

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
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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.¹ 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.^{2,3} Cameron discusses reasons that this transformation and the VSL terminology itself can obscure communication.⁴ 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:

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

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

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

$$e(0) = \int_0^\infty s(a) da. \tag{3}$$

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

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

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.

Hammit 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.³ 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.⁵ 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.⁶ 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.⁷

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.⁸ 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.³ 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.

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

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.⁹⁻¹² Tierney has documented political difficulties associated with this perspective, however.¹³

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

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

(180 x 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 $\Delta\text{SMU}(e_i, e_j)$, 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 9×10^{-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:

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

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

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

Equation (10) is our basic equation. From Table A3.4, we can approximate values for $\Delta\text{SMU}(e_i, e_j)$ 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 $n(a)$.^{8,14}

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.^{12,15} 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.¹¹ 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.¹⁶ 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}

	Loss of life expectancy (days)	
a* = age of incidence of mortality risk m ($=10^{-4}$)	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).^{1,3}

Table A3.6

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

World Bank region	Income per capita without health expenditures (2011 US \$)					Life expectancy (years)				
	(a) 1990	(b) 2000	(c) 2011	(d) Change, 1990-2000 (=b-a)	(e) Change, 2000-2011 (=c-b)	(f) 1990	(g) 2000	(h) 2011	(i) Change, 1990-2000 (=g-f)	(j) Change, 2000-2011 (=h-g)
LOW & MID-DLE 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 ^a		Change in full income ^a		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 1.6%	667 2.4%	691 3.1%	2293 8.1%	53%	29%
East Asia & Pacific	161 1.6%	339 1.6%	1086 11.0%	2923 13.9%	15%	12%
Europe & Central Asia	-208 -0.3%	1137 2.0%	-1961 -2.9%	4351 7.7%	11%	26%
Latin America & Caribbean	1148 1.8%	916 1.2%	2028 3.2%	2596 33%	57%	35%
Middle East & North Africa	1000 4.3%	392 1.3%	1492 6.4%	1019 3.3%	67%	38%
South Asia	275 5.0%	323 3.9%	478 8.7%	906 11.0%	58%	36%
Sub-Saharan Africa	40 .04%	1088 9.4%	-7 -0.1%	1388 12.0%	-578%	78%
HIGH INCOME	3047 1.1%	3680 1.0%	8672 31%	6356 1.7%	35%	58
WORLD	1146 1.4%	1560 1.5%	2054 2.5%	3050 3.0%	56%	49%

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

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

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

^a 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) Annual value of change in mortality rates 2000-2011 (as % of GDP per capita in 2000)	(b) Annual value of change in mortality associated with 1-year increase in life expectancy (% of GDP)	Value of 1-year increase in life expectancy, VLY (as a multiple of GDP per capita)	
			(c) r = 3%	(d) 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^a

		Low income countries ^b		Lower middle income countries ^b	
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	
	Deaths averted^c	Unweighted	Weighted^d	Unweighted	Weighted^d
5	stillbirths averted (thousands)	250	20	500	40
6	deaths age 0-4 averted (thousands)	1200	600	1600	800
7	maternal deaths averted (thousands)	90	90	90	90
8	TB deaths averted (thousands)	200	200	290	290
9	HIV/AIDS death averted, over age 5 (thousands)	440	440	410	410
10	Total, rows 5-9 (thousands)	2200	1350	2900	1600
11	cost per death averted (row 2÷row 10)(2011 \$)	12,000	19,000	16,000	29,000
	Benefit-cost calculations				
12	reduction in mortality (in SMUs) (row 10÷row 1)(2011 \$)		12		6
13	per capita value of mortality reduction ^f		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).¹⁵

