALY
0-9	0%	76.65	66.81	25.33	72.72	57.47	22.53	69.86	49.35	19.84
10-19	0%	66.71	56.86	23.61	62.81	48.54	20.89	59.96	41.42	18.31
20-29	0%	56.89	47.44	21.72	53.07	40.11	19.08	50.29	33.98	16.62
30-39	0%	47.18	38.41	19.52	43.47	32.07	16.96	40.80	26.90	14.64
40-49	1%	37.69	29.70	16.73	34.16	24.38	14.30	31.66	20.17	12.19
50-59	5%	28.57	21.92	13.79	25.33	17.58	11.52	23.09	14.30	9.64
60-69	10%	20.06	15.06	10.64	17.28	11.73	8.61	15.42	9.33	7.04
70-79	23%	12.50	9.07	7.14	10.33	6.75	5.50	8.95	5.20	4.34
80-90	40%	6.57	4.77	4.15	5.12	3.34	3.00	4.25	2.47	2.25
90-100	22%	3.04	2.21	2.07	2.24	1.46	1.39	1.78	1.03	1.00
weighted mean		10.14	7.53	5.71	8.42	5.64	4.39	7.33	4.38	3.47

Table 2
*Comparing LE, QALE and dQALYS by country for SMR =2 and qCM = 80%***

	United Kingdom			United States			Canada			Norway			Israel		
Age	LE	QALE	dQALY	LE	QALE	dQALY	LE	QALE	dQALY	LE	QALE	dQALY	LE	QALE	dQALY
0-9	69.86	49.35	19.84	72.72	57.47	22.53	70.62	50.31	21.71	72.08	48.35	16.74	71.34	49.54	21.97
10-19	59.96	41.42	18.31	62.81	48.54	20.89	60.74	42.40	19.78	62.18	41.30	15.92	61.47	41.75	20.27
20-29	50.29	33.98	16.62	53.07	40.11	19.08	51.24	35.42	18.09	52.58	34.55	14.93	51.79	34.16	18.13
30-39	40.80	26.90	14.64	43.47	32.07	16.96	41.92	28.84	16.28	43.00	27.87	13.56	42.17	26.88	15.65
40-49	31.66	20.17	12.19	34.16	24.38	14.30	32.73	22.37	13.97	33.55	21.42	11.81	32.75	20.14	12.90
50-59	23.09	14.30	9.64	25.33	17.58	11.52	24.04	16.43	11.38	24.51	15.47	9.72	23.92	14.18	10.02
60-69	15.42	9.33	7.04	17.28	11.73	8.61	16.22	11.22	8.63	16.38	10.25	7.35	15.93	9.10	7.09
70-79	8.95	5.20	4.34	10.33	6.75	5.50	9.73	6.70	5.65	9.53	5.79	4.68	9.19	5.07	4.32
80-90	4.25	2.47	2.25	5.12	3.34	3.00	4.96	3.42	3.11	4.54	2.76	2.47	4.42	2.44	2.24
90-100	1.78	1.03	1.00	2.24	1.46	1.39	2.10	1.45	1.39	1.73	1.05	1.01	1.89	1.04	1.01
weighted mean	7.33	4.38	3.47	8.42	5.64	4.39	6.32	4.35	3.64	6.93	4.27	3.33	7.74	4.43	3.54

**Discount rates vary by country: UK uses 3.5%, Norway 4%, US, Canada and Israel use 3%

Figure 1
Age distribution among COIVID-19 deaths for UK, US, Canada, Norway and Israel

