CHAPTER 7

Human Health: The Twentieth-Century Transformation of Human Health – Its Magnitude and Value

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> I have tried always to remember a simple truth about the past that the historically inexperienced are prone to forget. Most people in the past either died young or expected to die young, and those who did not were repeatedly bereft of those they loved . . . the power of death cut people off in their prime and made life seem precarious and filled with grief. It also meant that most of the people who built civilizations of the past were young when they made their contributions.
>
> – Niall Ferguson, *Civilization: The West and the Rest* (2011, pp. xxii–xxiii)

Ferguson refers to a past with mortality far higher than today, a past in which people not only died young but lived with frequent illness, undernutrition and (for women) the often debilitating consequences of high fertility. This past was not so very long ago. Section 1 will present long trends in life expectancy in the country where it is highest. From a period of virtually no change in mortality prior to 1790, improvements became rapid in the nineteenth century and extremely rapid in the period 1880–1960. During this latter period life expectancy in the leading country increased by 3.2 years per decade. And, as this chapter will document, not only did the leading country rapidly improve but much of the rest of the world converged toward the leader.

Our agenda in this chapter is, first, to review briefly the magnitude and likely origins of mortality decline in the twentieth century. While some of that decline results from improvements in income – and all the health-related goods that income buys – we conclude that improvements in health technology dominate the explanation for health gains. In Section 2, the core of the chapter, we develop measurements of twentieth century mortality reductions in terms of reduction in the expected number of years of life lost (YLLs) by a typical individual relative to an idealized norm. This norm is the United Nations' projected mortality profile for Japan in 2050. (An alternative to Japan 2050 as a norm is to use the lowest mortality country at any given time as the norm for that time. Annex 7.2 presents results obtained under this assumption.) Part 2 also presents money metric valuation of the YLL declines using methods standardized by the Copenhagen Consensus. The chapter conveys results for a number of individual countries and regions as well as for the world as a whole. Section 3 of the chapter presents examples to provide a more granular feel for the origins of mortality decline and the nature of remaining problems. Section 4 concludes.

It is worth noting at the outset that other chapters in this collection – on education, nutrition, water and sanitation and air pollution, for examples – explore in detail some of the underlying reasons for mortality change.

The Magnitude and Origins of Mortality Decline in the Twentieth Century

Figure 7.1 shows female life expectancy levels – in the country with the then highest female life expectancy – from the mid eighteenth century to the present time. Figure 7.2 shows the rate of increase in female life expectancy (in

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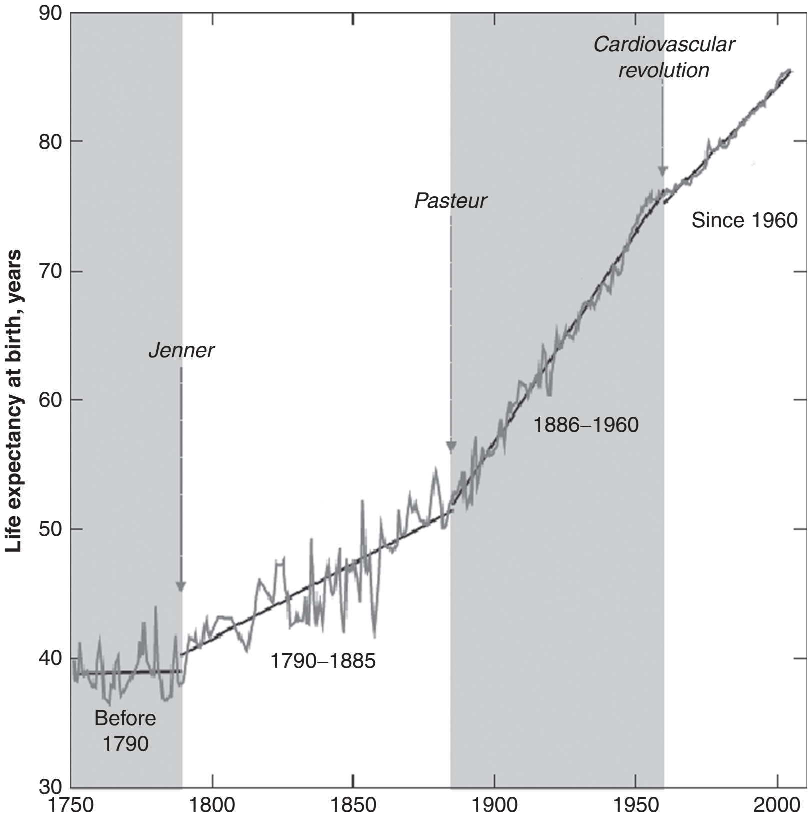


Figure 7.1 *Highest observed national female life expectancies at a given moment in the world (1750–2005). Source: Vallin and Meslé (2010).*

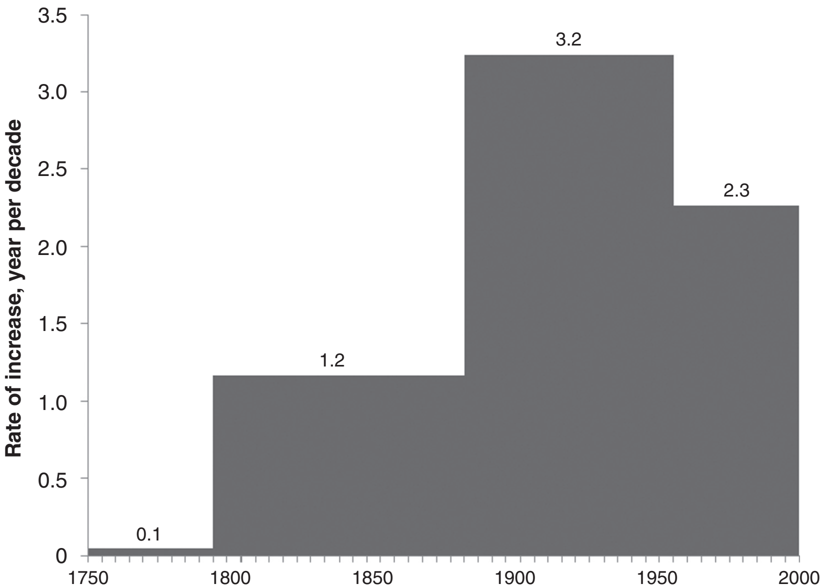


Figure 7.2 *The rate of increase in highest female life expectancy, years per decade*

years of life expectancy per decade) based on Figure 7.1. It is hard to overstate the magnitude of the improvements in longevity from 1800 on (or how little improvement there had been previously). And rapid as the leader's improvement was for many decades, at 3.2 years per decade, global convergence is more impressive. In India, for example, life expectancy grew at a rate of over 4.5 years per decade between 1960 and 2002.

Mortality declines in the twentieth century varied by age group – with the sharpest declines in childhood deaths below age 5 and less marked declines in middle age (defined here as age 30–69 years).[1] Mortality from infectious diseases fell far faster than did mortality from non-communicable diseases. Moreover, the main contributors to the declines varied over time, in part because the higher levels of income achieved by low-and middle-income countries in more recent decades have enabled them to purchase more technological progress (at any given level of income). Thus low-and middle-income countries have benefitted in the second half of the twentieth century from the diffusion of technological advances in higher-income countries in the first half of the twentieth century. In some cases, advances in education have enabled more effective use of these technologies, most notably from improvements in maternal education enabling better use of oral rehydration therapies or case management of sick children (Kidane and Morrow 2000).

Technological advances and their effective diffusion account for most of the large declines in premature mortality in the twentieth century worldwide, particularly for the declines in mortality observed in low-and middle-income countries from about 1950 onwards. Income and, to a lesser extent, education were less important predictors of these massive declines in premature deaths (Easterlin 1999; Jha *et al.* 2004;. Jamison *et al.* 2013). Two caveats on causality relations among income, technology, and mortality change are worth considering. First, most of the twentieth century had large gaps in evidence on diseases, expenditures, and their outcomes. The gaps persist. For example, less than a third of all deaths worldwide have reasonably reliable causes of death given to them, as they occur without any medical attention (Jha 2012). Second, income and education influence many aspects of the use of technology. For example, higher income enables better access to improved water supply and to sanitation, which does (albeit quite expensively) reduce childhood deaths from diarrhea. Higher income also supports improved communication, changes in transportation, and other dimensions of infrastructure that might have more distal impacts on mortality reduction. There are also concomitant changes in changing occupation, such as safer, less manually demanding jobs, as well as changes in gender-participation in labour markets. All of these have an impact on reduced mortality. However, as reviewed elegantly by Easterlin (1999), the main contribution to the large declines in mortality arose from more proximate measures of public health including public health institutions.

Additionally, the specific choices made by households (or more commonly by governments) such as the use of smallpox vaccines in the late nineteenth and early twentieth centuries in turn depended on having some wealth (but smallpox eradication was independent of household decisions). In contrast, public health institutions and regulations that are quite important in interrupting the spread of infectious agents (say the ability of enforcing quarantine laws against suspected smallpox cases), or control of risk factors for chronic diseases (say enforced bans on smoking in public places) are often *poorly* correlated with income

[1] Avoidance of disability is also important. Mortality does not capture all illnesses, specifically neuropsychiatric and musculoskeletal diseases. However, the correlation of mortality with morbidity for most major diseases is quite strong, and in low-income countries, a greater proportion of the combined total of deaths and disability arise from mortality than is the case in high-income countries. Moreover, it is important to note that measurement error in disability estimates is much greater than for mortality, and often can exceed the desired change in health outcomes. For example, a health policy planner may desire a 10% improvement in an under-5 health outcome, but if measurement error exceeds 10% in the health outcome measure, she or he will not know if the intervention worked. Since it is usually possible to tell the difference between a dead person and a living one, restricting analyses to mortality should reduce measurement error in health policy-making. This chapter focuses on mortality reduction only and for that reason understates both the magnitude of health problems in, say, 1900 and the magnitude of subsequent progress.

levels. Thus, the impact on specific (and usually poorly measured) diseases (such as age-specific smallpox mortality) is difficult to quantify. There are also changes in the natural virulence of infectious agents over time (and much less likely increases in the resistance of humans to these agents). For example, there might well have been changes in unmeasured etiologic factors for tuberculosis that led to its declines in the early twentieth century, independent of treatment, which was not introduced widely until the 1950s (Nagelkerke 2012). These problems in measurement and attribution have contributed, along with ideological perspectives, to a wide range of interpretations on the reasons for mortality decline, ranging from factors like nutrition, changes in societal structures, or other more distal effects (see Easterlin 1999 for a relevant review). Even interpretations that suggest income to be an important driver of mortality declines (e.g. Pritchett and Summers 1996) allow ample scope for the importance of technical change. Moreover, some types of knowledge, such as the germ theory and the understanding of transmission of infectious disease, need little income to implement (Preston and Haines 1991). Analyses might well suggest that income played *no* role. The British-led army in India was instructed to march at right angles to the wind during cholera outbreaks, for example. Applied research that understood cholera transmission and clustering of outbreaks led to use of far more effective measures than wind avoidance (Davis 1951).

Some studies have attempted to assess what fraction of the decline in under-5 mortality arises from different sources. Jamison *et al*. (2013) for example estimate improved levels of education and technical progress are the largest contributors. Panel A of Figure 7.3 shows their results for all low- and middle-income countries for 1970–2000, and panel B shows their results for India.

Many of these interventions, particularly against infection and micronutrient deficiency, cost little and are highly efficacious. This is not to discount other more distal factors as having a role, for example by generating the wealth needed to purchase these interventions, the education to use them properly, or societal structures to ensure their widespread application. But in the absence of such specific technologies, it is hard to imagine that there would have been decline in mortality for these specific causes.

[2] An alternative reference population would be that of the best performing country in the year of the analysis. Annex 7.2 contains alternative calculations based on this assumption.

Estimation of the Number of Years of Life Lost (YLLs) and Its Money Metric Value

This section begins by describing the methods used in order to estimate the number of years of life lost (YLLs) for a given country or region and year. The countries and regions analyzed were China, India, Japan, the United States of America, sub-Saharan Africa, the world, the "Less developed regions" and the "More developed regions" as defined by the United Nations (2009). The time-span considered for the analysis was 1900–2050. Estimates of YLLs were calculated, for purposes of the Copenhagen Consensus Center analysis, using the United Nations' projected survival curve for Japan in 2050 as a reference.[2] Results are reported as a snapshot every 10 years for the years 1900, 1910, up to 2050. We then convert to money metric losses using a value of 2 for the ratio of the value of a statistical life year (VSLY) to per capita GDP.

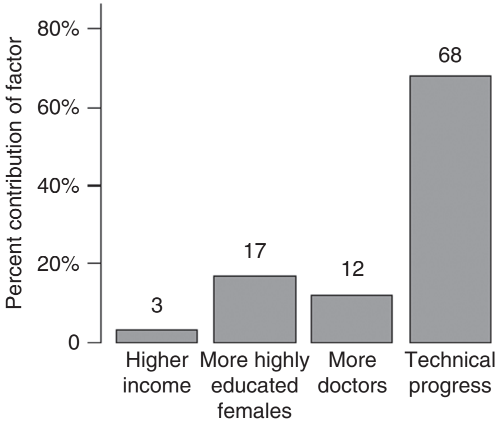
2.1. Background and Methods

Notation

Consider a country or region i in year t. We note $e_{i,t}(a)$ the life expectancy at age a for the country/region i in year t. For country or region i in year t, we denote $s_{i,t}(a)$ to be the survival curve, which shows the probability that an individual of the population considered would survive from birth to age a given the age-specific survival rates at time t implied by the survival curve. Figure 7.4a displays survival curves for the Japanese population for the years 2005–2010 and for the Mozambican population for the year 1990. The age specific mortality rate at age a – or *hazard rate* – in population i in year t, $\mu_{i,t}(a)$, is given by:

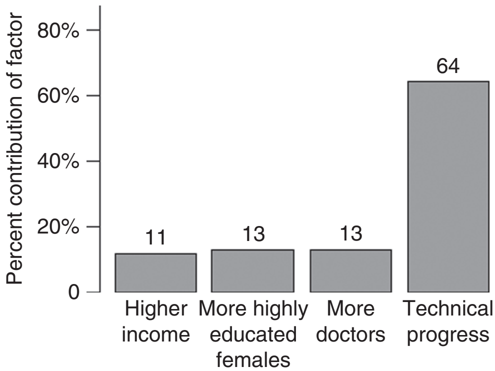
$$\mu_{i,t}(a) = -\frac{s'_{i,t}(a)}{s_{i,t}(a)} \tag{7.1}$$

Panel A: All low- and middle-income countries



Note: Child mortality (5*q*0) across all low- and middle-income countries declined by 52% between 1970 and 2000 – from 130 per 1,000 to 62 per 1,000, i.e. at an average rate of 3.5% per year. This graph shows the fraction of the decline that can be attributed to several specific factors.

