

## VALUATION OF CHANGES IN MORTALITY RATES

|  |   |
|--|---|
| Background .....   | 2 |
| Life expectancy increases and full income, 1990-2011 ..... | 3 |
| The value of a life year (VLY), 2000-2011 .....            | 5 |
| Benefits and costs of the convergence agenda .....         | 6 |

### Tables

|  |    |
|--|----|
| Table A3.1 Life expectancy as a function of age for Mozambique (1990), the United States (2005-2010) and Japan (UN Projections for 2045-2050) .....                              | 7  |
| Table A3.2 Loss of life expectancy from a mortality risk of $10^{-4}$ .....  | 8  |
| Table A3.3 Annual mortality rates at different ages and life expectancies in Japan .....   | 9  |
| Table A3.4 Reductions in annual mortality rates associated with a three-year increase in life expectancy in Japan .....  | 10 |
| Table A3.5 Adjusting value of standardized mortality unit (VSMU) for age .....   | 11 |
| Table A3.6 Income and life expectancy, by region - 1990, 2000, and 2011 .....  | 12 |
| Table A3.7 Income per capita with and without health expenditures, by region - 1990, 2000, and 2011 .....  | 13 |
| Table A3.8 Fraction of economic growth attributable to life expectancy improvements, by region, 1990-2000 and 2000-2011 .....  | 14 |
| Table A3.9 Fraction of economic growth attributable to life expectancy improvements, by region, 1990-2000 and 2000-2011 (value of reduction in over-70 mortality excluded) ..... | 17 |
| Table A3.10 Value of a life year (VLY) in 2000-2011 (expressed as a multiple of GDP per capita in 2000) .....  | 18 |
| Table A3.11 Benefits and costs of convergence .....  | 19 |

### Figures

|   |    |
|---|----|
| Figure A3.1 Annual mortality rates as a function of age and life expectancy in Japan .....  | 20 |
| Figure A3.2 The effects of mortality decline among the young and the old on estimates of full income growth: a sensitivity analysis ..... | 21 |

|                  |    |
|------------------|----|
| References ..... | 22 |
|------------------|----|

This Appendix briefly reviews methods used by economists to estimate the value of small changes in mortality rates. As market prices are unavailable for assessing the value of these changes, indirect evidence is employed. The Appendix then utilizes this information for three purposes:

- (i) to define ‘full income’ and to estimate the amount of full income growth that results from mortality change;
- (ii) to estimate the value of a life year (VLY), i.e. the value of a one-year increase in life expectancy in different circumstances; and
- (iii) to estimate the benefits of the convergence agenda discussed in Section 4 of the main paper and to weigh those benefits against the estimated costs of achieving them.

## Background

The economics literature reports the value of changes in mortality in terms of the ‘value of a statistical life’ (VSL) or, sometimes, the ‘value of a statistical life year’ (VSLY). Viscusi and Aldy report the results of a large number of such studies.<sup>1</sup> Assessments of VSL start from assessment of how much compensation individuals need (or say they would need) to accept a small increase in the probability of their death over a short time period, typically one year. Rather complex constructions are often then used to transform this small number into a VSL.<sup>2,3</sup> Cameron discusses reasons that this transformation and the VSL terminology itself can obscure communication.<sup>4</sup> As the application of valuation of small mortality changes can proceed without that transformation, this report follows Cameron in eschewing use of the term ‘VSL’.

Change in mortality risk can be expressed in a mathematically equivalent way in terms of change in life expectancy, given an underlying survival curve. It will often aid intuition to do so. This note describes the calculation of the ‘value of a life year’ (VLY) in terms of the change in mortality rates associated with a one year increase in life expectancy.

A population’s age-specific mortality rates at a point in time can be expressed in terms of a survival curve,  $s(a)$ , where

$s(a)$  gives the probability of survival to age  $(a)$ . [ $s(a)$  is the inverse cumulative of the distribution of age of death.] Alternatively, age-specific mortality rates can be expressed directly as a ‘hazard’ function,  $\mu(a)$  where:

$$\mu(a) = - \left[ \frac{s'(a)}{s(a)} \right], \text{ or} \quad (1)$$

$$s(a) = e^{- \int_0^a \mu(a) da}. \quad (2)$$

Life expectancy at birth,  $e(0)$ , is simply the integral of the survival curve:

$$e(0) = \int_0^\infty s(a) da. \quad (3)$$

The expected years of life remaining for an individual who has survived to age  $a$ ,  $e(a)$ , is given by:

$$e(a) = \frac{1}{s(a)} \int_a^\infty s(a) da. \quad (4)$$

Table A3.1 shows  $e(a)$  for selected values of  $a$  for three survival curves- those associated with Mozambique in 1990, the United States in 2008 and (projected) for Japan in 2045-50.

The translation from change in mortality risk to gain (or loss) in life expectancy goes from the initial survival curve [and related  $e(a)$ ] through the change in the hazard function,  $\Delta\mu(a)$ , to the new survival curve (equation 2) and its life expectancy. The calculation simplifies if the change in mortality rate can be viewed as concentrated at a single age. Empirical assessments of the value placed on mortality change are often undertaken in terms of the change in annual mortality rate extended over one year. In particular, since the changes in annual mortality rates being valued are typically on the order of 1/10,000 per year for one year, it is a reasonable approximation to assume an instantaneous change in mortality of  $m$  (where we can think of  $m$  as on the

order of  $10^{-4}$ ). If this occurs at age  $a^*$ , the ‘new’ survival curve  $s_n(a)$  is given by:

$$s_n(a) = \begin{cases} s(a) & 0 \leq a < a^* \\ (1 - m)s(a) & a \geq a^*. \end{cases} \quad (5)$$

The life expectancy difference at age  $a^*$  for the two survival curves is then:

$$\begin{aligned} \Delta \text{life expectancy} &= \frac{1}{s(a^*)} \int_{a^*}^{\infty} s(a) da - \frac{1}{s(a^*)} \left[ \int_{a^*}^{\infty} (1 - m)s(a) da \right] \\ &= e(a^*) + me(a^*) - e(a^*) = me(a^*). \end{aligned} \quad (6)$$

From equation 6 and using values of  $e(a)$  from Table A3.1 (but expressed in days rather than years), we have the life expectancy loss associated with  $m$  and  $a^*$  given in Table A3.2. For a 30 year old Mozambican male in 1990, for example, a mortality risk of  $10^{-4}$  ( $= 10^{-4}/\text{year} \times 1 \text{ year}$ ) is 1.2 days. To give a sense of the magnitude of a  $10^{-4}$  mortality risk, the risk of death from general anesthesia for a healthy person has probably declined from about  $10^{-4}$  to  $10^{-5}$  in the past 40 years.

Hammitt and Robinson suggest that average remaining life expectancy in U.S. VSL studies is around 45 years and they point to VSL studies in the US that result in a value of 1.4% of annual income of a  $10^{-4}$  mortality risk, corresponding at the time to a VSL (for a 35 year old) of \$6.3 million.<sup>3</sup> To put this same result in terms of the value of reduced life expectancy, the value of a one day loss in life expectancy is about 0.9% of annual income.