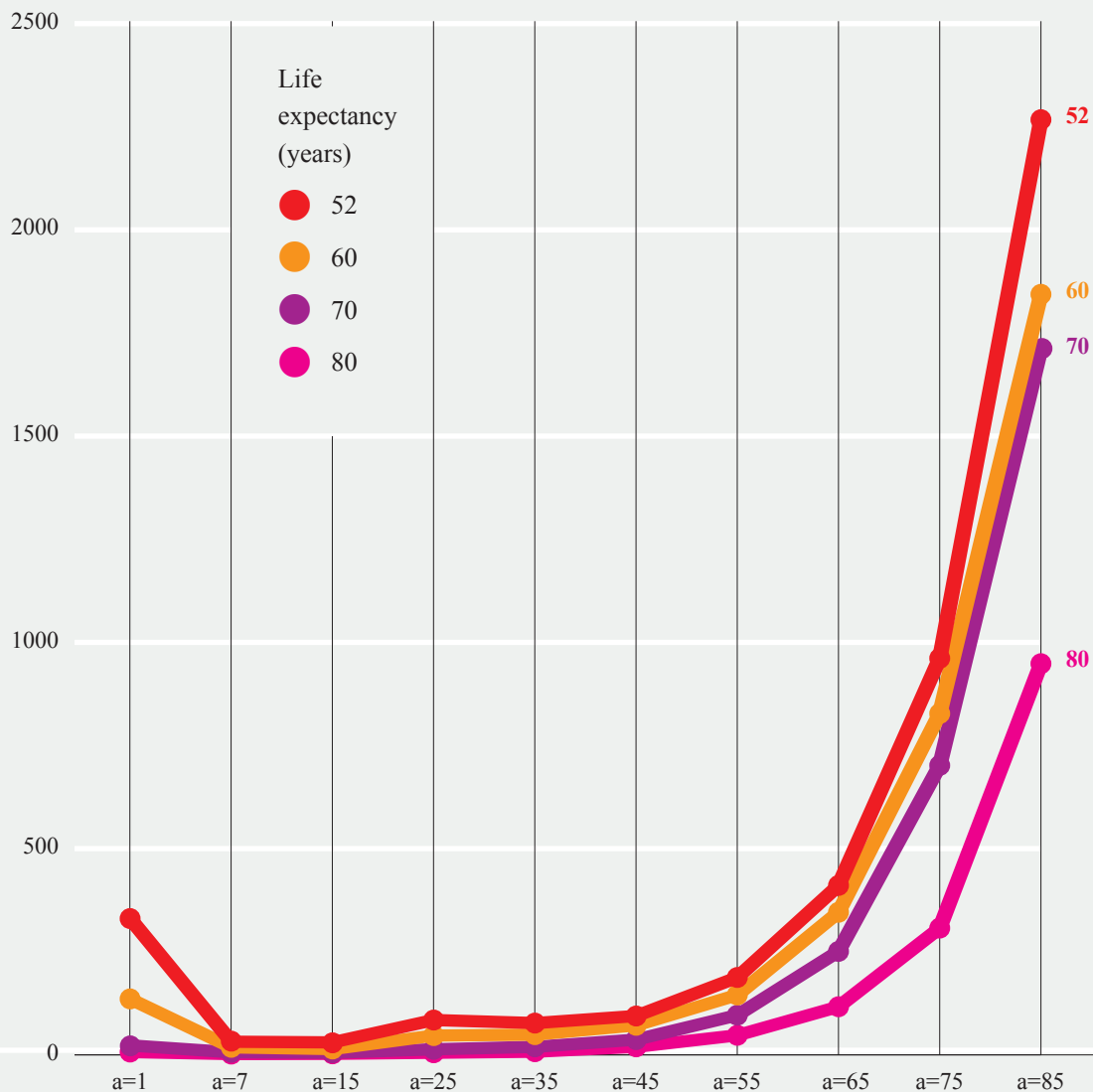
e. This Appendix uses the term 'standard mortality' (or SMU) to denote a 10⁻⁴ probability of dying.

f. See equation 8 of this Appendix.

Figure A3.1

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

Annual probability of dying in standardized mortality units (SMUs)



Data from Appendix 3, Table A3.4.

Note: The graph 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.