Panel B: India



Note: Child mortality (5*q*0) in India declined by 58% between 1970 and 2000 – from 188 per 1,000 to 80 per 1,000, i.e. at an average rate of 2.9% per year. This graph shows the fraction of the decline that can be attributed to several specific factors.

Figure 7.3 *Factors accounting for decline in child mortality, 1970–2000*

Figure 7.4b displays hazard rates by age group for the Japanese population for the years 2005–2010 and for the Mozambican population for the year 1990.

We defined our *reference population*, as that of the country which had the highest (projected) life expectancy at birth, according to the United Nations, for the period we review (1900–2050). The Japanese population in 2050 thus serves as the reference population, which we named JPN2050. In 2050, a Japanese newborn would be expected to live about 87.2 years according to the United Nations (2009), and that is the highest life expectancy in their projections. We noted $e_J(a)$ the life expectancy at age a for a Japanese individual from JPN2050. Figure 7.5 displays life expectancy as a function of age for JPN2050, as well as for the Mozambican population in 1990.

For country/region i, and year t, we define the number of *years of life lost* $\mathrm{YLL}_{i,t}$, relative to the Japanese population, to be:

$$YLL_{i,t} = \sum_a -s'_{i,t}(a)e_J(a) \qquad (7.2)$$

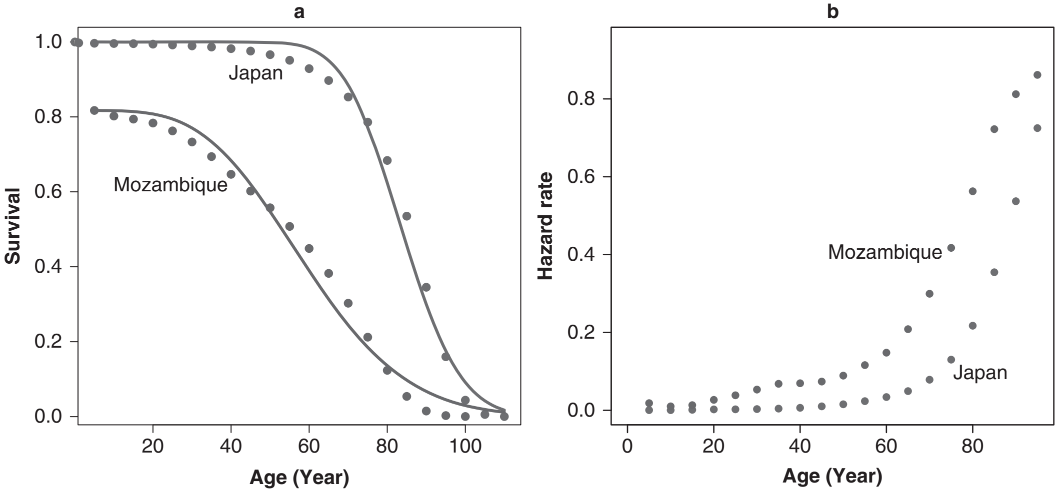


Figure 7.4 *Empirical and fitted survival curves (a), and hazard rates (b) as a function of age, for the Japanese population for the period 2005–2010 and for the Mozambican population for the year 1900*

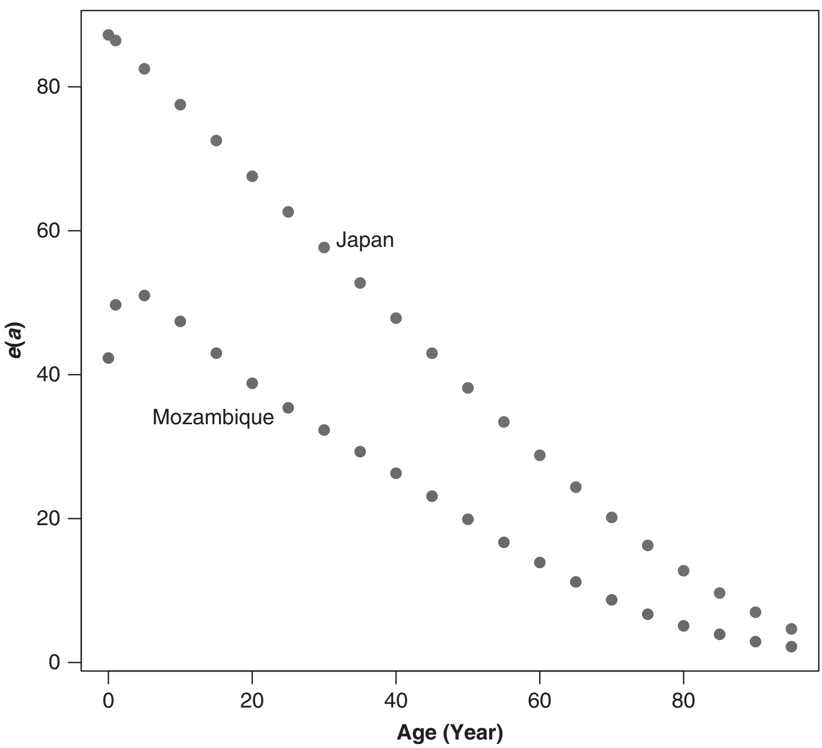


Figure 7.5 *Life expectancy as a function of age for JPN2050, and the Mozambican population in 1990*

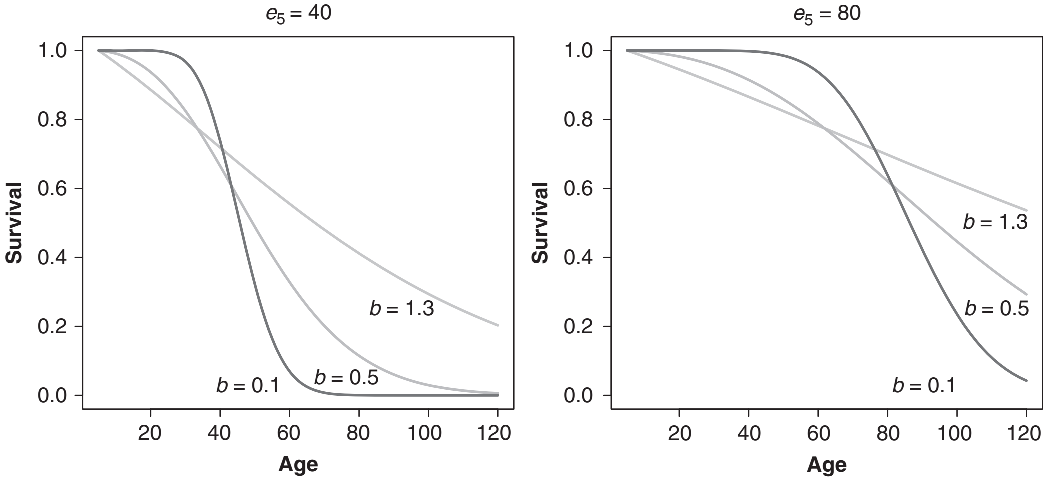


Figure 7.6 *Hypothetical survival curves for different values of the couplet* (e_5, b*). On the left-hand side,* $e_5 = 40$*; on the right-hand side* $e_5 = 80$*. On both figures,* b *takes the following values:* b = *0.1 (purple), 0.5 (green), 1.3 (gray)*

s' is being used to denote a vector here and a scalar earlier. $e_J = (e_J(0), e_J(5), \ldots, e_J(100))$, and $s'_{i,t} = (s'_{i,t}(0), s'_{i,t}(5), \ldots, s'_{i,t}(100))$.[3] Recall $e_J(5k)$ is the life expectancy at age $5k$ for JPN2050, $-s'_{i,t}(5k)$ is the probability of dying between ages $5k$ and $5(k+1)$. This chapter uses YLL as its fundamental measure of health losses relative to the reference population.

We characterized a population from country or region i in year t by two indicators: (1) the number of $\text{YLL}_{i,t,u5}$ for deaths occurring at ages under 5, and (2) the number of $\text{YLL}_{i,t,a5}$ resulting from deaths above 5. The first kind of YLL is given by:

$$\begin{aligned} YLL_{i,t,u5} &= -s'_{i,t}(0)e_J(0) \\ &= \left(s_{i,t}(0) - s_{i,t}(5)\right)e_J(0) = q5_{i,t}e_J(0) \end{aligned} \tag{7.3}$$

where $q5_{i,t}$ is the probability of dying between ages 0 and 5 in country/region i, and year t. The over age 5 YLL is given by:

$$YLL_{i,t,a5} = -\sum_{k=1}^{20} s'_{i,t}(5k)e_J(5k) \tag{7.4}$$

where $s'_{i,t}(5k) = s_{i,t}(5k+5) - s_{i,t}(5k)$.

In this study we consistently estimate the YLLs arising from deaths before age 5 and those arising from age 5 and older. Hence in addition to q_5 we need the survival curves for ages ≥5. For a given population, we estimated a survival curve $s_{i,t,5}(a)$ for $a \geq 5$. We approximated $s_{i,t,5}(a)$ by the following mathematical formulation:

$$s_{i,t,5}(a) = \frac{\Gamma\left(\frac{2-b}{b}, \frac{2-b}{b}\frac{a-5}{e_5}\right)}{\Gamma\left(\frac{2-b}{b}\right)} 0 < b < 2 \tag{7.5}$$

where $\Gamma(x,s) = \int_x^{+\infty} t^{s-1}e^{-st}dt$ is the incomplete gamma function and $\Gamma(s) = \int_0^{+\infty} t^{s-1}e^{-st}dt$ is the complete gamma function; e_5 is the life expectancy at age 5 and corresponds to $e_5 = \int_5^{+\infty} s_{i,t,5}(a)da$. The parameter b captures the *rectangularity* of the survival curve and draws on the formal identity of survival curves and discount functions. Equation 7.5 is a survival curve based on the gamma discounting function of Jamison and Jamison (2011), and their speed parameter ρ (we have $b = 2 - \rho$). Figure 7.6 presents several shapes of hypothetical survival curves s for different values of the couplet (e_5, b). Notice how for given e_5, varying b varies the rectangularity of the survival curve. Our purpose in using a parametric survival curve (equation 7.5) is to allow us to generate survival curves when only life expectancy is known by using an empirical relation between e_5 and b that we now describe in the next subsection.

[3] United Nations (2009) gives life expectancies at ages $a = 5k$ where $k = 0, 1, 2, \ldots, 20$.

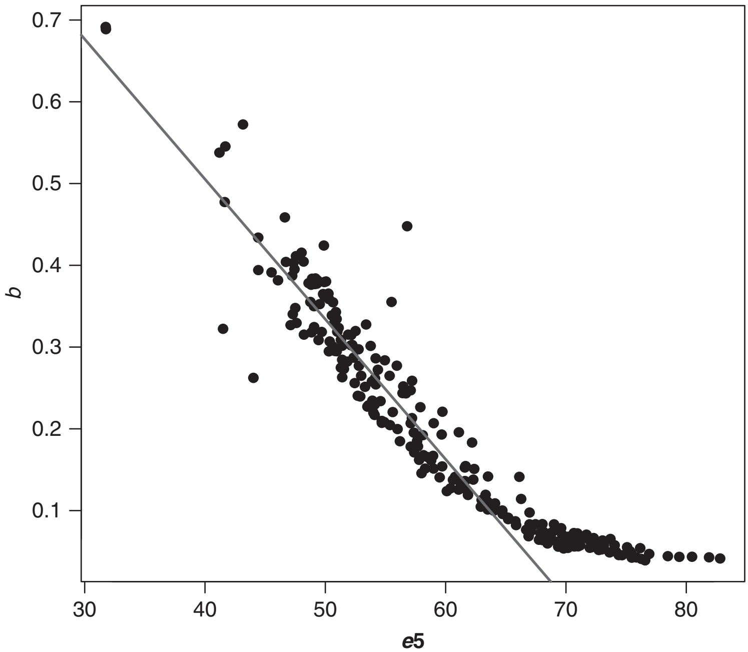


Figure 7.7 *Empirical relationship between rectangularity,* b*, of the survival curve age 5 onward as a function of life expectancy at age 5,* e_5*. The regression line for lower life expectancies (*$e_5 < 65$*) is* $b = 1.19 - 0.017\ e_5$, $R^2 = 0.86$

This completes our development of notation and basic concepts.

Data and Empirical Relationship between *b* and e_5

We determined an empirical relationship $b(e_5)$ in order to estimate survival curves once given life expectancy at age 5, i.e. e_5. For that purpose, we fitted survival curves given by equation (7.5) to demographic life tables presenting a wide range of values for e_5. The life tables collected for our analysis were obtained from several sources. The Human Mortality Database (2011) provided life tables for England and Wales (1841–2009), France (1816–2007), Iceland (1838–2008), Japan (1947–2009), Sweden (1751–2009), and the United States (1933–2007). Davis (1951) provided life tables for India for the decades 1911–1921 and 1931–1941. We used life tables for 1990 and 2008 for males and females, provided by the World Health Organization (2010b) for 19 sub-Saharan African countries and Bangladesh, Brazil, China, Egypt, India, Indonesia, the Islamic Republic of Iran, Mexico, Pakistan, and the Philippines. The life expectancies at age 5 ranged from 31.8 to 78.1 years of age (corresponding to India in 1910: Davis (1951) and Japan in 2005–2007: Human Mortality Database 2011). The couplets (e_5, b) obtained after fitting of equation (7.5) are displayed on Figure 7.7.

Estimation of Survival Curves above Age 5

For China (CHN), India (IND), Japan (JPN), the United States of America (USA), sub-Saharan Africa (SSA), the "Less developed regions" (LDR), the "More developed regions" (MDR), and the world (WLD), over the period 1900–2050, we estimated a survival curve $s_{i,t,5}(a)$ for age 5 onward for each year starting a decade, i.e. 1900, 1910, 1920, …, 2040, 2050. For 2000–2050, all survival curves were estimated using direct fits to the life tables provided by the

United Nations (2009). For the USA and the period 1930–2000, and JPN in the period 1950–2000, the survival curves were estimated using direct fits to the life tables provided by Human Mortality Database (2011). For CHN, IND, SSA, LDR, MDR, and WLD, in the period 1900–2000, the survival curves were estimated using the relationship $b = f(e_5)$, once e_5 was known (Figure 7.7). The same approach was used to estimate the survival curves for USA in the period 1900–1930, and for JPN in the period 1900–1950. For CHN, IND, SSA, over the period 1980–2000, both e_0 and $q5$ (probability of dying before age 5) were given by United Nations (2009) and e_5 was derived in the following manner:[4]

$$e_5 = \frac{1}{1 - q_5}\left[e_0 - 5 + \frac{5}{2}q5\right] \tag{7.6}$$

All remaining e_5 values were either derived by linear extrapolation or through relationship (7.6) while using a relationship between e_0 and $q5$ extracted from the available data from the United Nations (2009). Input data were extracted from several sources including United Nations (2009), CDC (2004), Human Mortality Database (2011), Davis (1951), and Feachem and Jamison (1991). All data inputs used are collected in Table 7.1.