We seek to estimate the contribution of small changes in life expectancy to changes in full income for a broad range of initial life expectancies. Japan provides good historical data that will allow us to approximate changes in age specific mortality rates for other countries, at different levels of life expectancy (Tables A3.3 and A3.4; Figure A3.1). We use the term *standardized mortality unit* (SMU) to denote a risk of death of  $10^{-4}$  and our tables and figures use SMUs as their units.

### Life expectancy increases and full income, 1990-2011

Over 40 years ago, Dan Usher made the observation that among the important omissions from GNP was any measure of the value of changes in the health of a country’s population.<sup>5</sup> Yet (early) information was available on the value individuals placed on small changes in risk of death. Usher utilized this information to calculate—for a number of countries—the value of changes in life expectancy and to compare that value to the value of change in GNP. In an important historical study for the U.S., Nordhaus used methods evolved from those of Usher to conclude that in the first half of the 20th century the value of mortality reduction was somewhat larger than the value of increase in GDP, whereas in the second half of the century, it was somewhat smaller.<sup>6</sup> What was remarkable empirically is that—since GDP in the U.S. had grown six-fold during the century—the value of mortality reduction was enormous. In another significant contribution, Becker et al. found, using similar methods, that global inequality has been decreasing when the value of mortality decline is considered, although it is rapidly increasing when GDP alone is considered.<sup>7</sup>

GDP as a measure fails to include not only the value of changes in mortality, but also the cost of natural resource depletion, the cost of environmental degradation, and other potentially important factors. Nonetheless the term ‘full income’ change is being used to denote measures that include change in GDP plus the value of change in mortality. While acknowledging that the term ‘full income’ is incomplete, we use it in conformance with increasingly common usage.

In this section we assess the value of changes in full income for countries grouped by World Bank region for the periods 1990 to 2000 and 2000 to 2011. To do this, we use World Bank data on GDP and on life expectancy.<sup>8</sup> To obtain the value of changes in mortality, we transform changes in life expectancy into changes in age-specific mortality rates at all ages. This requires underlying survival curves appropriate to different life expectancies and, as a reasonable approximation, we use Japanese survival curves from 1947 (life expectancy = 52 years) through 1995 (life expectancy = 80 years). Table A3.3 shows these numbers expressed in terms of mortality rates.

In order to assess the value of a changed survival curve resulting from a change in life expectancy, we need to place a value on the changes in mortality that occurs at each age. This is a problem. Most of the empirical research reported in the VSL literature provide assessments of the value of reducing mortality by, say,  $10^{-4}$  (or one SMU) for people in middle age.<sup>3</sup> If the value of an SMU (or VSMU) for a 35 year old is estimated, as they do, at 1.4% of annual income, what would be the value for an 85 year old? The  $10^{-4}$  risk costs the 35 year old 1.6 days of life expectancy, but costs the 85 year old only about 4 hours. Our analysis makes various assumptions about how to assign value to a mortality change of one SMU at different ages, but each is a variant of assuming that value as a function of age is directly proportional to the years of life lost at that age, relative to the reference age of 35 (for which we have empirical estimates of the VSMU). i.e.

$$VSMU(a) = \frac{e(a)}{e(35)} [VSMU(35)] . \quad (7)$$

Table A3.5 shows values. Crawford et al, Cropper et al, Aldy and Viscusi and the Institute of Medicine each adduce empirical evidence that deaths at older ages relative to middle age —i.e. with fewer life-years to lose—tend to be discounted relative to younger deaths.<sup>9-12</sup> Tierney has documented political difficulties associated with this perspective, however.<sup>13</sup>

We take from the VSL literature (e.g. Hammitt and Robinson) that a reasonable value for high-income countries of VSMU (35) is:

$$\begin{aligned} VSMU(35) &= 180 \text{ (GDP per capita)} (10^{-4}) \\ &= 1.8\% \text{ of GDP per capita} . \quad (8) \end{aligned}$$

( $180 \times \text{GDP per capita}$  is the VSL. There is much discussion concerning how the ratio of VSL to income might vary with income but the assumption of constancy is both reasonable and simple so that is what we assume.)

The value to a country of changes in survival at different ages will, of course, depend on the density of the age

distribution of its population, call it  $n(a)$ . The difference in SMUs at age  $a$  associated with two different life expectancies we denote as  $\Delta SMU(e_i, e_j)$ , where  $e_i$  is earlier life expectancy and  $e_j$  is the later one. Table A3.4 shows values for when  $e_j$  exceeds  $e_i$  by 3 years. For example, if initial life expectancy is 65 years, the table shows that a gain of 9 SMUs for a 45 year old would be associated with increasing life expectancy from the initial 65 years to 68 years. That is, with that increase in life expectancy, the probability of dying in the year following the 65th birthday would decline by  $9 \times 10^{-4}$ .

The following equation then gives us the annual per capita value of an increase in life expectancy from  $e_i$  to  $e_j$  years when GDP is  $y$  per capita:

$$V(e_i, e_j, y) = \int_0^\infty n(a) VSMU(a) \Delta SMU(e_i, e_j) da . \quad (9)$$

From equations (7) and (8) this becomes:

$$V(e_i, e_j, y) = 0.018y \int_0^\infty n(a) \Delta SMU(e_i, e_j) \frac{e(a)}{e(35)} da . \quad (10)$$

Equation (10) is our basic equation. From Table A3.4, we can approximate values for  $\Delta SMU(e_i, e_j)$  and from Table A3.5, we can approximate values for  $e(a)/e(35)$ . World Bank data sets provide relevant information on  $y$  and United Nations Population Division data sets provide relevant information on  $n(a)$ .<sup>8,14</sup>

We use equation (10) to provide estimates of the value of mortality decline for the World Bank's regional groupings of countries for the periods 1990-2000 and 2000-2011. Because our calculations will add a value associated with mortality decline to GDP change in order to obtain change in full income, we feel it appropriate to adjust our concept of income by subtracting expenditures on health. Table A3.6 presents the relevant data on income and on life expectancy. (Table A3.7 shows income figures both including and excluding health expenditures as well as the percent difference between these numbers.)

Table A3.8a shows the results of our calculations of full income. The first two columns show, for the periods 1990-2000 and 2000-2011, the value of the change in mortality over that period calculated from equation (10). For example, the table shows that for low- and middle-income countries as a group for the period 2000-2011 that the annual value of mortality change was \$667 or 2.4% of the value of income per capita in 2000. The associated increase in life expectancy (Table A3.6) was from 65 to 67.9 years. Full income growth for 2000-2011 was \$667 plus the growth in income per capita (excluding health expenditures) of \$1625 for a total of \$2293, as shown in the 4th column of Table A3.8a. Thus, in this period, the value of mortality decline accounted for 29% of growth in full income. In high-income countries in this period, mortality decline accounted for 58% of the growth in full income, although that large fraction reflects slow income growth across the high income countries.