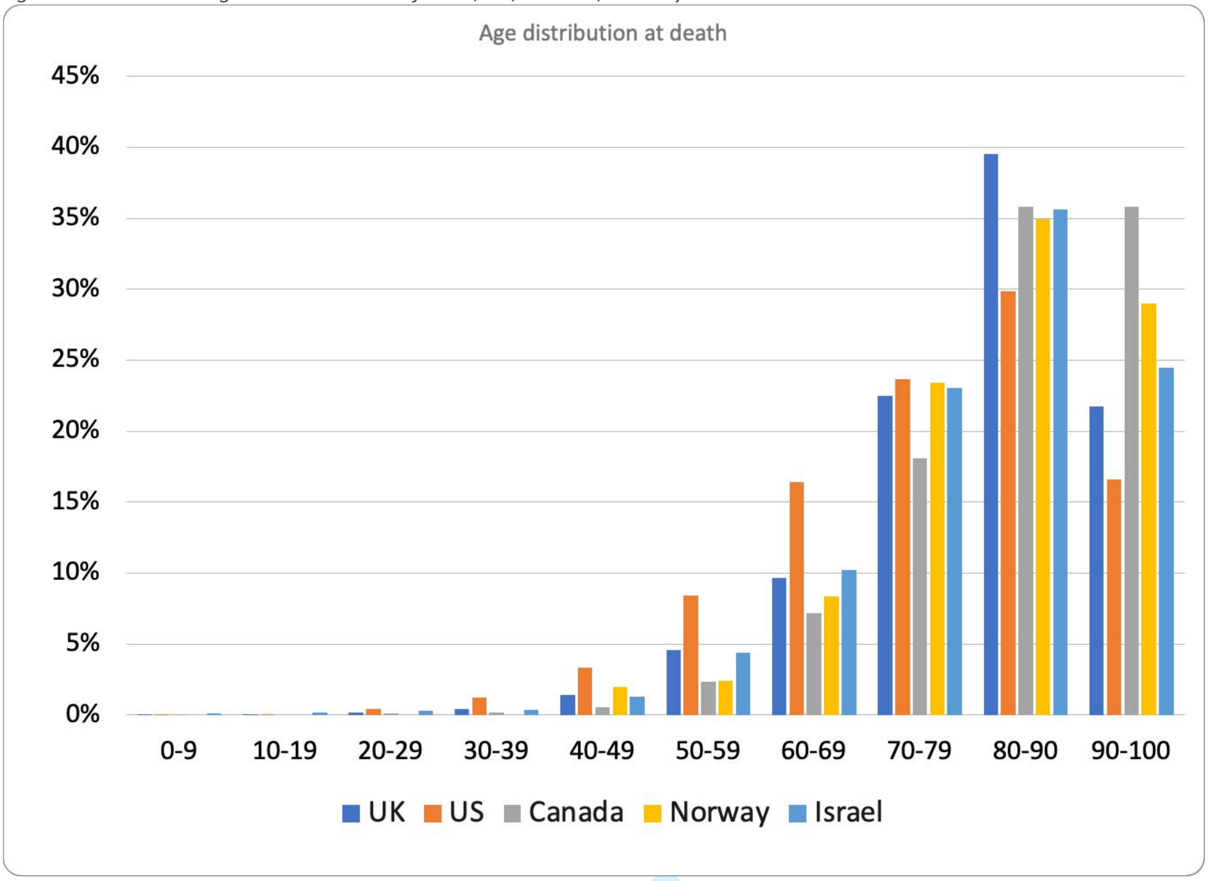

Figure 2
Discounted QALYs, QALE and LE lost due to COVID-19 deaths by country:
Panel A – total losses, and Panel B – losses per million of population