Money Metric Value of YLLs

For region or country i in year t, we estimated a money metric value of $\mathrm{YLL}_{i,t}$, noted $\mathrm{MMVYLL}_{i,t}$ in the following way:

$$\mathrm{MMVYLL}_{i,t} = \gamma \mathrm{YLL}^*_{i,t} I_{c,t} \tag{7.7}$$

where we derived a weighted measure of YLL i.e $\mathrm{YLL}^* = \mathrm{YLL}_{a5} + 0.54\ \mathrm{YLL}_{u5}$ as given by Jamison *et al.* (2006), I_c is the income per capita in 1990 International Geary–Khamis dollars (CCC 2011; Maddison 2011),[5] and γ is the value of YLL in units of per capita income, i.e. it is the VSLY. We take here $\gamma = 2$, the lower value given in Jamison *et al.* (2008).[6] We then estimated lifetime income per capita $LI_{c,i,t}$ in the following manner:

$$LI_{c,i,t} = e_{0,i,t} I_{c,i,t} \tag{7.8}$$

where $e_{0,i,t}$ is the life expectancy at birth in country or region i in year t. Finally, we define the ratio a as:

$$a_{i,t} = \mathrm{MMVYLL}_{i,t}/LI_{c,t} \tag{7.9}$$

Reductions in YLLs

We estimated YLL_J i.e. the number of years of life lost for JPN2050, our reference population. We found $\mathrm{YLL}_{J,u5} = 0.3$, $\mathrm{YLL}_{J,a5} = 10.1$, leading to $\mathrm{YLL}_J = 10.4$. (Note that the existence of non-zero YLLs in the reference population results from the non-rectangularity of the survival curve. Figure 7.7 suggests that after a life expectancy of about 75 years, life expectancy improvements cease to be accompanied by increased rectangularity.)

For each country and region i and year t, we subtracted the quantities associated with the reference population, i.e. we estimated:

$$\mathrm{YLL}_{i,t,u5} = q5_{i,t} e_j(0) - \mathrm{YLL}_{J,u5} \tag{7.10}$$

and:

$$\mathrm{YLL}_{i,t,a5} = -\sum_{k=1}^{20} s'_{i,t}(5k) e_J(5k) - \mathrm{YLL}_{J,a5} \tag{7.11}$$

which leads to the total unweighted YLLs:

$$\mathrm{YLL}_{i,t} = q5_{i,t} e_J(0) - \sum_{k=1}^{20} s'_{i,t}(5k) e_J(5k) - \mathrm{YLL}_J \tag{7.12}$$

Table 7.2 lists the YLL_{u5} (7.10), the YLL_{a5} (7.11), and the total unweighted YLL (7.12) for each year

[4] This relation is derived from the identity expressing e_0 as the sum of integrals of the survival curve from 0 to 5 and from 5 to infinity and the approximation that the survival curve is linear between 0 and 5.

[5] For the period 2010–2050, projections of income per capita were estimated based on levels from Maddison (2011) in 2010 and assuming a constant growth rate of 2% for Japan and the United States, and of 5% for China and India for the period 2010–2050.

[6] Note that we could have values of γ varying with income as suggested by Hammitt and Robinson (2011). We chose here a constant value across income levels in the interest of simplicity of exposition.

Table 7.1 Input parameters – e_0 and e_5 (years), q_5 (per 1,000 live births), and b (millions of births), selected countries and country groupings, 1900–2050

	Life expectancy at birth, e_0 (years)				Life expectancy at age 5, e_5 (years)				Under-5 mortality rate, q_5, per 1,000 live births				Births per year (millions)		
Geographical area	1900	1950	2000	2050	1900	1950	2000	2050	1900	1950	2000	2050	1950	2000	2050
World[a]	32	47	66	76	40	53	67	73	335	167	77	31	98.3	133.9	121.7
China[b]	28	41	72	79	36	49	69	75	344	194	32	12	25.0	18.1	14.2
India[c]	23	38	62	73	32	43	63	71	464	227	90	39	16.9	27.6	19.8
Japan[d]	45	62	82	87	52	62	78	83	220	77	4	3	2.0	1.1	0.7
United States[e]	49	69	78	83	55	66	70	80	182	35	8	5	4.0	4.2	4.6
Sub-Saharan Africa[f]	20	38	50	66	31	43	54	65	500	270	161	58	9.3	28.9	35.1
More developed regions[g]	47	66	76	83	54	65	72	78	190	59	9	5	18.7	13.4	13.0
Less developed regions[g]	26	41	64	74	34	46	65	72	415	219	85	34	79.6	120.5	108.7

Note: Input parameters e_0 (years), e_5 (years), and q_5 (per 1,000) in 1900, 1950, 2000, and 2050; e_0 for 1950, 2000, 2050, e_5 for 2000, 2050, and q_5 for 2000, 2050 were taken from United Nations (2009).
[a] Acemoglu and Johnson (2007) and weighted average from other country/regions using CCC (2011) for the weights.
[b] Riley (2005) and weighted average from other country/regions using CCC (2011) for the weights.
[c] Riley (2005) and authors' assumption.
[d] Davis (1951) and authors' assumption.
[e] Kinsella (1992), Human Mortality database (2011), and authors' assumption.
[f] CDC (2004).
[g] Feachem and Jamison (1991) and authors' assumption.

Table 7.2 Years of life lost (YLLs) per birth, selected countries and country groupings, over and under age 5, and total, 1900–2050

	(a) Under-5 YLLs (YLL_{u5})				(b) Over-5 YLLs (YLL_{a5})				($c = a + b$) Total YLLs (unweighted)			
	1900	1950	2000	2050	1900	1950	2000	2050	1900	1950	2000	2050
World	28.9	14.3	6.5	2.4	16.7	15.6	9.1	5.7	45.6	29.9	15.5	8.2
China	29.7	16.6	2.5	0.8	18.4	17.1	8.1	4.4	48.1	33.7	10.6	5.2
India	40.2	19.5	7.6	3.1	15.1	19.3	11.3	6.7	55.2	38.8	18.9	9.8
Japan	18.9	6.4	0.1	0	14.5	12.3	2.7	0	33.4	18.6	2.8	0
United States	15.6	2.8	0.4	0.2	14.0	10.4	6.5	1.8	29.6	13.2	6.9	2.0
Sub-Saharan Africa	43.3	23.3	13.7	4.7	13.7	17.7	14.6	10.8	57.0	41.0	28.3	15.5
More developed regions	16.3	4.9	0.5	0.2	14.3	11.3	7.1	2.5	30.6	16.1	7.6	2.6
Less developed regions	35.9	18.8	7.1	2.7	16.3	15.6	9.9	6.4	52.2	34.4	17	9.1

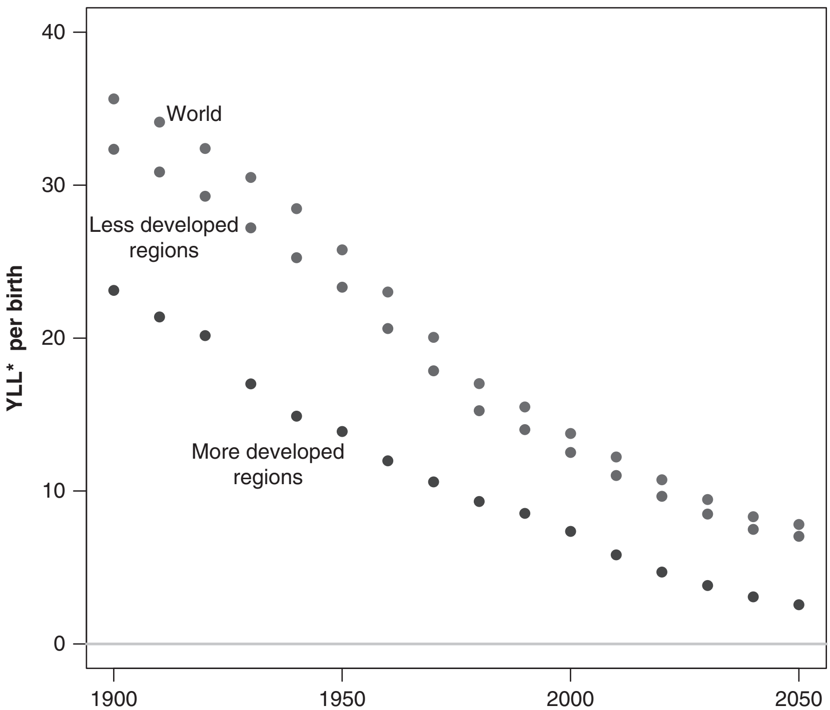


Figure 7.8 *Years of life lost (YLL*) over the period 1900–2050 for the world, the less developed regions, and the more developed regions*

and country/region, for the period 1900–2050. Figure 7.8 graphs the total number of YLLs per birth for the period 1900–2050 for the world, the "Less developed regions," and the "More developed regions."

YLLs due to "Mortality Shocks"

For each major "mortality shock" of the twentieth century including World War I, the "Spanish" pandemic flu of 1918, World War II, the Bengal famine

Table 7.3 Years of life lost (YLLs) per person, major mortality shocks of the twentieth century

Event	Excess deaths (millions)	Population affected (millions)	YLL per capita [a]
World War I (1914–18)	17	1,803	0.62
Influenza pandemic (1918)	50	1,843	1.22
World War II (1939–45)	71	2,275	3.14
Bengal famine (1943)	3	401	0.50
Chinese famine (1958–61)	29	637	3.03

[a] The YLLs per capita are calculated based on the total number of excess deaths over the indicated time period, not per year (as are most YLLs reported in this Chapter).

Source: Ashton *et al*. (1984), Devereux (2000), Wikipedia (2011a, 2011b), Johnson *et al*. (2002), Copenhagen Consensus Center (2011), United Nations (2009).

of 1943 in India, the Great Chinese famine of 1958–1961, we estimated YLLs per capita at the world level, except for the Great Chinese famine (at the China level) and for the Bengal famine (at the India level). For World War I and II, we used deaths data provided by Wikipedia (Wikipedia 2011a, 2011b). We estimated the YLLs corresponding to military casualties with $e_J(20)$. The YLLs corresponding to civil casualties were estimated using the age distribution of the world population in 1910 and 1940, while using a linear regression between the age distribution of the population as a function of life expectancy at birth for the period 1950–2000 extrapolated from United Nations (2009). For the "Spanish" pandemic flu, we used death numbers from Johnson and Mueller (2002) and attack rates from Luk *et al*. (2001) with the extrapolated age distribution of the world population in 1910 as above. Total world population numbers were obtained from the Copenhagen Consensus Center (2011). For the Bengal famine, we used death numbers from Devereux (2000), the extrapolated age distribution of the Indian population in 1940 as above, and the total population of India in 1943. For the Great Chinese famine, we used death numbers from Ashton *et al*. (1984), the age distribution of the Chinese population in 1950, and the total population of China in 1957 (United Nations 2009). World population data at different times were obtained by the Copenhagen Consensus Center (2011). Table 7.3 lists the YLLs associated with each of the major mortality shocks.

Money Metric Value of YLL Reduction

Table 7.4 lists the values $\text{YLL}_{\text{VSL},i,t} = \gamma \text{YLL}^*_{i,t}$, the $\text{MMVYLL}_{m,i,t}$ (equation 7.7), and the ratio $a_{i,t}$ (equation 7.9) for each year and country/region, for the period 1900–2050. Figure 7.9 graphs the ratios $a_{i,t}$ for the period 1900–2050 for: (a) China, India, Japan, and the United States; (b) the world, the "Less developed regions," and the "More developed regions."

Specific Health Problems: Accomplishments and Challenges

In this section, the statistical picture of gains provided in the previous section is illustrated by two specific examples of health accomplishments of the twentieth century: marked increases in child survival and the eradication of smallpox. The discussion then turns to one example of a major challenge that remains on the agenda of the twenty-first century: tobacco-attributable deaths. This is chosen to illustrate the importance of technological diffusion in affecting change (and also, in the case of tobacco and adult chronic diseases, the enormous returns possible if technologies were applied more widely). The other highly quantitatively significant challenge of the twenty-first century is the AIDS epidemic. That has been extensively covered in a recent Copenhagen Consensus Center publication so we discuss it no further here.

Accomplishments: Child Survival

Major declines in childhood mortality started in the late nineteenth century in the currently high-income countries, and in the mid twentieth century

Table 7.4 Value of statistical life years of life lost per birth (YLL_{VSL}), money metric value of years of life lost per birth (MMVYLL), and ratio *a* of MMVYLL over lifetime income per capita, selected countries and country groupings, 1900–2050

	YLL_{VSL}				MMVYLL($)				Ratio *a*			
	1900	1950	2000	2050	1900	1950	2000	2050	1900	1950	2000	2050
World	64.7	46.6	25.0	14.1	40,737	49,347	74,140	132,008	2.1	1.5	0.8	0.5
China	68.9	52.1	19.0	9.6	37,545	23,349	64,883	200,644	2.4	1.9	0.7	0.3
India	73.5	59.7	30.8	16.8	44,038	36,977	58,343	154,800	3.5	2.9	1.5	0.8
Japan	49.5	31.4	5.5	0	58,384	63,054	113,222	0	1.1	0.7	0.1	0
United States	44.8	23.8	13.5	3.8	179,985	221,036	370,334	212,861	0.9	0.5	0.3	0.1
Sub-Saharan Africa	74.2	60.5	44.0	26.7	22,305	27,688	31,398	40,643	3.9	3.1	2.3	1.4
More developed regions	46.2	27.8	14.7	5.1	56,588	65,027	128,389	112,704	1.0	0.6	0.3	0.1
Less developed regions	71.3	51.5	27.5	15.6	22,417	22,071	42,646	127,586	3.0	2.2	1.2	0.7

Note: YLL_{VSL} are calculated from the per person YLLs reported in Table 7.2 in the following: $YLL_{VSL} = 2\ (YLL_{a5} + 0.54\ YLL_{u5})$; MMVYLL are calculated from the YLL_{VSL} in the following: MMVYLL = YLL_{VSL} × GDP per capita, where GDP per capita is expressed in 1990 International Geary–Khamis dollars; *a* is calculated as MMVYLL divided by the lifetime income per capita as defined by equation (7.8) in the main text.

in the currently low-income countries. The declines are much more complete in high-income countries, meaning that today 99% of children born in these countries can expect to reach their fifth birthday. However, the pace of decline has been rapid in low-and middle-income countries, especially since 1950.