For countries with initially low levels of life expectancy, much of any life expectancy gain results from declines in infant and child mortality. It is plausible that many societies and individuals will value reducing death rates at very young ages less than reducing death rates among, say, 25 year olds. In such instances, equation (7) would prove invalid for younger ages. Empirical evidence on this point is limited but following Institute of Medicine and Jamison et al, we adjust values downward by 50% in 0-4 year olds.<sup>12,15</sup> We also assess the effects of a more extreme adjustment by placing no value on reductions in mortality rates below age 10. Tables A3.8b and A3.8c show results based on these alternative assumptions. For the high income countries, results are essentially invariant with respect to these alternative assumptions, but for initially high mortality regions, the effects are substantial. In South Asia, for example, the annual value of mortality decline in 2000-2011 assuming full weighting of child deaths (equation 7) is 3.9% of initial GDP. Assigning no value to reducing under-10 mortality reduces this to 1.6%. Including mortality reduction at all ages, but discounting child mortality (Table A3.8b) gives the intermediate value of 2.9%. *We use Table A3.8b for our headline figures in the main text.*

To illustrate how much of mortality change in low mortality environments results from reduction in mortality rates at older ages, we retained the formulation of equation (7) except that we assigned no value to mortality rate reductions over age 70 (Table A3.9). This drops the annual value of mortality change in high income countries from 1% of GDP to about 0.4%: 60% of all the value of the life expectancy increase of 2.5 years in the high income countries in 2000-2011 resulted from declines in over-70 mortality rates.

Figure A3.2 illustrates the importance of assumptions concerning the value of mortality reductions at different ages. The first panel, for South Asia 1990-2000, shows no sensitivity to the assumption made about value of mortality reduction at older ages but shows great sensitivity to assumptions about child mortality. The second panel, for high-income countries in 2000-2011 shows the opposite pattern.

### The value of a life year (VLY), 2000-2011

The preceding discussion has led to estimates of the annual value of changing life expectancy from  $e_i$  years to  $e_j$  years when income is  $y$ . Our headline results Table A3.8b shows these values to range across regions in 2000-2011 from 1.0% to 5.7% of GDP. The word ‘annual’ is central to interpreting these results. The change in life expectancy is assumed to be permanent and hence reductions in age-specific mortality rates are assumed to be permanent. That is, the mortality reductions whose value we estimate recur year after year. It is natural to ask what the sum of the value is of the mortality changes over time. Answering this question requires assuming a value,  $r$ , for the discount rate that translates the value of a mortality rate reduction in the future to its ‘present value’. Assuming that the discount rate is constant over time, we can calculate for each region the present value of its life expectancy gain and standardize to get the value of a 1-year gain in life expectancy or VLY:

$$VLY = r^{-1}V(e_i e_j, y)/(e_j - e_i) . \quad (11)$$

Table A3.10 shows VLYs (expressed as a multiple of y) for different regions in the period 2000-2011 for discount rates of 3% per year and 7% per year. We consider 3% the more reasonable number to use.<sup>11</sup> At 3% the value of a one year increase in life expectancy in the low- and middle-income countries, for example, is estimated to be 2.3 times per capita income.

### Benefits and costs of the convergence agenda

The main text of the paper reports the results of an extensive effort to model the inputs required (and their costs) to achieve a ‘grand convergence’ by 2035. This convergence would bring mortality levels from maternal and childhood conditions, from TB and from AIDS to levels now achieved by high-performing middle income countries. The paper (and accompanying Appendices 4 and 5) details the consequences and the costs associated with the convergence agenda.

Using the approach to valuing changes in mortality reduction discussed earlier in this Appendix we can estimate the benefits, costs and benefit:cost ratios associated with that agenda. Our approach attempts only to provide first, approximate estimates (separately for low and for lower middle income countries). The general magnitude of the finally estimated B:C ratios—9 for low income countries, 20 for lower middle income ones—is sufficiently high that the results are robust to any alternative using remotely similar methods.

Table A3.11 shows the key parameters and results of the analysis. The notes to that table describe the methods. Three points are worth making in interpretation. First, the estimates of benefits exclude consideration of the value of fertility reduction and the value of control of nonfatal illness. Second, one would need to revise the value of mortality reduction downward by an order of magnitude to qualitatively affect the results. Third, a study closely related to ours—Stenberg et al—assessed benefits and costs of improving women’s and children’s health.<sup>16</sup> Although their assumptions differed in some respects, their estimated B:C ratios were close to but a little smaller than ours.

**Table A3.1 Life expectancy as a function of age for Mozambique (1990), the United States (2005-2010) and Japan (UN Projections for 2045-2050)**

| Age a | Life expectancy at age a for Mozambique in 1990, years | Life expectancy at age a for the United States in 2008, years | Life expectancy at age a for Japan in 2045-2050, years |
|-------|--|---|--|
| 0     | 42.3   | 78.3  | 87.2   |
| 1     | 49.7   | 77.8  | 86.4   |
| 5     | 51   | 73.9  | 82.5   |
| 10    | 47.4   | 68.9  | 77.5   |
| 15    | 43   | 64  | 72.5   |
| 20    | 38.8   | 59.2  | 67.6   |
| 25    | 35.4   | 54.4  | 62.6   |
| 30    | 32.3   | 49.7  | 57.7   |
| 35    | 29.3   | 45  | 52.7   |
| 40    | 26.3   | 40.3  | 47.8   |
| 45    | 23.1   | 35.7  | 43   |
| 50    | 19.9   | 31.2  | 38.2   |
| 55    | 16.7   | 27  | 33.4   |
| 60    | 13.9   | 22.8  | 28.8   |
| 65    | 11.2   | 19  | 24.4   |
| 70    | 8.7  | 15.4  | 20.2   |
| 75    | 6.7  | 12.1  | 16.3   |
| 80    | 5.1  | 9.2   | 12.7   |
| 85    | 3.9  | 6.8   | 9.6  |
| 90    | 2.9  | 4.8   | 7  |
| 95    | 2.2  | 3.3   | 4.7  |
| 100   | 1.7  | 2.3   | 2.2  |

Data for Mozambique and the United States from reference 17.

Data for Japan from reference 14.

Table A3.2

**Loss of life expectancy from a mortality risk of  $10^{-4}$**

| a* = age of incidence of mortality risk m ( $=10^{-4}$ ) | Loss of life expectancy (days) |                 |
|--|--------------------------------|-----------------|
|  | Mozambique 1990                | Japan 2045-2050 |
| 15 years   | 1.6 days                       | 2.6 days        |
| 30 years   | 1.2 days                       | 2.1 days        |
| 45 years   | 0.8 days                       | 1.1 days        |