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

Figure A3.2a South Asia, 1990-2000

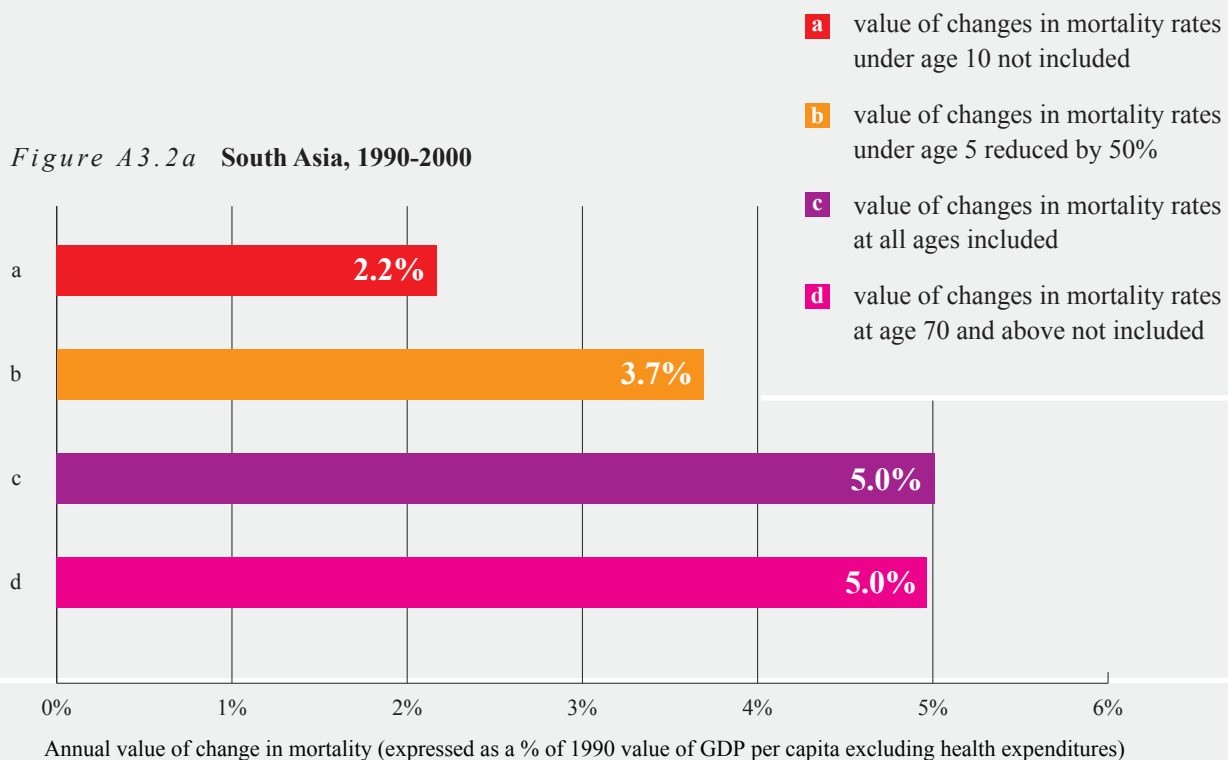
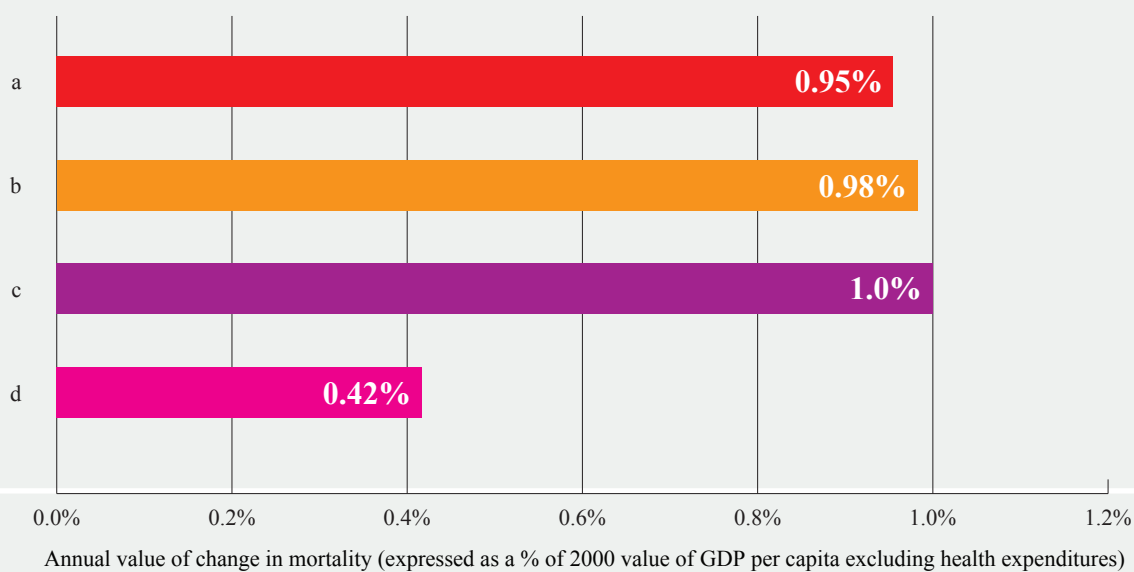


Figure A3.2b High-income countries, 2000-2011



Data from Appendix 3, Tables A3.8 and A3.9.

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