Staggering Declines in Child Mortality

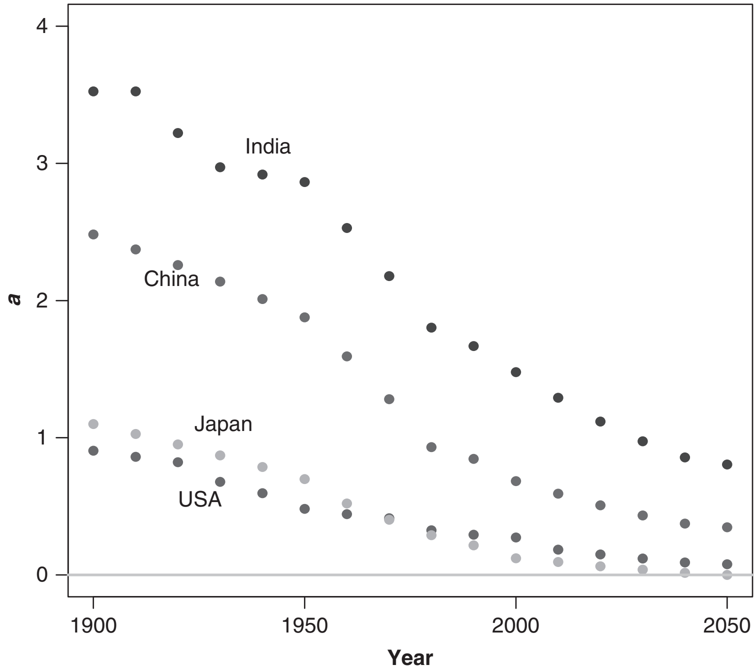
Declines in childhood mortality explain much of the remarkable improvements in life expectancy in the twentieth century as can be seen on Figure 7.10, which plots estimates and projections of the under-5 years of life lost as a percent of total years of life lost for the "More developed regions" and "Less developed regions" for the period 1900–2050.

Between 1900 and 2000, we estimate that crude death rates fell by nearly four-fifths and life expectancy at birth doubled from 32 to about 66 (Table 7.1); while death rates fell from about 40–50 to 10 per 1,000, the global population rose from 1.5 billion to over 6 billion. Thus, annual deaths totaled around 50–60 million throughout the last century. All told, there were about 5–6 billion deaths in the twentieth century. About 2 billion of these deaths were among children below age 5 years, despite the marked declines seen in recent decades. Child deaths far exceeded the several millions of deaths from more specific epidemics, such as the 20–60 million killed by the influenza epidemic of 1918–19, the 30 million (and growing) deaths from HIV, the 100 million deaths from tobacco, or the 200 million deaths from war and famine (see other chapters).

The staggering decline in child mortality is illustrated by a comparison of the levels and causes of child deaths in sub-Saharan Africa in 2008 to that from Liverpool, England in 1861–70 (Table 7.5).

Sub-Saharan Africa's real per capita income in 2008 was just over half of that of England around 1870. However, child mortality rates were two-thirds lower in Africa now than in England then (460 versus 140 per 1,000 live births). By 2008, the contribution of vaccine-preventable diseases, most notably diphtheria, measles, and scarlet fever, had fallen sharply. In contrast, the remaining causes of death arose largely from pneumonias, diarrhea and, in the African case, childhood malaria deaths (most of England had little malaria in the 1870s).

(a)



(b)

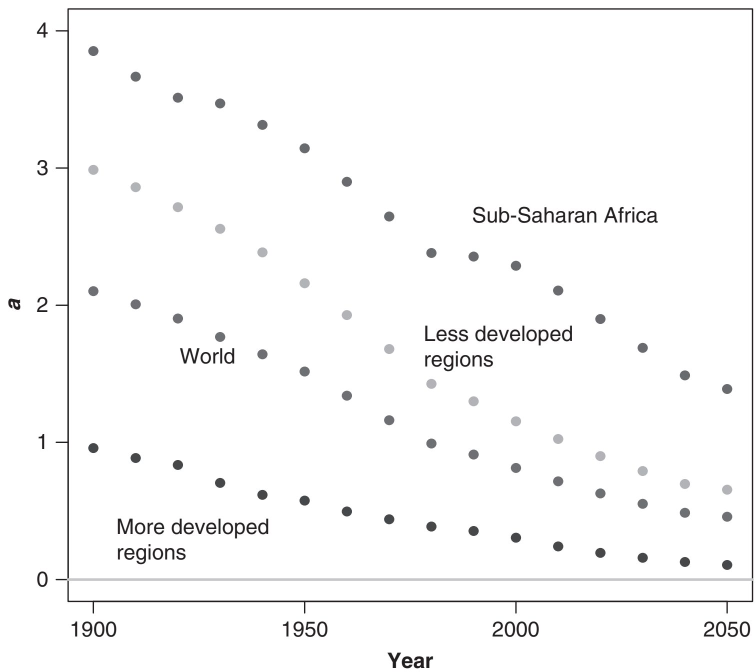


Figure 7.9 *Ratio of the money metric value of life years lost to expected lifetime income (a) over the period 1900–2050 for: (a) countries, i.e. India, China, Japan, the United States; (b) country groupings, i.e. the world, the less developed regions, the more developed regions, Sub-Saharan Africa*

Table 7.5 Child mortality in Liverpool (1860s) and sub-Saharan Africa (2008)

	Liverpool	Sub-Saharan Africa
Under-5 mortality rate (per 1,000 live births)	460	140
Per capita income (US$)[a]	3000	1700
Diseases		
Acute respiratory infections	17%	18%
Birth trauma/asphyxia	11%	8%
Diarrhea	12%	19%
Pulmonary vasculary disease	19%	6%
Tuberculosis	4%	–
Smallpox	1%	–
Malaria	0%	16%
Other infections	1%	18%
Injuries	4%	2%
Subtotal	**69%**	**87%**

[a] Adjusted to 1990 level.
Source: Farr (1889) and Lopez *et al*. (2006).

Put differently, if worldwide child mortality rates today were like those seen in England, or most Western countries near the beginning of the twentieth century, there would be about 30 million child deaths, rather than the 10 million deaths that occurred in children around 2001 (or 13.9 million if stillbirths are included (Jamison *et al*. 2006)). By 2000 child deaths in England had become quite rare. If the world had the same child mortality rates as seen in England today, only 1 million children would die worldwide (Peto 2006).

The Role of Technologies in Child Mortality Declines

Specific technologies have had different impacts on the decline in childhood mortality at different time periods. In the first half of the twentieth century, the available tools included knowledge of transmission of various infectious diseases (Preston and Haines 1991) including crude efforts around containment and isolation, contact tracing, improved sanitation, as well as specific vaccines. These tools, once

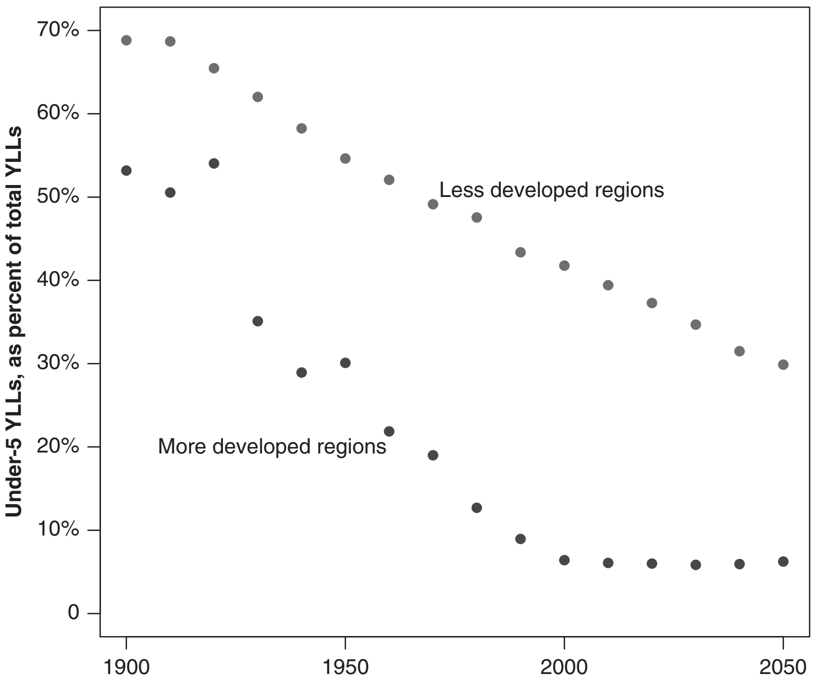


Figure 7.10 *Under-5 years of life lost per person (YLLs) as a percent of total YLLs, 1900–2050*

Table 7.6 Key discoveries in disease transmission and vaccines

Knowledge of transmission (and discoverers)	Vaccines and antibiotics (and discoverers)
1847 Measles (Panum)	1798 Smallpox (Jenner, plus tenth century China)
1847 Puerperal fever (Semmeweiss, Holmes)	1885 Rabies (Pasteur)
1854 Cholera (Snow)	1892 Diphtheria (von Behring)
1859 Typhoid (Budd)	1896 Cholera (Kolle)
1867 Surgical sepsis (Lister)	1906 Pertussis (Bordet-Gengou)
1898 Malaria (Ross)	1921 Tuberculosis (Calmette, Guérin)
1900 Yellow fever (Reed)	1927 Tetanus (Ramon, Zoeller)
1850–1920s Quarantine methods, sanitation improvements, case detection, contact tracing, and other public health efforts	1930 Yellow fever (Theiler) 1935 Sulfonamides (Ehrlich) 1941 Penicillin (Fleming) 1944 Streptomycin (Waksman) 1948 Broad-spectrum antibiotics (various) 1948 Diphtheria – tetanus – pertussis (various) 1950 Polio (Salk) 1954 Measles (Enders, Pebbles)

Source: Modified from Easterlin (1999).

implemented widely in Europe, led to substantial declines in child mortality in the early twentieth century. In the second half of the century, far greater reductions arose from childhood vaccinations (including the introduction of global campaigns to immunize children), oral rehydration therapies, antibiotic use and malaria control.

Easterlin (1999) describes some of the available tools in the first half of the twentieth century and their discovery years, and we have modified this table somewhat and added a table on more contemporary tools (Table 7.6).

The major tools of control in the early twentieth century comprised efforts to interrupt transmission of infectious diseases, often crudely. Plague epidemics and outbreaks were a major cause of childhood mortality worldwide. In India, plague deaths at all ages fell from about 500,000 in the period 1889–1918 to below 32,000 by 1935 with many of these deaths concentrated in children. The chief reasons for the decline were increases in rat immunity (rats transmit the *Yersinia pestis* bacteria into human populations). However, declines occurred also due to crude efforts to control the rat population, and to a much more limited extent the use of vaccines and, at a later point, sulfa drugs (Davis 1951). Similarly, cholera epidemics were substantial in many parts of the world, and the understanding of transmission from water sources and via fecal contact led to crude measures involving containment that reduce the spread and severity of periodic outbreaks. Notably, the periodic religious pilgrimages of several million Hindus often led to cholera outbreaks. Simple efforts to bring basic sanitation and (to a more limited extent) temporary vaccination to the large number of annual pilgrims reduced cholera outbreaks. Reductions in famines arising from better agricultural practices and irrigation supply (see chapter on nutrition) were also partly responsible for the reductions in cholera, as famines can lower human immunity and also contribute to spreading the virus more rapidly.

By 1950–4, the probability of newborns dying before age 5 was still about 23%, but fell to 14% by 1970–4, to 9% in 1990–4, and to about 6% in the present decade (Ahmad *et al*. 2000). The declines from about 1950 onward in child mortality mostly arose from the use of modern technologies. Table 7.7 describes the declines in infectious diseases, which is the leading cause of death among children that arose from specific technologies in the second half of the twentieth century. Improved environmental living conditions paired with the ability to identify new microbes and develop vaccines as well as antimicrobials account for the 90% or greater reduction in infectious disease mortality in the USA. In the last half century, more than 30 common infectious diseases are controllable with live or killed viral or bacterial vaccines, or those based on bacterial sugars and proteins (Jha *et al*., 2004).

Table 7.7 Examples of science contribution to declines in infectious disease mortality in the second half of the twentieth century

Condition and intervention	Annual deaths prior to intervention (and reference year) in thousands	Annual deaths after intervention (and reference year) in thousands
Immunization services – against polio, diphtheria, pertussis, tetanus, and measles	~5,200 (1960)	1,400 (2001)
Eradication campaign – smallpox	~3,000 (1950)	0 (1979)
Diarrhea – oral rehydration therapy	~ 4,600 (1980)	1,600 (2001)

Source: Jamison *et al*. (2008).

In 1970, perhaps only 5% of the world's children under 5 were immunized against measles, tetanus, pertussis, diphtheria, and polio. The Expanded Programme on Immunization (EPI) has raised this to about 85% of children by 2000, saving perhaps 3 million lives a year (England *et al*. 2000). Diarrheal deaths among children have fallen by several million partly as a result of the development of oral rehydration therapy – much of which was the result of population research laboratories in Bangladesh. Delivery of a combination of anti-tuberculosis drugs with direct observation (or DOTS) has lowered case-fatality rates from well over 60% to 5%, and also decreased transmission. The percentage of the world's tuberculosis cases treated with DOTS has risen from about one in ten in 1990 to about one in three today (Dye 2000). The most spectacular success in immunization is the WHO-led eradication of smallpox, which culminated in the eradication of smallpox in human populations by 1979. We discuss smallpox in greater detail below.

Prior to 1950, the only major antibiotics were sulfonamides and penicillin. Subsequently, there has been remarkable growth in discovery and use of antimicrobial agents with different mechanisms of action effective against bacteria, fungi, viruses, protozoa, and helminths. These new agents have contributed importantly to the steady decline in child mortality.

The Uncertain but Perhaps Large Contribution of Malaria Control

Preston (1980) provides a useful set of estimates of the contribution of specific infectious diseases to reductions in mortality from 1900 to 1970. We provide an updated version in Table 7.8.

Preston's estimates of the contribution of technologies to mortality declines are consistent with others. However, he adds the important, and yet variable estimates of reduced mortality from malaria control. Perhaps 13%–33% of the overall decline in mortality during these seven decades might have arisen from malaria control, chiefly from indoor residual spraying, but also from early antimalarial drugs like quinine. Mandle (1970) finds that a very large part of the declines in mortality in British Guiana, especially in the period just after World War II, arose from malaria control (Figure 7.11).