Table A3.3

## Annual mortality rates at different ages and life expectancies in Japan

| Life expectancy | 1q1 | 1q7 | 1q15 | 1q25 | 1q35 | 1q45 | 1q55 | 1q65 | 1q75 | 1q85 |
|-----------------|-----|-----|------|------|------|------|------|------|------|------|
| 52 (1947)       | 331 | 32  | 30   | 85   | 77   | 94   | 188  | 411  | 962  | 2267 |
| 53              | 304 | 30  | 29   | 83   | 75   | 92   | 183  | 400  | 922  | 2184 |
| 54              | 277 | 28  | 28   | 81   | 73   | 90   | 179  | 389  | 882  | 2101 |
| 55              | 250 | 25  | 26   | 80   | 71   | 88   | 174  | 377  | 842  | 2018 |
| 56              | 223 | 23  | 25   | 78   | 69   | 86   | 169  | 366  | 803  | 1935 |
| 57 (1948)       | 197 | 21  | 24   | 76   | 67   | 84   | 165  | 355  | 763  | 1853 |
| 58 (1949)       | 184 | 21  | 20   | 67   | 60   | 82   | 154  | 350  | 767  | 1765 |
| 59 (1950)       | 144 | 19  | 16   | 54   | 54   | 77   | 149  | 354  | 828  | 1890 |
| 60              | 136 | 18  | 14   | 47   | 49   | 72   | 145  | 346  | 828  | 1844 |
| 61 (1951)       | 128 | 18  | 13   | 40   | 44   | 66   | 142  | 338  | 827  | 1798 |
| 62              | 108 | 16  | 12   | 36   | 41   | 64   | 135  | 335  | 804  | 1786 |
| 63 (1952)       | 89  | 14  | 10   | 32   | 37   | 62   | 129  | 332  | 782  | 1775 |
| 64 (1954)       | 69  | 13  | 8    | 29   | 32   | 56   | 121  | 300  | 749  | 1677 |
| 65 (1957)       | 53  | 10  | 8    | 23   | 29   | 53   | 126  | 310  | 835  | 1987 |
| 66              | 48  | 10  | 8    | 23   | 28   | 50   | 120  | 294  | 779  | 1815 |
| 67 (1958)       | 43  | 10  | 7    | 22   | 26   | 48   | 115  | 279  | 723  | 1644 |
| 68 (1960)       | 36  | 8   | 6    | 19   | 24   | 44   | 111  | 282  | 768  | 1784 |
| 69 (1962)       | 30  | 7   | 6    | 16   | 22   | 42   | 104  | 268  | 781  | 1883 |
| 70 (1964)       | 23  | 6   | 5    | 14   | 20   | 37   | 96   | 251  | 702  | 1712 |
| 71 (1966)       | 20  | 6   | 5    | 13   | 20   | 37   | 90   | 245  | 644  | 1673 |
| 72 (1970)       | 17  | 5   | 5    | 11   | 17   | 34   | 82   | 231  | 657  | 1655 |
| 73 (1971)       | 16  | 4   | 4    | 9    | 16   | 33   | 76   | 207  | 599  | 1515 |
| 74 (1974)       | 15  | 4   | 4    | 9    | 13   | 31   | 66   | 191  | 558  | 1565 |
| 75 (1976)       | 12  | 4   | 3    | 8    | 12   | 31   | 63   | 173  | 513  | 1485 |
| 76 (1979)       | 11  | 3   | 3    | 7    | 11   | 27   | 59   | 150  | 452  | 1300 |
| 77 (1982)       | 10  | 2   | 3    | 6    | 10   | 24   | 58   | 136  | 427  | 1200 |
| 78 (1985)       | 8   | 2   | 3    | 6    | 9    | 22   | 56   | 127  | 383  | 1178 |
| 79 (1990)       | 8   | 2   | 2    | 6    | 8    | 19   | 51   | 116  | 330  | 1079 |
| 80 (1995)       | 7   | 2   | 3    | 5    | 8    | 20   | 48   | 117  | 307  | 948  |

Data from reference 18.

**Note:** The table shows the probability (per 10,000) that an individual die in the one year following the 1st, 7th, 15th, 25th, 35th, 45th, 55th, 65th, and 75th birthdays, for different life expectancies based on the historical experience of Japan.

Table A3.4

## Reductions in annual mortality rates associated with a three-year increase in life expectancy in Japan

| Initial life expectancy (years) | Reductions in mortality rate in SMUs at age |   |    |    |    |    |    |    |     |      |
|---------------------------------|---|---|----|----|----|----|----|----|-----|------|
|                                 | 1   | 7 | 15 | 25 | 35 | 45 | 55 | 65 | 75  | 85   |
| 52                              | 80  | 6 | 4  | 5  | 6  | 6  | 14 | 33 | 119 | 249  |
| 53                              | 80  | 6 | 4  | 5  | 6  | 6  | 14 | 33 | 119 | 249  |
| 54                              | 80  | 6 | 4  | 5  | 6  | 6  | 14 | 33 | 119 | 249  |
| 55                              | 66  | 5 | 7  | 13 | 11 | 6  | 20 | 27 | 76  | 254  |
| 56                              | 79  | 4 | 10 | 25 | 15 | 9  | 21 | 13 | -25 | 46   |
| 57                              | 61  | 3 | 10 | 30 | 18 | 13 | 20 | 9  | -64 | 9    |
| 58                              | 57  | 3 | 7  | 26 | 16 | 16 | 12 | 13 | -60 | -33  |
| 59                              | 35  | 3 | 4  | 17 | 13 | 13 | 13 | 19 | 24  | 104  |
| 60                              | 46  | 4 | 4  | 15 | 12 | 10 | 16 | 14 | 46  | 69   |
| 61                              | 58  | 4 | 5  | 12 | 12 | 11 | 21 | 38 | 78  | 121  |
| 62                              | 56  | 6 | 4  | 13 | 12 | 12 | 10 | 25 | -31 | -200 |
| 63                              | 42  | 4 | 3  | 10 | 10 | 12 | 9  | 38 | 3   | -40  |
| 64                              | 26  | 4 | 1  | 7  | 6  | 8  | 6  | 22 | 26  | 33   |
| 65                              | 16  | 2 | 2  | 4  | 5  | 9  | 15 | 28 | 67  | 203  |
| 66                              | 18  | 3 | 1  | 7  | 6  | 8  | 16 | 26 | -2  | -68  |
| 67                              | 20  | 3 | 2  | 9  | 6  | 11 | 19 | 28 | 21  | -68  |
| 68                              | 16  | 3 | 1  | 6  | 4  | 6  | 21 | 38 | 124 | 111  |
| 69                              | 13  | 2 | 2  | 5  | 5  | 8  | 22 | 37 | 124 | 228  |
| 70                              | 7   | 2 | 1  | 4  | 4  | 4  | 20 | 44 | 103 | 198  |
| 71                              | 6   | 2 | 1  | 4  | 6  | 7  | 24 | 54 | 86  | 108  |
| 72                              | 5   | 1 | 1  | 3  | 5  | 3  | 19 | 58 | 144 | 170  |
| 73                              | 6   | 2 | 2  | 3  | 5  | 6  | 17 | 57 | 147 | 214  |
| 74                              | 5   | 1 | 1  | 3  | 4  | 6  | 8  | 55 | 131 | 365  |
| 75                              | 4   | 1 | 1  | 2  | 3  | 10 | 8  | 46 | 130 | 306  |
| 76                              | 3   | 1 | 1  | 1  | 3  | 8  | 8  | 34 | 122 | 221  |
| 77                              | 3   | 0 | 0  | 1  | 2  | 5  | 10 | 19 | 120 | 252  |

Calculated from Appendix 3, Table A3.3.

**Note:** Entries in the table show the change in annual mortality probabilities at different ages associated with a three-year increase in life expectancy from the indicated initial levels. Units are standardized mortality units (SMUs), i.e. probabilities of 1/10,000.