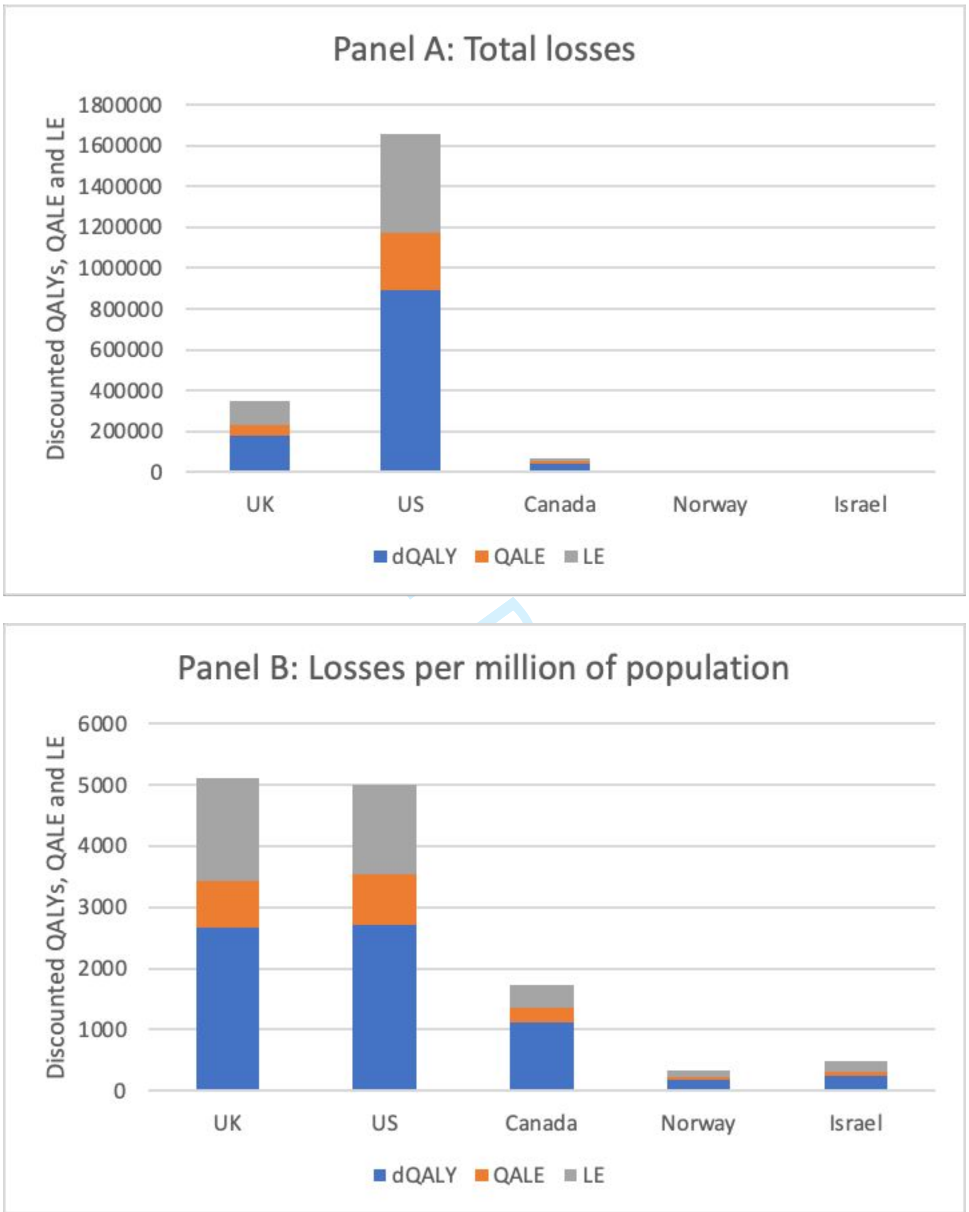

Table A1

Life expectancy (LE), quality adjusted life expectancy (QALE) and discounted QALYs (dQALY) as a function of age and SMR, US

		SMR=1 | qCM=1 | r=0.03			SMR=1.5 | qCM=0.9 | r=0.03			SMR=2 | qCM=0.8 | r=0.03		
Age	Age at death	LE	QALE	dQALY	LE	QALE	dQALY	LE	QALE	dQALY
0-9	0%	74.42	65.49	27.75	69.89	55.72	24.50	66.55	47.40	21.42
10-19	0%	64.52	55.57	25.52	60.02	46.82	22.35	56.72	39.52	19.41
20-29	0%	54.94	46.46	23.29	50.61	38.75	20.20	47.45	32.45	17.41
30-39	1%	45.60	37.90	20.87	41.50	31.23	17.89	38.57	25.91	15.28
40-49	3%	36.39	29.66	17.98	32.57	24.02	15.15	29.87	19.67	12.76
50-59	8%	27.63	22.11	14.81	24.20	17.52	12.19	21.84	14.11	10.08
60-69	16%	19.67	15.42	11.42	16.81	11.92	9.14	14.91	9.44	7.41
70-79	24%	12.49	9.43	7.65	10.30	7.00	5.85	8.90	5.37	4.59
80-90	30%	6.76	5.10	4.51	5.30	3.60	3.26	4.41	2.67	2.45
90-100	17%	3.11	2.35	2.22	2.31	1.57	1.51	1.85	1.12	1.08
weighted mean		13.10	10.23	7.62	11.05	7.81	5.96	9.73	6.13	4.76

Table A2

Life expectancy (LE), quality adjusted life expectancy (QALE) and discounted QALYs (dQALY) as a function of age and SMR, Canada