In more recent years, artemisinin combination therapies have shown to be powerful tools to reduce malaria mortality (Gomes *et al*. 2009), and indeed childhood malaria deaths in Africa might be falling in response to expanded use of insecticide-treated nets and treatment. In this context, important findings from a large Indian mortality survey suggest that India might well have over 200,000 malaria deaths below age 70, as against the WHO estimate of 15,000 at all ages. Malaria appears not only to be a killer of children, but also of adults (Figure 7.12). Indeed, similar patterns are reported in Mozambique and other countries in Africa. If it is true that malaria remains a common killer of adults, then the same strategies that have been applied to reduce childhood deaths from malaria in Africa might well substantially reduce adult deaths from malaria worldwide.

Nutrition and Infection

How has nutrition reduced childhood mortality? Nutritional gains have been substantial (see

Table 7.8 Infectious diseases responsible for mortality declines in less developed countries and related control measures

Dominant mode of transmission	Disease	Approximate percent of mortality decline accounted for by disease, 1900–1970,	Principal method of prevention deployed	Principal methods of treatment deployed
Airborne	Influenza/pneumonia/bronchitis	30		Antibiotics
	Respiratory tuberculosis	10	Immunization; identification and isolation	Chemotherapy
	Smallpox	2		Chemotherapy
	Measles	1		
	Diphtheria and pertussis	2	Immunization	Antibiotics
	Subtotal airborne	**45**		
Water-, food-, and feces-borne	Gastroenteritis Cholera Typhoid	7 1 1	Purification and increased supply of water; sewage disposal; personal sanitation	Rehydration Rehydration, antibiotics
	Subtotal water-, food-, feces-borne	**9**		
Vector-borne	Malaria	13–33	Insecticides, drainage, larvicides	Quinine drugs
	Typhus	1	Insecticides, partially effective vaccines	Antibiotics
	Plague	1	Insecticides, rat control, quarantine	
	Subtotal vector-borne	**15–35**		
	TOTAL	**69–89**		

Source: Modified from Preston (1980).

Chapter 8). For example, physical growth (height-for-age) rose among 10-year-old Norwegian females from 1920 to 1970 from 130.2 cm to 139.6 cm (and was only about 107.4 cm in 1800: Brundtland, *et al.* 1975). This massive increase of about 1.9 cm per decade or 0.84 standard deviation per generation has also been accompanied by increases in cognitive growth. Dutch males had, in 1982 1.2-fold higher IQ relative to their own fathers in 1952, and about 10-fold higher than men in 1800. This increase of about 7 IQ points per decade or 1.4 standard deviation per generation is also related to better nutrition (Ruger *et al.* 2006). Famines and mass droughts have become less and less common in the twentieth century (despite short-term fluctuations), in part due to better food availability, and the effects of the Green Revolution on crop yields and durability. In turn, better diets, particularly but not only during early life, have substantially improved anthropometrics, schooling, adult cognitive skills, earnings, and wages of the next generation.

Nutrition is not only a function of available energy or protein, and diet alone fails to explain the widely variable prevalence of malnutrition in low- and middle-income countries. Nutrition is strongly correlated with childhood infections (Caulfield *et al.* 2006). Infectious diseases raise metabolic demands and decrease the absorption of food, and infection control from immunizations, and antimicrobials have helped reduce the worldwide prevalence of severe

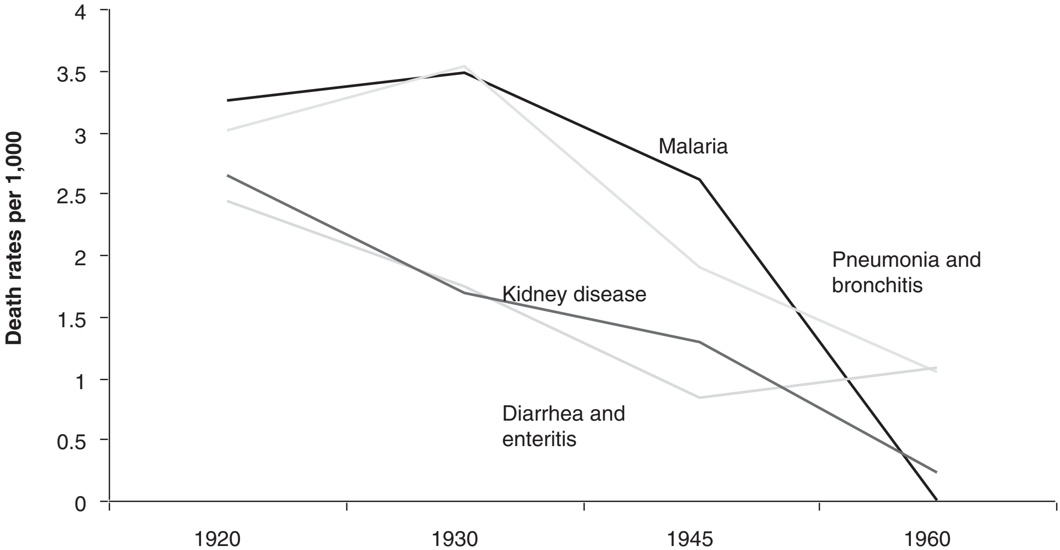


Figure 7.11 *Mortality trends and specific diseases in British Guiana*

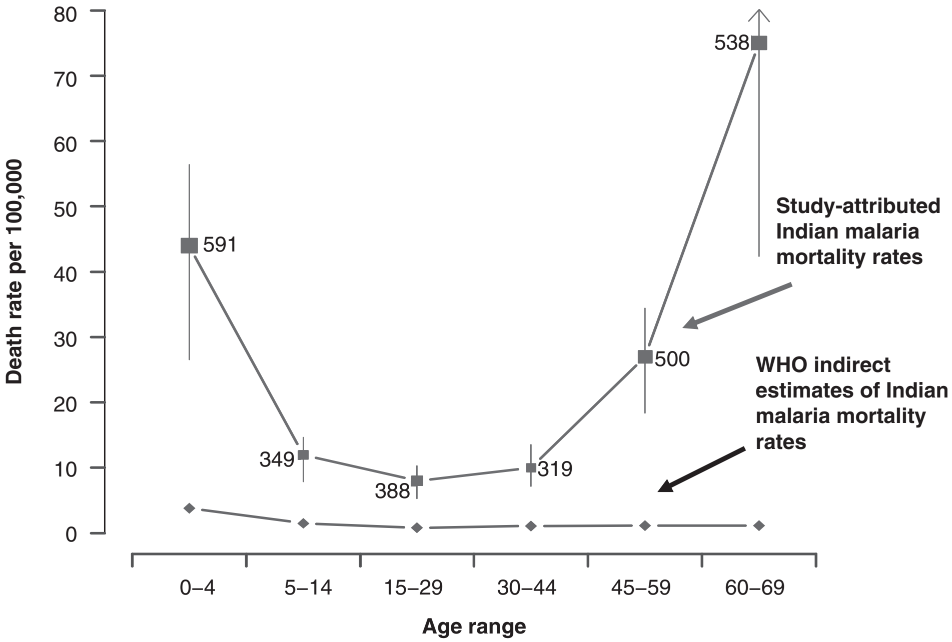


Figure 7.12 *Age-specific all-India malaria-attributed death rates estimated from a large mortality study and those estimated indirectly for WHO*

malnutrition, such as kwashiorkor or marasmus (Caulfield *et al*. 2006). Maternal breastfeeding is a key nutritional intervention to protect against infection. Indeed, Chile saw increases in child mortality among more affluent women than among poorer women, as a result of decreases in breastfeeding by the affluent women (Plank and Milanesi 1973). More recent efforts with specific micronutrients such as iron, folate, and zinc have been shown to be effective in reducing childhood anemia (Zlotkin *et al.* 2005) and subsequent mortality. Randomized trials of insecticide-treated mosquito nets and of specific respiratory antigens have often shown a bigger decline in child mortality than expected from malaria and pneumonia, respectively, and this might be attributed to lowering secondary causes of death from reduced malnutrition.

Current and Future Child Mortality

Despite these substantial achievements in child survival, major challenges still exist. As of 2008, about 9 million children still died before age 5. India alone had 2.3 million child deaths in 2005, of which nearly half occurred in the first month of life and 30% in the first week of life (Million Death Study Collaborators 2010). Indian child mortality has fallen by about 2% per year since 1971 as a whole in India and all states have shown declines. Differences in income levels and growth rates across Indian states do not appear to account for the variation in decline in child mortality (Measham *et al.* 1999). Rather, coverage with the EPI package, treatment of acute respiratory infection in a medical facility and use of oral rehydration therapy for diarrhea show a clear gradient from worst to best performing states on under-5 mortality (Jha 2001). Today, about three-fifths of all childhood deaths occur in just nine states. At ages 1–59 months, girls in some regions have four to five times higher mortality from pneumonia or diarrhea as boys in other regions (Million Death Study Collaborators 2010). Discrepancies in child mortality across states are so large that if the worst third and middle third states had under-5 mortality rates equal to that of the best third, over 1 million under-5 deaths would be avoided annually (Jha 2001).

Notwithstanding these challenges, child mortality declines are likely to continue. In Africa, for example, overall child mortality fell from 1990 to 2000 despite increases in childhood deaths from malaria and from mother to child transmission of HIV (Ahmad *et al.* 2000), and despite economic stagnation. Concerted efforts around reducing childhood mortality now focus on reducing neonatal mortality by improving prenatal and intrapartum care (skilled attendance, emergency obstetric care, and simple immediate care for newborn babies), postnatal family–community care (preventive postnatal care, oral antibiotics, and management of pneumonia), and tetanus toxoid immunization as well as expanding the use of highly effective newer antigens in immunization programs.

On current projection (Table 7.1), child mortality is projected to fall from about 77 per 1,000 live births in 2000 to 31 per 1,000 live births in 2050. These reductions are likely to continue as forthcoming analyses find the costs of reducing child mortality continue to fall yearly. This improving cost function is largely because of 40 years of public attention, donor assistance, and research funding have, together, created cost-effective and widely practicable interventions for child and maternal health, and more recently to control of HIV/AIDS, malaria and tuberculosis. Increasing coverage of inexpensive health interventions such as immunization, insecticide-treated nets, prevention of mother-to-child transmission of HIV, and micronutrients are contributing to the decline in child mortality and are getting cheaper by the year (Hum *et al.* 2013).

Accomplishments: Smallpox Eradication

In 1979 the WHO eradicated smallpox, a disease that perhaps had caused 300 million deaths in the course of the twentieth century. Successful eradication arose from a combination of two major factors. First, declines in smallpox in the first half of the twentieth century were substantial mostly due to widespread use of vaccination, as well as general understanding of isolation and control of outbreaks (paired with increases in general nutrition and hence resistance of humans to withstand the periodic outbreaks of smallpox). Second, in 1967 the WHO initiated a global eradication campaign which succeeded in the course of 12 years (Figure 7.13).

Smallpox before Eradication

Prior to any widespread control, smallpox may have been the leading cause of death worldwide. Smallpox may have killed perhaps 2–15 million of the total Aztec population of 30 million, and was responsible for periodic epidemics killing hundreds of thousands in cities as far apart as London and Tokyo. Nor did smallpox spare the rich and only strike the poor. Smallpox infected Egyptian pharaoh Ramses V in 1157 BC and Queen Elizabeth I in 1562 and it killed a Roman emperor in 180 BC (Fenner *et al*. 1988). In India in 1937–1941, smallpox accounted for between 12% and 20% of the deaths in the first year of life and about 19%–30% of the deaths between ages 1 and 9 years (Davis 1951). India had about half of the world's cases in the two decades prior to eradication. Between one in five and one in three of all cases died.

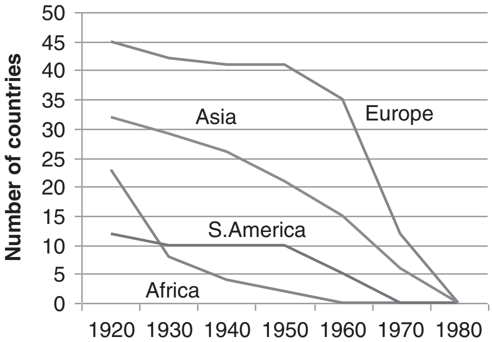


Figure 7.13 *Number of countries reporting smallpox by region, 1920–1980*

Introduction of smallpox vaccination began in crude forms as early as the eighth century in China. The technique, called variolation, involved using the scabs of smallpox victims injected into healthy people so as to provide some protection. The Chinese even used inhalation approaches for vaccination. These technologies spread westward, and were brought from Constantinople to England in the early eighteenth century. Vaccination using Jenner's discoveries became widespread by the later nineteenth century, and was far more practicable and less painful than the variolation.

Where vaccination became commonly used, such as in Finland, death rates fell substantially (Figure 7.14). In many currently high-income countries, public health infrastructure expanded, including the ability to forcibly quarantine suspected cases, have mandatory examination of incoming ships, and require compulsory vaccination or revaccination of children and others.

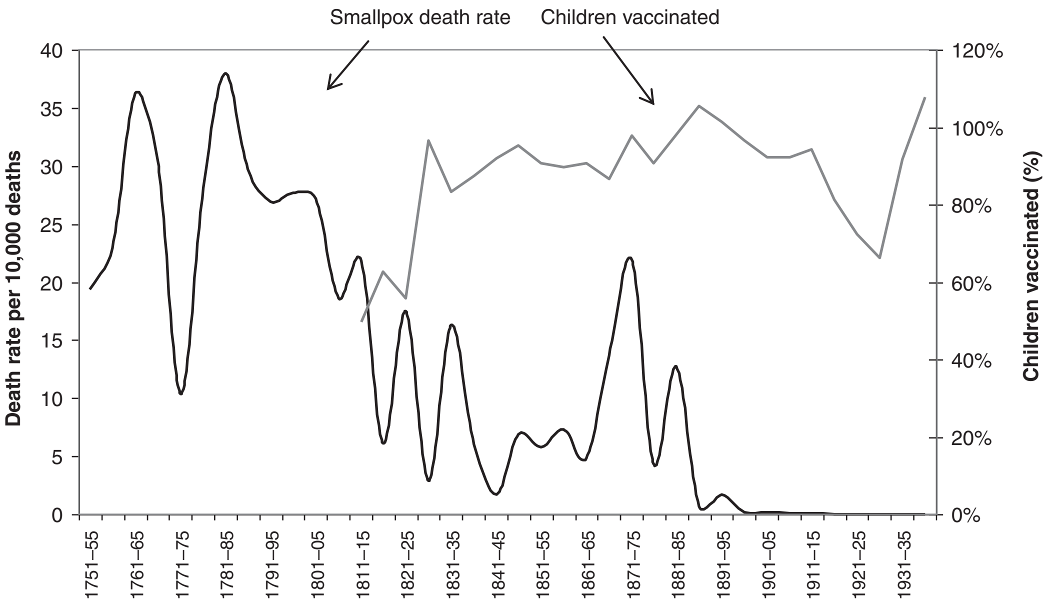


Figure 7.14 *Trends in smallpox deaths and immunization, Finland, 1750–1935*

London's public health act of 1875 gave broad powers to the police and public health officials to enforce these laws.