Table A3.5

**Adjusting VSMU for age**

| Age a | VSMUs |              |
|-------|-------|--------------|
|       | e(a)  | e(a) / e(35) |
| 1     | 78.3  | 1.73         |
| 7     | 72.5  | 1.60         |
| 15    | 64.6  | 1.43         |
| 25    | 54.9  | 1.21         |
| 35    | 45.2  | 1.00         |
| 45    | 35.7  | 0.79         |
| 55    | 26.6  | 0.59         |
| 65    | 18.3  | 0.41         |
| 75    | 10.9  | 0.24         |
| 85    | 5.6   | 0.12         |

Data from reference 18.

**Note:** e(a) denotes life expectancy at age a, which is calculated in this table using Japan's life tables in 1990. 35 is the reference age from which the empirically estimated value of risk is assumed to have been estimated. We use 35 years since  $e(35)=45.2$  and 45 is the value of remaining life expectancy reported by Hammitt and Robinson (2011, p.19, Table 2) for the midpoint age in studies in the U.S. See also Viscusi and Aldy (2003, p.52, Table 10).<sup>1,3</sup>

Table A3.6

**Income and life expectancy, by region - 1990, 2000, and 2011**

| World Bank region          | Income per capita without health expenditures<br>(2011 US \$) |             |             |   |   | Life expectancy (years) |             |             |   |   |
|----------------------------|---|-------------|-------------|---|---|-------------------------|-------------|-------------|---|---|
|                            | (a)<br>1990   | (b)<br>2000 | (c)<br>2011 | (d)<br>Change,<br>1990-<br>2000<br>(=b-a) | (e)<br>Change,<br>2000-<br>2011<br>(=c-b) | (f)<br>1990             | (g)<br>2000 | (h)<br>2011 | (i)<br>Change,<br>1990-<br>2000<br>(=g-f) | (j)<br>Change,<br>2000-<br>2011<br>(=h-g) |
| LOW & MIDDLE INCOME        | \$2254  | \$2576      | \$4201      | \$321                                     | \$1626                                    | 63.1 years              | 65 years    | 67.9 years  | 1.9 years                                 | 2.9 years                                 |
| East Asia & Pacific        | 987   | 1911        | 4495        | 925                                       | 2583                                      | 67.9                    | 70.0        | 72.4        | 2.1                                       | 2.4                                       |
| Europe & Central Asia      | 6859  | 5106        | 8320        | -1753                                     | 3214                                      | 68.1                    | 67.5        | 70.7        | -0.6                                      | 3.2                                       |
| Latin America & Caribbean  | 6291  | 7171        | 8850        | 880                                       | 1680                                      | 68.2                    | 71.6        | 74.4        | 3.4                                       | 2.8                                       |
| Middle East & North Africa | 2343  | 2835        | 3462        | 492                                       | 627                                       | 64.1                    | 69.4        | 72.3        | 5.3                                       | 2.9                                       |
| South Asia                 | 548   | 752         | 1334        | 203                                       | 583                                       | 58.5                    | 61.9        | 65.6        | 3.4                                       | 3.7                                       |
| Sub-Saharan Africa         | 1100  | 1053        | 1353        | -47                                       | 300                                       | 49.5                    | 49.7        | 54.6        | 0.2                                       | 4.9                                       |
| HIGH INCOME                | 27834   | 33459       | 36134       | 5625                                      | 2675                                      | 75.5                    | 77.6        | 80.1        | 2.1                                       | 2.5                                       |
| WORLD                      | 8304  | 9212        | 10757       | 909                                       | 1545                                      | 65.4                    | 67.2        | 69.9        | 1.8                                       | 2.7                                       |

Data from reference 8 and 19.

**Note:** Low & Middle Income and High Income groupings use the World Bank's most recent income classification, held constant over the period 1990 to 2011 (so the composition of the countries within categories is constant over the period). Income data for Middle East & N Africa are in 2010 US\$ because of data availability.

Table A3.7

**Income per capita with and without health expenditures, by region - 1990, 2000, and 2011**

| World Bank region          | Income per capita (2011 US \$) |       |       | Income per capita excluding health expenditures (2011 US \$) |       |       | Difference as percent of income per capita |       |       |
|----------------------------|--------------------------------|-------|-------|--|-------|-------|--|-------|-------|
|                            | 1990                           | 2000  | 2011  | 1990   | 2000  | 2011  | 1990                                       | 2000  | 2011  |
| LOW & MIDDLE INCOME        | 2370                           | 2718  | 4455  | 2254   | 2576  | 4201  | 4.9%                                       | 5.2%  | 5.7%  |
| East Asia & Pacific        | 1020                           | 1994  | 4717  | 987  | 1911  | 4495  | 3.3%                                       | 4.1%  | 4.7%  |
| Europe & Central Asia      | 7205                           | 5394  | 8906  | 6859   | 5106  | 8320  | 4.8%                                       | 5.3%  | 6.6%  |
| Latin America & Caribbean  | 6718                           | 7673  | 9585  | 6291   | 7171  | 8850  | 6.4%                                       | 6.5%  | 7.7%  |
| Middle East & North Africa | 2451                           | 2978  | 3663  | 2343   | 2835  | 3462  | 4.4%                                       | 4.8%  | 5.5%  |
| South Asia                 | 571                            | 783   | 1386  | 548  | 752   | 1334  | 3.9%                                       | 4.0%  | 3.7%  |
| Sub-Saharan Africa         | 1166                           | 1119  | 1447  | 1100   | 1053  | 1353  | 5.7%                                       | 5.9%  | 6.5%  |
| HIGH INCOME                | 30747                          | 37188 | 41062 | 27834  | 33459 | 36134 | 9.5%                                       | 10.0% | 12.0% |
| WORLD                      | 9102                           | 10145 | 11987 | 8304   | 9212  | 10757 | 8.8%                                       | 9.2%  | 10.3% |

Data from reference 8 and Appendix 3, Table A3.6.

**Note:** Low & Middle Income and High Income groupings use the World Bank's most recent income classification, held constant over the period 1990 to 2011 (so the composition of the countries within categories is constant over the period). Income data for Middle East & N Africa are in 2010 US because of data availability. 1995 health expenditure data used as an estimate for 1990 due to data availability.

Table A3.8a

**Fraction of economic growth attributable to life expectancy improvements, by region, 1990-2000 and 2000-2011, not discounted (all ages)**

| World Bank region          | Value of change in mortality <sup>a</sup> |              | Change in full income <sup>a</sup> |               | Value of change in mortality as a percent of change in full income |           |
|----------------------------|---|--------------|------------------------------------|---------------|--|-----------|
|                            | 1990-2000                                 | 2000-2011    | 1990-2000                          | 2000-2011     | 1990-2000  | 2000-2011 |
| LOW & MIDDLE INCOME        | 370<br>1.6%                               | 667<br>2.4%  | 691<br>3.1%                        | 2293<br>8.1%  | 53%  | 29%       |
| East Asia & Pacific        | 161<br>1.6%                               | 339<br>1.6%  | 1086<br>11.0%                      | 2923<br>13.9% | 15%  | 12%       |
| Europe & Central Asia      | -208<br>-0.3%                             | 1137<br>2.0% | -1961<br>-2.9%                     | 4351<br>7.7%  | 11%  | 26%       |
| Latin America & Caribbean  | 1148<br>1.8%                              | 916<br>1.2%  | 2028<br>3.2%                       | 2596<br>33%   | 57%  | 35%       |
| Middle East & North Africa | 1000<br>4.3%                              | 392<br>1.3%  | 1492<br>6.4%                       | 1019<br>3.3%  | 67%  | 38%       |
| South Asia                 | 275<br>5.0%                               | 323<br>3.9%  | 478<br>8.7%                        | 906<br>11.0%  | 58%  | 36%       |
| Sub-Saharan Africa         | 40<br>.04%                                | 1088<br>9.4% | -7<br>-0.1%                        | 1388<br>12.0% | -578%  | 78%       |
| HIGH INCOME                | 3047<br>1.1%                              | 3680<br>1.0% | 8672<br>31%                        | 6356<br>1.7%  | 35%  | 58        |
| WORLD                      | 1146<br>1.4%                              | 1560<br>1.5% | 2054<br>2.5%                       | 3050<br>3.0%  | 56%  | 49%       |