		SMR=1 | qCM=1 | r=0.03			SMR=1.5 | qCM=0.9 | r=0.03			SMR=2 | qCM=0.8 | r=0.03		
Age	Age at death	LE	QALE	dQALY	LE	QALE	dQALY	LE	QALE	dQALY
0-9	0%	77.66	68.95	27.95	73.59	58.90	24.75	70.62	50.31	21.71
10-19	0%	67.73	59.01	25.79	63.69	49.98	22.68	60.74	42.40	19.78
20-29	0%	58.01	50.10	23.93	54.08	42.05	20.88	51.24	35.42	18.09
30-39	0%	48.40	41.63	21.96	44.62	34.54	18.95	41.92	28.84	16.28
40-49	1%	38.87	33.25	19.40	35.27	27.14	16.47	32.73	22.37	13.97
50-59	2%	29.67	25.39	16.46	26.35	20.27	13.66	24.04	16.43	11.38
60-69	7%	21.08	18.20	13.17	18.18	14.13	10.60	16.22	11.22	8.63
70-79	18%	13.50	11.62	9.29	11.20	8.68	7.17	9.73	6.70	5.65
80-90	36%	7.46	6.43	5.62	5.91	4.58	4.10	4.96	3.42	3.11
90-100	36%	3.53	3.04	2.84	2.62	2.03	1.93	2.10	1.45	1.39
weighted mean		8.93	7.69	6.20	7.32	5.67	4.68	6.32	4.35	3.64

Table A3

Life expectancy (LE), quality adjusted life expectancy (QALE) and discounted QALYs (dQALY) as a function of age and SMR, Norway

		SMR=1 | qCM=1 | r=0.04			SMR=1.5 | qCM=0.9 | r=0.04			SMR=2 | qCM=0.8 | r=0.04		
Age	Age at death	LE	QALE	dQALY	LE	QALE	dQALY	LE	QALE	dQALY
0-9	0%	78.35	65.30	21.27	74.73	56.25	18.97	72.08	48.35	16.74
10-19	0%	68.41	56.45	20.39	64.81	48.30	18.11	62.18	41.30	15.92
20-29	0%	58.63	47.87	19.31	55.12	40.65	17.06	52.58	34.55	14.93
30-39	0%	48.87	39.36	17.83	45.46	33.06	15.61	43.00	27.87	13.56
40-49	2%	39.19	31.12	15.93	35.89	25.73	13.75	33.55	21.42	11.81
50-59	2%	29.76	23.37	13.63	26.68	18.91	11.52	24.51	15.47	9.72
60-69	8%	20.94	16.29	10.88	18.23	12.80	8.92	16.38	10.25	7.35
70-79	23%	13.07	9.93	7.53	10.92	7.47	5.88	9.53	5.79	4.68
80-90	35%	6.81	5.18	4.41	5.39	3.69	3.24	4.54	2.76	2.47
90-100	29%	2.95	2.24	2.08	2.16	1.48	1.41	1.73	1.05	1.01
weighted mean		9.52	7.31	5.45	7.93	5.49	4.21	6.93	4.27	3.33

Table A4

Life expectancy (LE), quality adjusted life expectancy (QALE) and discounted QALYs (dQALY) as a function of age and SMR, Israel

		SMR=1 | qCM=1 | r=0.03			SMR=1.5 | qCM=0.9 | r=0.03			SMR=2 | qCM=0.8 | r=0.03		
Age	Age at death	LE	QALE	dQALY	LE	QALE	dQALY	LE	QALE	dQALY
0-9	0%	77.79	66.56	28.08	74.03	57.49	24.97	71.34	49.54	21.97
10-19	0%	67.86	56.76	26.13	64.14	48.70	23.12	61.47	41.75	20.27
20-29	0%	58.04	47.15	23.67	54.39	40.10	20.80	51.79	34.16	18.13
30-39	0%	48.25	37.92	20.82	44.69	31.86	18.10	42.17	26.88	15.65
40-49	1%	38.59	29.30	17.67	35.15	24.19	15.12	32.75	20.14	12.90
50-59	4%	29.30	21.50	14.29	26.10	17.34	11.95	23.92	14.18	10.02
60-69	10%	20.59	14.61	10.72	17.78	11.40	8.67	15.93	9.10	7.09
70-79	23%	12.85	8.87	7.16	10.60	6.59	5.50	9.19	5.07	4.32
80-90	36%	6.90	4.76	4.20	5.34	3.32	3.00	4.42	2.44	2.24
90-100	24%	3.28	2.26	2.12	2.38	1.48	1.42	1.89	1.04	1.01
weighted mean		10.65	7.55	5.84	8.86	5.68	4.48	7.74	4.43	3.54