Smallpox vaccination spread widely, including to low-income countries. Banthia and Dyson (2000) describe how increases in vaccination were recorded in the Bombay census of 1881–91, and their comparison of coverage rates with self-reported smallpox shows remarkable declines. Nearly 80% of the roughly 30 million people in Bengal were inoculated and once replaced by vaccination around 1870, smallpox cases and mortality fell dramatically. A spectacular increase in vaccination occurred in Indonesia (then Netherlands East Indies). The numbers of vaccination rose from under 60,000 in 1890–9 to nearly 1.7 million by 1900–19 and to 7.3 million by 1920, from a total population of about 45 million Indonesians. This led to a marked decline in smallpox mortality (Davis 1951).

Global Eradication

The next major phase involved global eradication. A WHO effort organized all countries to launch a global eradication campaign. Eradication was technically possible as the causative virus for smallpox (with two variants *Variola major* and *Variola minor)* resides only in humans. The initial effort focused on increasing coverage of the routine vaccines. However, two key areas of operational research refocused the program so that it could achieve eradication. These were active case detection and ring vaccination. Under active case detection, mobile teams investigated outbreaks using local information. In the case of India, Bangladesh, Nepal, Pakistan, Ethiopia, and Somalia, country-wide house-to-house searches were conducted by a large number of health staff over the course of 3–4 weeks to discover possible cases. Ring vaccination involved finding people who were exposed to an infected person. Then the exposed person and those people he or she had been in contact with are given the vaccine. That is, the smallpox vaccine is given to those people who had been, or could have been, exposed to an infected person. This approach creates a "ring" of vaccinated people around the people who were infected with smallpox and stops the spread of the disease.

The smallpox eradication program cost an estimated \$300 million over its 12-year life and displaced routine immunization costs that totaled \$300 million in 1968 alone (World Bank 1993). These financial benefits, and the millions of lives saved annually, are more fully discussed in Fenner *et al.* (1988).

Challenges: Tobacco Control

On current smoking patterns, there will be an estimated 1 billion smoking-attributable deaths in this century, mostly in low- and middle-income countries. In contrast, there were "only" 100 million tobacco deaths in the twentieth century, mostly in high-income and Eastern European countries who took up smoking en masse generally before or around World War II (Peto *et al.* 1994; Jha 2009). Most of these future tobacco-related deaths will occur in low-income countries, and half or more will occur during productive middle age (defined here as about 30–69 years). A substantial proportion of these deaths will occur among the poorest or least educated members in each of these countries. Currently, about 70% of the 40 million deaths among adults over age 30 years worldwide are due to cancer, vascular and respiratory diseases, and tuberculosis (Lopez *et al.* 2006), each of which are made more common by smoking. Smoking currently causes about 5–6 million deaths annually worldwide from all causes (Jha 2009). About 50% of all current smoking related deaths occur in low-income countries.

Here, we review the twentieth-century development in tobacco hazards, and examine in particular, the benefits of cessation, which has now become widespread among males in high-income countries. We examine the importance of taxation to increase cessation. The key relevance here is not to the 100 million deaths in the twentieth century which have already occurred, but to the avoidability of the 1 billion deaths in this century.

Trends in Smoking in Developed and Developing Countries

Widespread automation of cigarette production in the early twentieth century turned cigarettes into a global commodity. Lung cancer was a rare disease prior to World War II, and the large increase in lung cancer rates lagged behind the onset of consumption by three or more decades. Among British doctors who were born in the first few decades of the twentieth century (1900–1930) and followed those born in the second half of it (1951–2001), death rates were three times higher among doctors who smoked than those who did not (Doll *et al*. 2004). Prolonged smokers lost about 10 years of life compared to non-smokers. Similarly, the main increase in cigarette smoking in the USA occurred from 1920 to 1940, and peaked at about 10 cigarettes per adult only around 1960 (Jha 2009). Yet the rates of lung cancer in middle age and at older ages, almost all of which are due to smoking, peaked almost 30 years later.

The full effects of smoking have not yet been observed in low- and middle-income countries. China has over 300 million smokers and India has over 120 million smokers, most of whom are male (Jha *et al*. 2013). Moreover, China reports a marked increase in cigarette production since 2000, which might be from increased smoking among younger adults. India's per capita adult male consumption is over six bidis (small locally manufactured smoked tobacco products) or cigarettes per day, although there is some uncertainty in this, particularly for bidi use (Jha *et al*. 2011). This is comparable to the per capita adult consumption in France prior to 1990, and higher than that seen for adults today in Canada, which has declined from about 11 cigarettes per capita in the 1960s to below five in 2010.

Effects of Cessation on Lung Cancer and Total Deaths

Widespread smoking cessation in high-income countries has afforded researchers the opportunity to study the impact of quitting at various ages on the risk of death from tobacco-attributable diseases. Doctors in the UK who quit smoking before the onset of major disease avoided most of the excess hazards of smoking. In comparison to those who continued smoking, the average gain in life expectancy for those who quit smoking at 60, 50, 40, and 30 years of age, was about 3, 6, 9, and nearly 10 years, respectively (Peto *et al*. 2000). Cessation before middle age prevents more than 90% of the lung cancer mortality attributable to smoking, with quitters possessing a pattern of survival similar to that of persons who have never smoked.

Overall Current Risks from Smoking

Provided due allowance is made for the long delay between smoking onset and disease, reasonably consistent quantitative estimates of risk emerge: about one in two of all long-term smokers worldwide are killed by their addiction (Jha 2009). It is already apparent that a substantial proportion of tobacco-related deaths worldwide occur in middle age : 50% in the USA and UK, 50% in China (Liu *et al*. 1998), and a surprisingly high 70% in India.

At present, about 80% of worldwide smoking-related deaths occur in men (Jha 2009), but this is chiefly because men who died recently smoked more commonly and more intensively when they were young than did the female smokers. The smoker : non-smoker mortality risks in US women after 2000 are actually greater than in men (Jha *et al*. 2013). Additionally, the consequences of smoking vary by socio-economic group. For example, in several high-income countries and Poland, smoking-related deaths were shown to account for at least half of the differences in middle age risk of death between rich, educated men and poorer, less educated men (Jha *et al*. 2006).

Future Risks from Smoking and Estimates

The future risks of smoking among men in low- and middle-income countries and women worldwide will depend on the duration of smoking (and cessation rates) in the population, variation in the diseases which are made common by smoking, and in the products and patterns of smoking. First, the full effects of smoking will only be apparent when the death rates from smoking in middle age among those who have started smoking as young adults rise 30–40 years later. Death rates from smoking in older age will rise only about 20 years after this (Jha

2009). For example, of all US male deaths at ages 35–69, the proportion attributable to tobacco in 1950 was only 12%, rising to 33% in 1990, when the increase in US male tobacco-related deaths had been completed (about three decades after peak male tobacco consumption).

Plausible projections of future smoking-related deaths rely on smoking prevalence and uptake (cessation is minimal in low- and middle-income countries), growth in population and growth in the age-specific tobacco-attributable death rates. Sir Richard Peto (2006) estimates that global tobacco-related deaths will reach about 450 million between 2000 and 2050. Worldwide annual tobacco-related mortality will rise to about 10 million per year or 100 million per decade around 2030, with some further increases in later decades. Further estimations are more uncertain, but based upon current initiation and cessation rates and projected population growth, from 2050–2100 there would be, conservatively, an additional 500 million tobacco-related deaths (i.e. an average of 10 million deaths per year).

How Can Cessation Rates be Raised Rapidly Worldwide?

Cessation by today's smokers is the only practicable way to avoid a substantial proportion of tobacco-related deaths worldwide before 2050. Halving the worldwide per capita adult consumption of tobacco by 2020 (akin to the declines in adult smoking in the UK over the last three decades) would prevent about 160–180 million tobacco-related deaths over the next few decades (Peto *et al*. 1994; Jha 2009). In contrast, halving the percentage of children who become prolonged smokers (from about 30% to 15% over two decades) would prevent some 20 million deaths over the next few decades, but its main effect would be to lower mortality rates in 2050 and beyond.

Higher taxation is the single most important intervention to raising global smoking cessation rates. Other interventions, specifically on information for consumers, banning advertising and promotion, and restricting public smoking as well as cessation for smokers also raise quit rates. For brevity, only taxes are discussed here. Detailed reviews of tobacco control strategies are published elsewhere (Jha and Chaloupka 2000; Jha *et al*. 2006; Jha 2009).

Aggressive taxation is the key strategy for low- and middle-income countries to reduce smoking at a rate faster than that achieved by high-income countries. Powerful policy interventions to tax and regulate consumption and to inform consumers have reduced consumption in most high-income countries (WHO, 2010a). The US and UK each took about 35 years and Canada about 25 years to halve per adult cigarette consumption (from about ten per adult per day to about five: Forey *et al*. 2009).

However, France took only 15 years to halve consumption (Hill 2010). France's uptake of smoking was chiefly after World War II and its prevalence rose until the mid-1980s. From 1990 to 2005, cigarette consumption fell from about six cigarettes per adult per day. This sharp decline was mostly due to a sharp increase in tobacco taxation starting in 1990 under the then president Jacques Chirac (Figure 7.15). These price increases raised the inflation-adjusted price threefold. Among men, the corresponding lung cancer rates at ages 35–44, which is a good measure of recent smoking in the population, fell sharply from 1997 onward. During this period, revenues in real terms rose from about €6 billion to €12 billion. Tax levels stagnated from 2004 onward when Nicolas Sarkozy became finance minister as has the decline in per capita cigarette consumption.

An increase in cigarette taxes of 10% globally would raise cigarette tax revenues by nearly 7%, as the fall in demand is less than proportional to the price increase in most countries (Jha and Chaloupka 1999). However, taxes are underused in most developing countries (WHO 2010a). Taxes tend to be absolutely higher and account for a greater share of the retail price (71% as of 2006) in high-income countries. In low- and middle-income countries, taxes account for 54% of the final price of cigarettes. In South Africa, tax as a percentage of retail price fell to about 20% around 1990, but has subsequently risen to nearly 40% (Van Walbeek 2005). As a result, consumption fell from about four cigarettes per adult per day to two over a decade. Poland's recent tax increases have doubled the

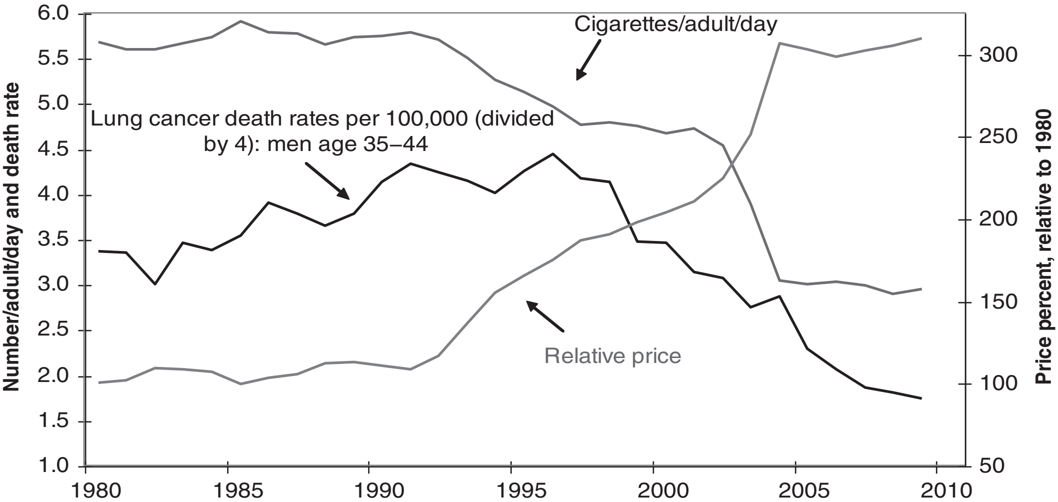


Figure 7.15 *France: smoking, tobacco prices, and male lung cancer rates at young ages, 1980–2010*

real price of cigarettes and lowered consumption. Mauritius and Mexico recently raised taxes by about 30%, which has already produced a drop in consumption.

A tax increase needed to raise the street prices of cigarettes by 70% would involve a 2- to 2.8-fold increase across countries (Jha 2009). The increase would raise the street price for a pack of 20 cigarettes from about US$0.7 to US$1.3 in low-income countries, from about US$1.3 to US$2.3 in middle-income countries, and from US$3.7 to US$6.3 in high-income countries. Such increases, while large, have been achieved in numerous countries, including Canada, France, Poland, and South Africa and within the various states of the USA. Indeed, the 2.5-fold increase in the US federal cigarette tax as of 2009 (rising by 62 cents to US$1.01 per pack) might get about 1 million Americans to quit smoking and deter another 2 million youth from starting, thus saving over 1 million lives.

Our purposes in this discussion of smoking are twofold. First, the growing consequences of the smoking epidemic provide a quantitatively important exception to the general rule of rapid progress in health. Second, we have attempted to show that knowledge-based approaches to control have every potential for ultimately yielding success of the sort experienced elsewhere in the health sector.

Conclusion

The twentieth century saw life expectancy rise by about 3 months for every calendar year. This extraordinary transformation of mortality is chiefly, but not exclusively, a result of the creation and widespread use of specific technologies. What was the value of this transformation? And what then are the implications for this century?

First, by any reasonable measure of value, the value of the health gains in the past century has been enormous.

Second, ongoing investments in widely applicable treatments and policies remain the best engine of future reductions. Specifically, the ongoing investments in child health and infectious disease control should continue to make possible the creation of new powerful interventions, and ongoing operations research and public support for child health should enable the use of these interventions much more widely. In contrast, the future looks less rosy for adult health. The costs of achieving adult survival are rising each year, in part due to the effects of the tobacco and HIV epidemic, (Hum *et al.* 2012). Moreover, the major enterprise of public support, research attention, and widespread operations research remain scanty at best. Nowhere is this demonstrated more powerfully than for tobacco taxation. A worldwide coordinated major increase in tobacco taxation is not hard to make practicable – the only obstacles are widespread indifference or misunderstanding of tobacco hazards among the public and politicians, and well-organized and funded opposition from the tobacco industry. Similar widely cost-effective strategies (Jamison *et al*. 2008) focused on long-term management with combination drugs for heart attacks and strokes are also widely practicable.