<sup>a</sup> Entries are the value of changes in mortality (or full income) expressed in 2011 \$ per year.

Data from reference 14, 18, and Appendix 3, Table A3.6.

**Note:** In percentages are the average annual value of change in mortality (or of full income) expressed as a % of the initial value of income. Approximate age-adjusted VSMUs from Appendix 3 (Table A3.5).

Table A3.8b

**Fraction of economic growth attributable to life expectancy improvements, by region, 1990-2000 and 2000-2011, discounted (all ages)**

| World Bank region          | Value of change in mortality <sup>a</sup> |              | Change in full income <sup>a</sup> |               | Value of change in mortality as a percent of change in full income |           |
|----------------------------|---|--------------|------------------------------------|---------------|--|-----------|
|                            | 1990-2000                                 | 2000-2011    | 1990-2000                          | 2000-2011     | 1990-2000  | 2000-2011 |
| LOW & MIDDLE INCOME        | 262<br>1.2%                               | 506<br>1.8%  | 583<br>2.6%                        | 2132<br>7.5%  | 45%  | 24%       |
| East Asia & Pacific        | 132<br>1.3%                               | 306<br>1.5%  | 1057<br>10.7%                      | 2889<br>13.7% | 13%  | 11%       |
| Europe & Central Asia      | -150<br>-0.2%                             | 954<br>1.7%  | -1903<br>-2.8%                     | 4167<br>7.4%  | 8%   | 23%       |
| Latin America & Caribbean  | 972<br>1.5%                               | 837<br>1.1%  | 1852<br>2.9%                       | 2517<br>3.2%  | 52%  | 33%       |
| Middle East & North Africa | 728<br>3.1%                               | 345<br>1.1%  | 1221<br>5.2%                       | 972<br>3.1%   | 60%  | 35%       |
| South Asia                 | 203<br>3.7%                               | 238<br>2.9%  | 406<br>7.4%                        | 821<br>9.9%   | 50%  | 29%       |
| Sub-Saharan Africa         | 24<br>0.2%                                | 654<br>5.7%  | -23<br>-0.2%                       | 954<br>8.2%   | -105%  | 69%       |
| HIGH INCOME                | 2941<br>1.1%                              | 3616<br>1.0% | 8567<br>3.1%                       | 6291<br>1.7%  | 34%  | 57%       |
| WORLD                      | 889<br>1.1%                               | 1191<br>1.2% | 1798<br>2.2%                       | 2735<br>2.7%  | 49%  | 44%       |

<sup>a</sup> Entries are the value of changes in mortality (or full income) expressed in 2011 \$ per year.

Data from reference 14, 18, and Appendix 3, Table A3.6.

**Note:** In percentages are the average annual value of change in mortality (or of full income) expressed as a % of the initial value of income. Approximate age-adjusted VSMUs from Appendix 3 (Table A3.5), but with the VSMU for under age 5 discounted by 50% (see text).

Table A3.8c

**Fraction of economic growth attributable to life expectancy improvements, by region, 1990-2000 and 2000-2011 (progress in under-10 mortality excluded)**

| World Bank region          | Value of change in mortality <sup>a</sup> |              | Change in full income <sup>a</sup> |               | Value of change in mortality as a percent of change in full income |           |
|----------------------------|---|--------------|------------------------------------|---------------|--|-----------|
|                            | 1990-2000                                 | 2000-2011    | 1990-2000                          | 2000-2011     | 1990-2000  | 2000-2011 |
| LOW & MIDDLE INCOME        | 153<br>0.7%                               | 304<br>1.1%  | 474<br>2.1%                        | 1930<br>6.8%  | 32%  | 16%       |
| East Asia & Pacific        | 92<br>0.9%                                | 260<br>1.2%  | 1016<br>10.3%                      | 2843<br>13.5% | 9%   | 9%        |
| Europe & Central Asia      | -76<br>-0.1%                              | 716<br>1.3%  | -1829<br>-2.7%                     | 3930<br>7.0%  | 4%   | 18%       |
| Latin America & Caribbean  | 719<br>1.1%                               | 712<br>0.9%  | 1600<br>2.5%                       | 2392<br>3.0%  | 45%  | 30%       |
| Middle East & North Africa | 373<br>1.6%                               | 280<br>0.9%  | 865<br>3.7%                        | 907<br>2.9%   | 43%  | 31%       |
| South Asia                 | 119<br>2.2%                               | 136<br>1.6%  | 322<br>5.9%                        | 719<br>8.7%   | 37%  | 19%       |
| Sub-Saharan Africa         | 6<br>0.1%                                 | 164<br>1.4%  | -14<br>-0.4%                       | 464<br>4.0%   | -14%   | 35%       |
| HIGH INCOME                | 2784<br>1.0%                              | 3513<br>1.0% | 8410<br>3.0%                       | 6188<br>1.7%  | 33%  | 57%       |
| WORLD                      | 558<br>0.7%                               | 770<br>0.8%  | 1467<br>1.8%                       | 2314<br>2.3%  | 38%  | 33%       |

<sup>a</sup> Entries are the value of changes in mortality (or full income) expressed in 2011 \$ per year.

Data from reference 14, 18, and Appendix 3, Table A3.6.

**Note:** In percentages are the average annual value of change in mortality (or of full income) expressed as a % of the initial value of income. Approximate age-adjusted VSMUs from Appendix 3 (Table A3.5).