The third major implication has to do with institutions. Previous careful reviews (WHO 1996) have supported worldwide efforts to accelerate research on neglected and unfinished agendas (such as selected tropical diseases) and on chronic diseases. To some extent, the major philanthropy of the Bill & Melinda Gates Foundation will continue research on promising interventions for child health and infectious diseases, although there are limitations to how the foundation chooses and funds innovations (Black *et al*. 2009; McCoy *et al*. 2009). Major institutions, are, as seen above, central to gains in health. Similar efforts and philanthropy are needed for chronic diseases.

Finally, while mostly beyond the scope of this chapter, a rethink in developmental assistance around health is required. Given income growth, and increased affordability (at least of child health interventions), it can be fairly argued that most funding for delivery of effective interventions should be the responsibility of governments as well as major global funds (such as the Global Fund for AIDS, Tuberculosis and Malaria or the Global Alliance for Vaccines and Immunization). This suggests that a substantial part of traditional bilateral aid, such as by USAID or the UK DFID, should be redirected to operations research as well as to chronic disease intervention research. Facilitating the application and diffusion of new health technologies and policies will yield the highest return on the aid dollar.

Finally, as illustrated by Annex Figure A7.1 (below) presenting the total money metric value of years of life lost as percent of GDP for selected regions for the period 1900–2050, the biggest decline has taken place in less developed regions where the ratio has fallen from 35% to 12% in the last century and expected to fall to 6.5% in 2050. The world as a whole has experienced a development bringing it from 32% to 5% in the same period. This is both a result of improved human health and economic growth.

References

Acemoglu, D. and S. Johnson, (2007) Disease and development: the effect of life expectancy on economic growth, *Journal of Political Economy* **115**: 925–985.

Ahmad, O. B., A. D. Lopez, and M. Inoue (2000) *The decline in child mortality: a reappraisal. Bulletin of the World Health Organization* **78**: 1175–1191.

Aral, S. O. and K. K. Holmes (2008) The epidemiology of STIs and their social and behavioral determinants: industrialized and developing countries. In: K. K. Holmes, P. Sparling, W. Stamm, *et al*. (eds.) *Sexually Transmitted Diseases*, 4th edn. New York: McGraw-Hill.

Ashton, B., K. Hill, A. Piazza, and R. Zeitz (1984) Famine in China, 1958–1961. *Population and Development Review* **10**: 613–645.

Banthia, T. and T. Dyson (2000). Smallpox and the impact of vaccination among the Parsees of Bombay. *Indian Economic and Social History Review* **37**: 22–51.

Basu, A. M. and R. Stephenson (2005) Low levels of maternal education and the proximate determinants of childhood mortality: a little learning is not a dangerous thing. *Social Science and Medicine* **60**: 2011–2023.

Black, R. E., M. K. Bhan, M. Chopra, I. Rudan, and C. G. Victora (2009) Accelerating the health impact of the Gates Foundation. *The Lancet* **373**: 1584–1585.

Bloom, D. E., D. Canning, and J. T. Jamison (2004) Health, wealth, and welfare. *Finance and Development* **40**: 10–15.

Bloom, D. E., A. Mahal, L. Rosenberg, *et al*. (2004) *Asia's Economies and the Challenge of AIDS*. Mandaluyong City, Philippines: Asian Development Bank.

Breman, J. G., M. S. Alilio, and A. Mills (2004) Conquering the intolerable burden of malaria: what's new, what's needed: a summary. *American Journal of Tropical Medicine and Hygiene* **71** (2 Suppl.): 1–15.

Brundtland, G. H., K. Liestol, and L. Walloe (1975) Height and weight of school children and adolescent girls and boys in Oslo 1970. *Acta Paediatricia* **64**: 565–573.

Caldwell, J. and P. McDonald (1982) Influence of maternal education on infant and child mortality: levels and causes. *Health Policy and Education* **2**: 251–267.

Carter, R. and K. N. Mendis (2002) Evolutionary and historical aspects of the burden of malaria. *Clinical Microbiology* **15**: 564–594.

Caulfield, L. E., S. A. Richard, J. A. Rivera, P. Musgrove, and R. E. Black (2006) Stunting, wasting, and micronutrient deficiency disorders. In: D. T. Jamison, J. G. Breman, A. R. Measham, *et al*. (eds.), *Disease Control Priorities in Developing Countries*. New York: Oxford University Press.

Center for Disease Control and Prevention (2004). *United States Life Tables, 2002: National Vital Statistics Report*. Atlanta, GA: CDC.

Coale, A. J. and P. Demeny (1966) *Regional Model Life Tables and Stable Populations* Princeton, NJ: Princeton University Press.

Copenhagen Consensus Center (2011): Population Data.

Crawford, C. B., B. E. Salter, and K. L. Lang (1989) Human grief: is its intensity related to the reproductive value of the deceased? *Ethology and Sociobiology* **10**: 287–307.

Cutler, D. M. and S. Kadiyala (2002) The return to biomedical research: treatment and behavioral effects In: K. M. Murphy and R. H. Topel (eds.), *Measuring the Gains of Medical Research: An Economic Approach*. Chicago. IL: University of Chicago Press.

Davis, K. (1951) *The Population of India and Pakistan* Princeton, NJ: Princeton University Press.

(1996) The amazing decline of mortality in underdeveloped areas. *American Economic Review* **46**: 305–318.

de Vlas, S. J., N. J. Nagelkerke, P. Jha, and F. A. Plummer (2002) Mother-to-child HIV transmission and ARVs. *Science* **298**: 2129.

Devereux, S. (2000) *Famine in the Twentieth Century*, Institute of Development Studies Working Paper No. 105. Brighton, UK: IDS.

Dhingra, N., P. Jha, V. P. Sharma, *et al*. (2010) Adult and child malaria mortality in India: a nationally representative mortality study. *The Lancet* **376**: 1768–1774.

Doll, R., R. Peto, J. Boreham, I. Sutherland (2004) Mortality in relation to smoking: 50 years' observations on male British doctors. *British Medical Journal* **328**: 1519–1533.

Dye, C. (2000) Tuberculosis 2000–2010: control, but not elimination. *International Journal of Tuberculosis and Lung Diseases* **4**(Suppl): S146–152.

Easterlin, R. A. (1999) How beneficent is the market? A look at the modern history of mortality. *European Review of Economic History* **3**: 257–294.

England, S., B. Loevinsohn, B. Melgaard, U. Kou, and P. Jha (2000) *The Evidence Base for Interventions to Reduce Mortality from Vaccine-Preventable Diseases in Low- and Middle-Income Countries*, CMH Working Paper Series WG5 Paper No. 10. Available at: www.cmhealth.org/docs/wg5_paper10.pdf.

Farr, W. (1889) Life and death in England. Reprinted in N. A. Humphreys (ed.) *Vital Statistics: A Memorial Volume of Selections from the Reports and Writings of William Farr, Bulletin of the World Health Organization* (2000) **78**: 88–96.

Feachem, R. G. and D. T. Jamison, (1991) *Disease and Mortality in Sub-Saharan Africa* Washington, DC: World Bank.

Fenner, D., D. A. Henderson, I. Arita, *et al*. (1988) *Smallpox and its Eradication*. Geneva: WHO.

Ferguson, N. (2011) *Civilization: The West and the Rest.* New York: Penguin Books.

Forey, B. J. Hamling, and P. Lee (eds.) (2009) *International Smoking Statistics: A Collection of Historical Data from 30 Economically Developed Countries*. New York: Oxford University Press.

Giovino, G. A., S. A. Mirza, J. M. Samet, *et al*. (2012) Tobacco use in 3 billion individuals from 16 countries: an analysis of nationally representative cross-sectional household surveys. *The Lancet* **380**: 668–679.

Global Forum on Health Research (2003) *The 10/90 Report on Health Research 2001–2002*. Geneva: WHO.

Gomes, M. F., M. A. Faiz, J. O. Gyapong, *et al*. (2009) Pre-referral rectal artesunate to prevent death and disability in severe malaria: a placebo-controlled trial. *The Lancet* **373**: 557–566.

Hammitt, J. K. and L. A. Robinson (2011) The income elasticity of the value per statistical life: transferring estimates between high and low income populations, *Journal of Benefit–Cost Analysis* **2**, Article 1. Available at www.bepress.com/jbca/vol2/iss1/1/

Hill, C. (2010) *Prévention et Facteurs de Risque*, Institut de cancérologie. Available at: www.igr.fr/fr/page/prevention-et-facteurs-de-risque_80

Hira, S. K., K. Panchal, P. A. Parmar, *et al*. (2004) High resistance to antiretroviral drugs: the

Indian experience. *International Journal of STD and AIDS* **15**: 173–177.

Hum, R., P. Jha, A. M. McGahan, and Y. L. Cheng (2013) Global divergence in critical income for adult and childhood survival: analyses of mortality using Michaelis-Menten. eLife Sciences 1: e06051, 2007. *eLife* (in press).

Human Mortality Database (2011) Available at www.mortality.org.

Institute of Medicine (1985) *Diseases of Importance in the United States, vol. 1, New Vaccine Development: Establishing Priorities*. Washington, DC: National Academies Press.

Jamison, D. T. and J. C. Jamison (2011) Characterizing the amount and speed of discounting procedures. *Journal of Benefit–Cost Analysis* **2** Article 2.

Jamison, D. T. (2006) Economic benefits of investing in disease control. In: D. T. Jamison, J. G. Breman, A. R. Measham, *et al.* (eds.), *Disease Control Priorities in Developing Countries*. New York: Oxford University Press.

Jamison, D. T., J. D. Sachs, and J. Wang (2001) The effect of the AIDS epidemic on economic welfare in Sub-Saharan Africa. *CMH Working Paper Series* **13**: 1–27. Available at: www.cmhealth.org/docs/wg1_paper13.pdf

Jamison, D. T., S. A. Sahid-Salles, J. Jamison, J. E. Lawn, and J. Zupan (2006) Incorporating deaths near the time of birth into estimates of the global burden of disease. In: A. D. Lopez, C. D. Mathers, M. Ezzati, D. T. Jamison, and C. J. L. Murray (eds.), *Global Burden of Disease and Risk Factors*. New York: Oxford University Press.

Jamison, D. T., P. Jha, and D. E. Bloom (2008) Disease control. In: B. Lomborg, (ed.), *Global Crises, Global Solutions: Costs and Benefits*. Cambridge: Cambridge University Press.

Jamison, D. T., S. M. Murphy, M. E. Sandhu, and J. Wang (2013) Why has under-5 mortality decreased at such different rates in different countries? *Journal of Health Economics* (accepted pending minor revisions).

Jha, P. (2001) Avoidable mortality in India: past progress and future prospects. *National Medical Journal of India* **15**: 6.

(2009) Avoidance of worldwide cancer mortality and total mortality from smoking. *Nature Reviews: Cancer* **9**: 655–664.

(2009) Avoidable global cancer deaths and total deaths from smoking. *Nature Reviews: Cancer* **9**: 655–664.

(2012) Counting the dead is among the world's best investments to reduce premature mortality. *Hypothesis* **10**, Article 1.

Jha, P. and F. J. Chaloupka (1999) *Curbing the Epidemic: Governments and the Economics of Tobacco Control*. Washington, DC: World Bank.

(2000) *Tobacco Control in Developing Countries*. Oxford: Oxford University Press.

Jha, P. and A. Mills (2002) *Improving Health Outcomes of the Poor*, Report of Working Group 5 of the Commission on Macroeconomics and Health. Geneva: WHO.

Jha, P., J. D. Nagelkerke, E. N. Ngugi, *et al.* (2001) Reducing HIV transmission in developing countries. *Science* **292**: 224–225.

Jha, P., A. Mills, K. Hanson, *et al.* (2002) Improving the health of the global poor. *Science* **295**: 2036–2039.

Jha, P., F. J. Chaloupka, J. Moore, *et al.* (2006) Tobacco addiction. In: D. T. Jamison, J. G. Breman, A. R. Measham, *et al.* (eds.), *Disease Control Priorities in Developing Countries*. New York: Oxford University Press.

Jha, P. D. Brown, A. S. Slutsky, *et al.* (2004) Health and economic benefits of an accelerated program of research to combat global infectious diseases. *Canadian Medical Association Journal* **172**: 1538–1539.

Jha, P., E. Guindon, R. A. Joseph, *et al.* (2011) A rational taxation system of bidis and cigarettes to reduce smoking deaths in India. *Economic and Political Weekly* **46**: 44–51.

Jha, P., C. Ramasundarahettige, V. Landsman, *et al.* (2013) 21st-century hazards of smoking and benefits of cessation in the United States. *New England Journal Medicine* **368**: 341–350.

Johnson, N. and J. Mueller (2002) Updating the accounts: global mortality of the 1918–1920 "Spanish" influenza pandemic. *Bulletin of the History of Medicine* **76**: 105–115.

Johnston, R. (2002) Microbicides: an update. *AIDS Patient Care and STDs* **16**: 419–430.

Kidane, G. and R. H. Morrow (2000) Teaching mothers to provide home treatment of malaria in Tigray, Ethiopia: a randomised trial. *The Lancet* **356**: 550–555.

Kinsella, K. G. (1992) Changes in life expectancy 1900–1990. *American Journal of Clinical Nutrition*, **55**: 1096S–1202S.

Kumar, R. (2004) Plague outbreak in 2001 in Northern India. Paper presented at *Controlling the Risk: Science to Combat Global Infectious*

Diseases, Toronto, Ontario, November 9–10, 2004. Available at: www.healtheconomics.org/conferences/

Laxminarayan, R., *et al*. (2005) Drug resistance. In: D. T. Jamison, J. G. Breman, A. R. Measham, *et al*. (eds.) *Disease Control Priorities in Developing Countries*. New York: Oxford University Press.

LeGrand, J. (1987) Inequalities in health. *European Economic Review* **31**: 182–191.

Liu, B. Q., R. Peto, Z. M. Chen, *et al*. (1998) Emerging tobacco hazards in China: 1. Retrospective proportional mortality study of one million deaths. *British Medical Journal* **317**: 1411–1422.

Lopez, A. D., C. D. Mathers, M. Ezzati, D. T. Jamison, and C. J. L. Murray (eds.) (2006) *Global Burden of Disease and Risk Factors*. New York: Oxford University Press.

Luk, J., P. Gross, and W. Thompson (2001) Observations on mortality during the 1918 influenza pandemic. *Journal of Infectious Diseases* **33**: 1375–1378.