Table A3.9

**Fraction of economic growth attributable to life expectancy improvements, by region, 1990-2000 and 2000-2011 (value of reduction in over-70 mortality excluded)**

| World Bank region          | Value of change in mortality <sup>a</sup> |                  | Change in full income <sup>a</sup> |                            | Value of change in mortality as a percent of change in full income |                            |
|----------------------------|---|------------------|------------------------------------|----------------------------|--|----------------------------|
|                            | (k)<br>1990-2000                          | (l)<br>2000-2011 | (m)<br>1990-2000<br>(=d+k)         | (n)<br>2000-2011<br>(=e+l) | (o)<br>1990-2000<br>(=k/m)   | (p)<br>2000-2011<br>(=l/n) |
| LOW & MIDDLE INCOME        | 344<br>1.5%                               | 684<br>2.4%      | 665<br>3.0%                        | 2310<br>8.2%               | 52%  | 30%                        |
| East Asia & Pacific        | 147<br>1.5%                               | 324<br>1.5%      | 1072<br>10.9%                      | 2908<br>138%               | 14%  | 11%                        |
| Europe & Central Asia      | -231<br>-0.3%                             | 1139<br>2.0%     | -1984<br>-2.9%                     | 4353<br>7.7%               | 12%  | 26%                        |
| Latin America & Caribbean  | 1079<br>1.7%                              | 764<br>1.0%      | 1959<br>3.1%                       | 2443<br>3.1%               | 55%  | 31%                        |
| Middle East & North Africa | 988<br>4.2%                               | 363<br>1.2%      | 1481<br>6.3%                       | 990<br>3.2%                | 67%  | 37%                        |
| South Asia                 | 272<br>5.0%                               | 317<br>3.8%      | 475<br>8.7%                        | 900<br>10.9%               | 57%  | 35%                        |
| Sub-Saharan Africa         | 40<br>0.4%                                | 1073<br>9.3%     | -7<br>-0.1%                        | 1373<br>11.9%              | -529%  | 78%                        |
| HIGH INCOME                | 1825<br>0.7%                              | 1534<br>0.4%     | 7451<br>2.7%                       | 4210<br>1.1%               | 24%  | 36%                        |
| WORLD                      | 1159<br>1.4%                              | 1450<br>1.4%     | 2067<br>2.5%                       | 2995<br>3.0%               | 56%  | 48%                        |

<sup>a</sup> Entries are the value of changes in mortality (or full income) expressed in 2011 \$ per year.

Data from reference 14, 18, and Appendix 3, Table A3.6.

**Note:** In percentages are the average annual value of change in mortality (or of full income) expressed as a % of the initial value of income. Approximate age-adjusted VSMUs from Appendix 3 (Table A3.5).

Table A3.10

**Value of a life year (VLY) in 2000-2011 (expressed as a multiple of GDP per capita in 2000)**

| World Bank region          | (a)<br>Annual value of change<br>in mortality rates<br>2000-2011 (as % of GDP<br>per capita in 2000) | (b)<br>Annual value of change in<br>mortality associated with<br>1-year increase in life<br>expectancy (% of GDP) | Value of 1-year increase in<br>life expectancy, VLY<br>(as a multiple of GDP per capita) |                  |
|----------------------------|--|---|--|------------------|
|                            |  |   | (c)<br>$r = 3\%$   | (d)<br>$r = 7\%$ |
| LOW & MIDDLE INCOME        | 1.8%   | 6.8%  | 2.3  | 1.0              |
| East Asia & Pacific        | 1.5%   | 6.6%  | 2.2  | 0.9              |
| Europe & Central Asia      | 1.7%   | 5.8%  | 1.9  | 0.8              |
| Latin America & Caribbean  | 1.1%   | 4.2%  | 1.4  | 0.6              |
| Middle East & North Africa | 1.1%   | 4.3%  | 1.4  | 0.6              |
| South Asia                 | 2.9%   | 8.5%  | 2.8  | 1.2              |
| Sub-Saharan Africa         | 5.7%   | 12.6%   | 4.2  | 1.8              |
| HIGH INCOME                | 1.0%   | 4.3%  | 1.4  | 0.6              |
| WORLD                      | 1.2%   | 4.8%  | 1.6  | 0.7              |

Data based on changes in the life expectancy reported in Table A3.6; income levels excluding health expenditures reported in Table A3.7; and annual values of change in mortality for 2000-2011 as reported in Table A3.8b.

**Note:** Entries in columns (c) and (d) show the present value of the mortality reduction's contribution to full income change calculated at the indicated discount rate.

Table A3.11

**Benefits and costs of convergence<sup>a</sup>**

|    |   | Low income countries <sup>b</sup> | Lower middle income countries <sup>b</sup> |                   |
|----|---|-----------------------------------|--|-------------------|
| 1  | population, billions  | 1.1                               |  | 2.8               |
| 2  | incremental expenditures (billions of 2011 \$)              | 25                                |  | 46                |
| 3  | incremental expenditures per capita (2011 \$)               | 23                                |  | 16                |
| 4  | per capita income (2011 \$)                                 | 1000                              |  | 3500              |
|    | <b>Deaths averted<sup>c</sup></b>                           | <b>Unweighted</b>                 | <b>Weighted<sup>d</sup></b>                | <b>Unweighted</b> |
| 5  | stillbirths averted (thousands)                             | 250                               | 20   | 500               |
| 6  | deaths age 0-4 averted (thousands)                          | 1200                              | 600  | 1600              |
| 7  | maternal deaths averted (thousands)                         | 90                                | 90   | 90                |
| 8  | TB deaths averted (thousands)                               | 200                               | 200  | 290               |
| 9  | HIV/AIDS death averted, over age 5 (thousands)              | 440                               | 440  | 410               |
| 10 | Total, rows 5-9 (thousands)                                 | 2200                              | 1350                                       | 2900              |
| 11 | cost per death averted (row 2÷row 10)(2011 \$)              | 12,000                            | 19,000                                     | 16,000            |
|    | <b>Benefit-cost calculations</b>                            |                                   |  |                   |
| 12 | reduction in mortality (in SMUs)<br>(row 10÷row 1)(2011 \$) |                                   | 12   | 6                 |
| 13 | per capita value of mortality reduction <sup>f</sup>        |                                   | 216  | 315               |
| 14 | benefit: cost ratio (row 13÷row 3)                          |                                   | 9  | 20                |

Data from text tables 7-9 and Appendix 1, Table A1.11

**Notes:**

a. This table reports average value of variables for the period 2012-2035. Thus the average value of incremental cost is being weighed against the average number of deaths averted (half the number in parenthesis in the final columns of tables 6 and 7 of the main text.) and the average value of those averted deaths.

b. Countries are classified by income categories of the World Bank as of July 1, 2012 and remain in those categories.

c. ‘Deaths averted’ refers to deaths averted in pregnancies that occur and excludes deaths averted from preventing pregnancies.

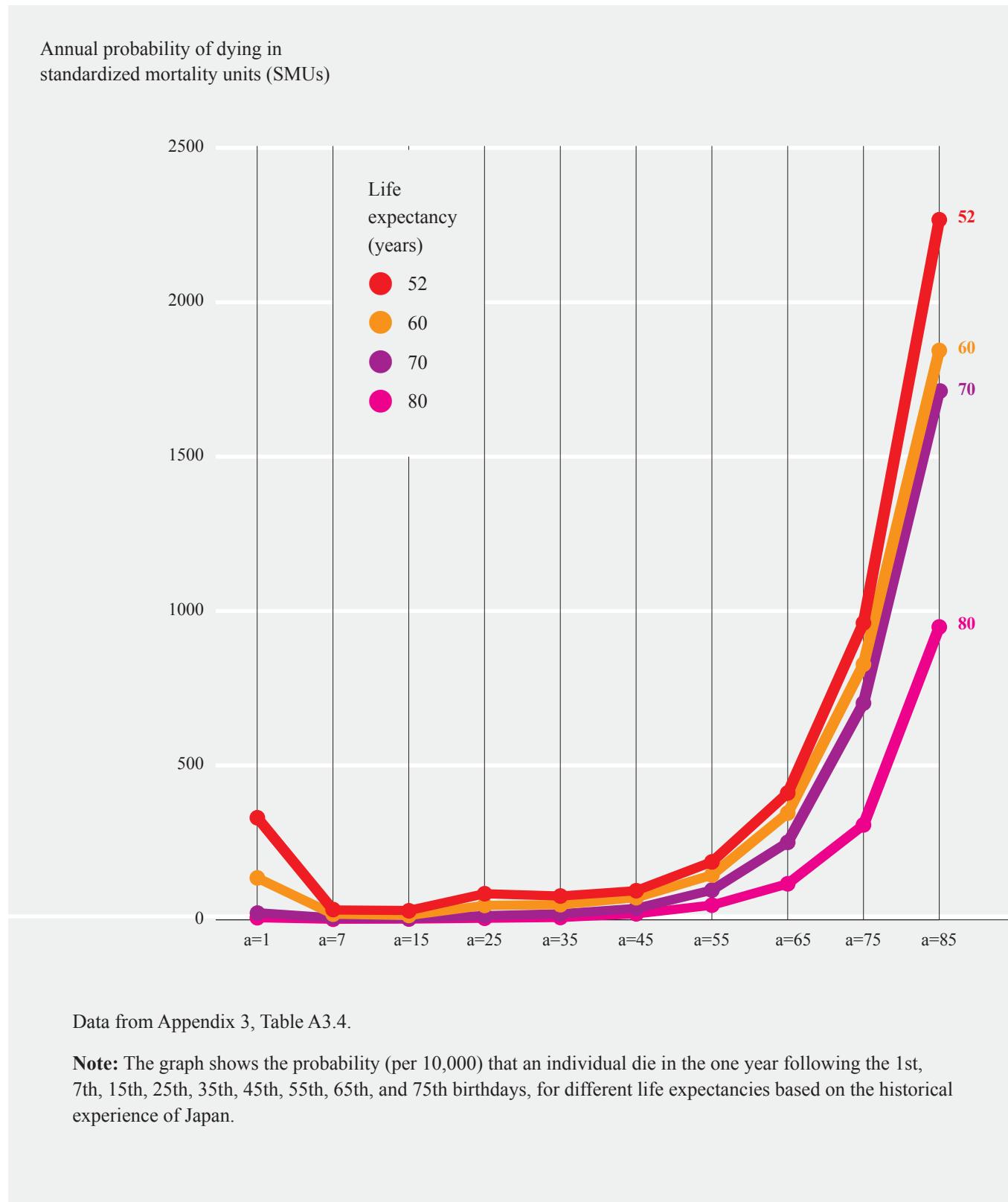
d. Consistently with the headline number presentations earlier in this Appendix (Tables A3.8b and A3.10) deaths occurring under age 5 are weighted at 50%. Stillbirths are weighted at 8%, broadly consistent with Jamison et al (2006, Table 6.5, column e).<sup>15</sup>

e. This Appendix uses the term ‘standard mortality’ (or SMU) to denote a  $10^{-4}$  probability of dying.

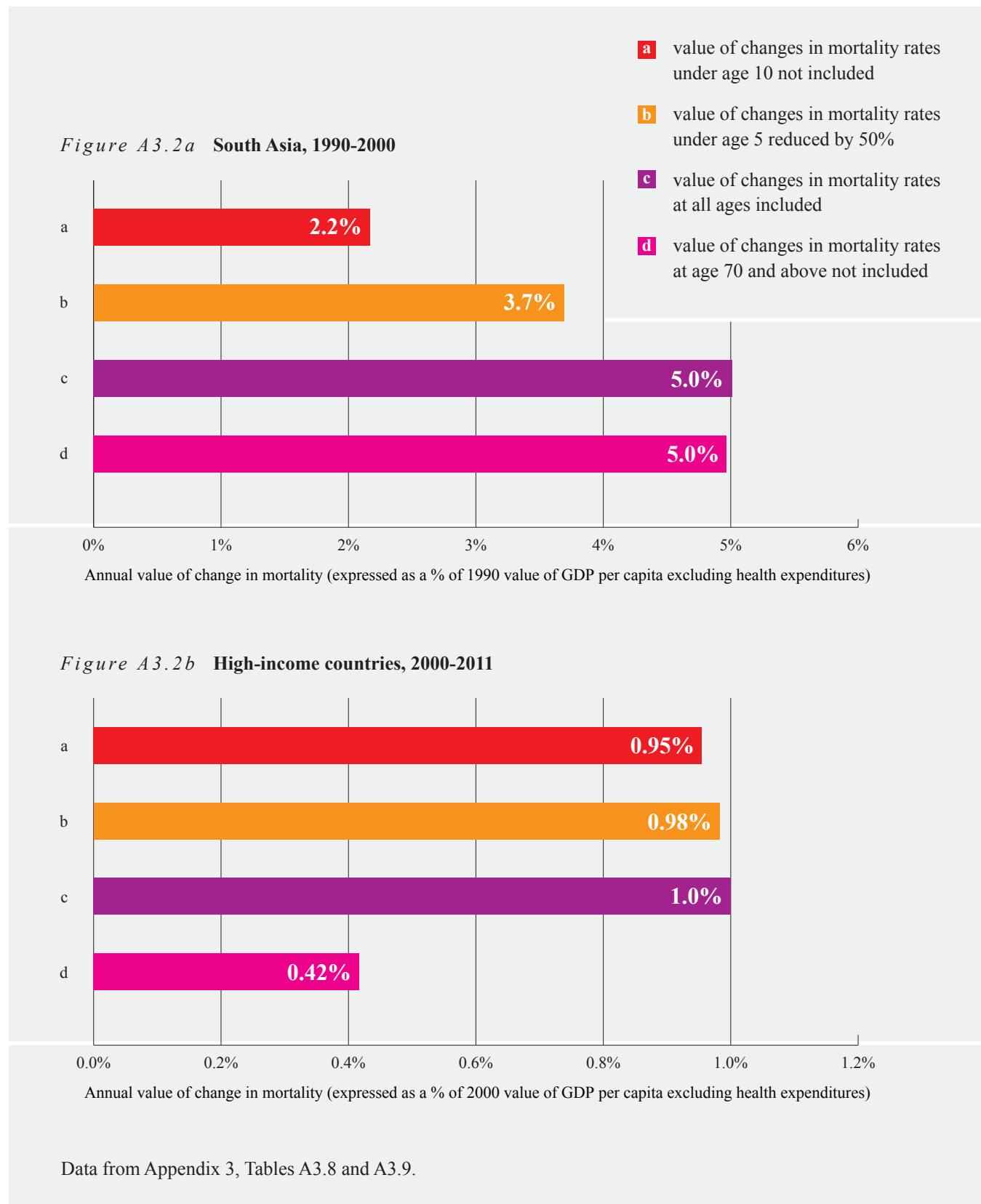
f. See equation 8 of this Appendix.

Figure A3.1

### Annual mortality rates as a function of age and life expectancy in Japan



**Figure A3.2 The effects of mortality decline among the young and the old on estimates of full income growth: a sensitivity analysis**



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