Maddison, A. (2011) *Statistics on World Population, GDP and Per Capita GDP, 1–2008 AD*. Available at: www.ggdc.net/MADDISON/oriindex.htm.

Mandle, J. R. (1970) The decline of mortality in British Guiana, 1911–1960. *Demography* **7**: 301–315.

Mathers, C. D., J. A. Salomon, C. J. L. Murray, and A. D. Lopez (2003) *Deaths and Disease Burden by Cause: Global Burden of Disease Estimates for 2001 by World Bank Country Groups*. Washington, DC: World Bank.

McCoy, D., G. Kembhavi, J. Patel, and A. Luintel, (2009) The Bill and Melinda Gates Foundation's grant-making programme for global health. *The Lancet* **373**: 1645–1653.

Measham, M. R., K. D. Rao, D. T. Jamison, J. Wang, and A. Singh (1999) Reducing infant mortality and futility, 1975–1990: Performance at all-India and state levels. *Economic and Political Weekly* **34**: 1359–1367.

Million Death Study Collaborators (2010) Causes of neonatal and child mortality in India: a nationally representative mortality study. *The Lancet* **376**: 1853–1860.

Munos, M. K., C. L. Walker, and R. E. Black, (2010) The effect of oral rehydration solution and recommended home fluids on diarrhea mortality. *International Journal of Epidemiology* **39**: 175–187.

Murphy, K. M. and R. H. Topel (2002) The economic value of medical research. In: K. M. Murphy, and R. H. Topel (eds.), *Measuring the Gains of Medical Research: An Economic Approach*. Chicago, IL: University of Chicago Press.

Nagelkerke, N. (2012) *Courtesans and Consumption: How Sexually Transmitted Infections Drive Tuberculosis Epidemics*. Amsterdam: Eburon Academic Publishers.

Nagelkerke, N. J. D., P. Jha, S. J. de Vlas, *et al*. (2002) Modelling HIV/AIDS epidemics in Botswana and India: impact of interventions to prevent transmission. *Bulletin of the World Health Organization* **80**: 89–96.

Nelson, K. E., D. D. Celentano, S. Eiumtrakol, *et al*. (1996) Changes in sexual behavior and a decline in HIV infection among young men in Thailand. *New England Journal of Medicine* **335**: 297–303.

Nordhaus, W. (2003) The health of nations: the contributions of improved health to living standards. In: K. M. Murphy and R. H. Topel (eds.), *Measuring the Gains from Medical Research: An Economic Approach*. Chicago. IL: University of Chicago Press.

Oeppen, J. and J. W. Vaupel (2002) Broken limits to life expectancy. *Science* **296**: 1029–1031.

Organisation for Economic Co-operation and Development (2003) *Trends in Developmental Assistance*. Paris: OECD. Available at: www.oecd.org/dataoecd/42/21/1860310.gif.

Perrin, L. and A. Telenti (1998) HIV treatment failure: testing for HIV resistance in clinical practice. *Science* **280**: 1871–1873.

Peto, R. (2006) Avoidable mortality. Paper presented at *Disease Control Priorities Launch Meeting*, Beijing, 2006. Available at: www.dcp2.org

Peto, R., S. Darby, H. Deo, *et al*. (2000) Smoking, smoking cessation, and lung cancer in the UK since 1950: combination of national statistics with two case-control studies. *British Medical Journal* **321**: 323–329.

Peto, R., A. D. Lopez, J. Boreham, M. Thun, and C. Heath Jr. (1994) *Mortality from Smoking in Developed Countries, 1950–2000*. Oxford: Oxford University Press.

Pitkanen, K. J., J. H. Mielke, L. B. Jorde (1989) Smallpox and its eradication in Finland: implications for disease control. *Population Studies* **43**: 95–111.

Plank, S. J., and M. L. Milanesi (1973) Infant feeding and infant mortality in rural Chile. *Bulletin of the World Health Organization* **48**: 203–210.

Preston, S. H. (1980) Causes and consequences of mortality declines in less developed countries during the twentieth century. In: R. A. Easterlin (ed.), *Population and Economic Change in Developing Countries*. Cambridge, MA: National Bureau of Economic Research.

Preston, S. H. and M. Haines (1991) *Fatal Years: Child Mortality in Late Nineteenth Century America*. Princeton, NJ: Princeton University Press.

Pritchett, L. and L. Summers (1996) Wealthier is healthier. *Journal of Human Resources* **31**: 841–868.

Riley, J. (2005a) Estimates of regional and global life expectancy, 1800–2001 *Population and Development Review* **31**: 537–543.

(2005b) The timing and place of health transitions around the world. *Population and Development Review* **31**: 741–764.

Ruger, J. P., D. T. Jamison, D. Bloom, and D. Canning, (2006) Health and the economy. In: M. H. Merson, R. E. Black, and A. J. Mills, (eds.), *International Public Health: Diseases, Programs, Systems, and Policies*. Sudbury, MA: Jones and Bartlett.

United Nations, (1998) *Revision of the World Population Estimates and Projections*. New York: Population Division, UN.

(2004) *Demographic Bulletin, Latin America: Life Tables, 1950–2025*. New York: Latin American and Caribbean Demographic Center, Population Division, UN.

(2009) *World Population Prospects: The 2008 Revision*. New York: Department of Economic and Social Affairs, Population Division, UN.

US Center for Disease Control (1999) *Achievements in Public Health, 1900–1999: Changes in the Public Health System*. Available at: www.cdc.gov/mmwr/PDF/wk/mm4850.pdf.

Usher, D. (1973) An imputation to the measure of economic growth for changes in life expectancy. In: M. Moss (ed.), *The Measurement of Economic and Social Performance*, New York: National Bureau of Economic Research.

Vallin, J. and F. Meslé (2009) The segmented trend line of highest life expectancies. *Population and Development Review* **35**: 159–187.

(2010) Will life expectancy increase indefinitely by three months every year? *Population and Societies* **473**: 1–4.

Van Walbeek, C. (2005) Tobacco control in South Africa. *Promotion & Education*, Suppl. **4**: 25–8, 57. (In French.)

Victora, C. G., J. Bryce, O. Fontaine, and R. Monasch, (2000) Reducing deaths from diarrhea through oral rehydration therapy. *Bulletin of the World Health Organization* **78**: 1246–1255.

Viscusi, W. K. and J. E. Aldy (2003) The value of a statistical life: a critical review of market estimates throughout the world. *Journal of Risk and Uncertainty* **27**: 5–76.

Vos, T. (2002) Shifting the goalpost: normative survivorship goals in health gap measures. In: C. J. L. Murray, J. A. Salomon, C. D. Mathers, and A. D. Lopez, (eds.), *Summary Measures of Population Health: Concepts, Ethics, Measurement and Applications*. Geneva: World Health Organization.

Weatherall, D., B. Greenwood, L. H. Chee, and P. Wasi, (2005) Science and technology for disease control: past, present, and future. In: J. G. Breman, A. R. Measham, D. T. Jamison *et al.*, (eds.), *Disease Control Priorities in Developing Countries*. New York: Oxford University Press.

Wikipedia (2011a) World War I casualties. *Wikipedia: The Free Encyclopedia*. Available at: en.wikipedia.org/

(2011b) World War II casualties. *Wikipedia: The Free Encyclopedia*. Available at: en.wikipedia.org/

Williamson, J. G. (1982) Was the Industrial Revolution worth it? Disamenities and death in nineteenth century British towns. *Explorations in Economic History* **19**: 221–245.

World Bank (1993) *World Development Report 1993: Investing in Health*. New York: Oxford University Press.

World Health Organization (1996) *Investing in Health Research and Development*, Report of the Ad Hoc Committee on Health Research Relating to Future Intervention Options. Geneva: WHO.

(2002) *Macroeconomics and Health: Investing in Health for Economic Development*, Report of the Commission on Macroeconomics and Health. Geneva: WHO.

(2003) *Global Forum for Health Research: The 10/90 Report on Health Research 2001–2002*. Geneva: WHO.

(2010a) *WHO Technical Manual on Tobacco Tax Administration*. Geneva: WHO.

(2010b) *Life Tables for WHO Member States, 1990, 2000, 2008, by Country and Region*. Geneva: WHO.

Zlotkin, S. H., C. Schauer, A. Christofides, *et al.* (2005) Micronutrient sprinkles to control childhood anaemia. *PLoS Med* **2**(1). DOI: 10.1371/journal.pmed.0020001

Annex 7.1

In this chapter, we developed measurements of twentieth-century mortality reductions in terms of reduction in the expected number of years of life lost (YLLs) by a typical individual relative to an idealized norm. The norm chosen in the main text of the paper is the United Nations' projected mortality profile for Japan in 2050, named "Japan 2050." This Annex 7.1 presents all the results obtained under this assumption (Annex Tables A7.1 – A7.5).

Annex Figure A7.1 illustrates the total money metric value of years of life lost as percent of GDP for selected regions for the period 1900–2050. The biggest decline has taken place in less developed regions where the ratio has fallen from 35% to 12% in the last century and is expected to fall to 6.5% in 2050. The world as a whole has experienced a development bringing it from 32% to 5% in the same period. This is both a result of improved human health and economic growth.

Table A7.1 Years of life lost per person under 5 (YLL_{u5}) (in years), selected countries and regions, 1900–2050

Year	China	India	Japan	USA	Sub-Saharan Africa	More Developed Regions	Less Developed Regions	World
1900	29.7	40.2	18.9	15.6	43.3	16.3	35.9	28.9
1910	27.1	40.2	16.4	13.8	39.3	14.1	34.3	27.1
1920	24.5	35.0	13.9	14.2	35.3	14.5	30.4	24.8
1930	21.9	29.7	11.4	6.7	31.3	7.1	26.5	19.8
1940	19.2	24.6	8.3	4.7	27.3	5.0	22.6	16.6
1950	16.6	19.5	6.4	2.8	23.3	4.9	18.8	14.3
1960	12.8	16.9	2.6	2.3	21.2	2.9	15.8	11.8
1970	9.0	14.3	1.1	1.7	19.1	2.2	12.7	9.8
1980	5.1	11.7	0.5	0.8	17.1	1.3	10.4	9.2
1990	3.2	9.4	0.2	0.6	15.8	0.8	8.4	7.6
2000	2.5	7.6	0.1	0.4	13.7	0.5	7.1	6.5
2010	2.0	6.1	0.1	0.3	11.3	0.4	5.9	5.3
2020	1.5	4.9	0.0	0.3	9.1	0.3	4.8	4.4
2030	1.2	4.1	0.0	0.2	7.1	0.2	3.9	3.5
2040	0.9	3.4	0.0	0.2	5.4	0.2	3.1	2.8
2050	0.8	3.1	0.0	0.2	4.7	0.2	2.7	2.4

Table A7.2 Years of life lost per person above 5 (YLL_{a5}) (in years), selected countries and regions, 1900–2050

Year	China	India	Japan	USA	Sub-Saharan Africa	More Developed Regions	Less Developed Regions	World
1900	18.4	15.1	14.5	14.0	13.7	14.3	16.3	16.7
1910	18.3	15.1	14.3	13.9	14.1	13.8	15.6	16.2
1920	18.1	14.7	13.9	12.7	14.7	12.3	16.0	15.9
1930	17.9	14.9	13.5	13.2	16.5	13.2	16.2	16.5
1940	17.5	17.1	12.9	12.2	17.2	12.2	16.2	16.3
1950	17.1	19.3	12.3	10.4	17.7	11.3	15.6	15.6
1960	15.2	17.2	10.3	9.7	16.4	10.4	14.5	14.3
1970	12.9	15.0	8.5	9.3	15.1	9.4	13.2	12.6
1980	10.2	12.5	6.2	7.6	13.7	8.6	11.4	10.3
1990	10.0	12.3	4.7	6.9	14.1	8.1	11.0	9.9
2000	8.1	11.3	2.7	6.5	14.6	7.1	9.9	9.0
2010	7.1	10.2	2.1	4.4	14.2	5.6	9.0	8.1
2020	6.2	9.0	1.4	3.6	13.4	4.5	8.1	7.3
2030	5.4	8.0	0.8	2.8	12.4	3.7	7.3	6.6
2040	4.7	7.1	0.3	2.2	11.4	3.0	6.7	6.0
2050	4.4	6.7	0.0	1.8	10.8	2.5	6.4	5.7

Table A7.3 Total years of life lost per person, selected countries and regions, 1900–2050

Year	China	India	Japan	USA	Sub-Saharan Africa	More Developed Regions	Less Developed Regions	World
1900	48.1	55.2	33.4	29.6	57.0	30.6	52.2	45.6
1910	45.4	55.2	30.6	27.6	53.4	27.9	49.9	43.3
1920	42.6	49.7	27.8	26.9	50.0	26.8	46.4	40.7
1930	39.7	44.7	24.8	19.9	47.8	20.3	42.7	36.3
1940	36.8	41.8	21.8	16.9	44.4	17.2	38.9	32.9
1950	33.7	38.8	18.6	13.2	41.0	16.1	34.4	29.9
1960	28.0	34.2	12.9	12.0	37.7	13.3	30.3	26.0
1970	21.9	29.3	9.6	11.0	34.3	11.6	25.9	22.4
1980	15.3	24.2	6.7	8.4	30.8	9.9	21.8	19.5
1990	13.2	21.7	5.0	7.5	29.9	8.9	19.4	17.5
2000	10.6	18.9	2.8	6.9	28.3	7.6	17.0	15.5
2010	9.1	16.3	2.2	4.7	25.5	6.0	14.9	13.5
2020	7.7	13.9	1.4	3.8	22.5	4.8	13.0	11.7
2030	6.6	12.0	0.8	3.0	19.5	3.9	11.2	10.1
2040	5.6	10.5	0.3	2.3	16.8	3.2	9.7	8.8
2050	5.2	9.8	0	2.0	15.5	2.6	9.1	8.2

Note: Values in this table are the sum of the values in the corresponding columns of Tables A7.1 and A7.2.

Table A7.4 Money metric value of years of life lost (MMVYLL), selected countries and regions, 1900–2050 ($)

Year	China	India	Japan	USA	Sub-Saharan Africa	More Developed Regions	Less Developed Regions	World
1900	37,545	44,038	58,384	179,985	22,305	56,588	22,417	40,737
1910	36,360	51,242	60,279	209,524	22,200	61,397	23,338	45,089
1920	35,106	42,665	72,592	219,538	24,049	68,458	24,410	48,913
1930	33,707	45,009	72,512	202,389	25,411	63,308	24,543	49,180
1940	31,373	41,759	101,726	201,551	25,947	60,974	24,499	49,545
1950	23,349	36,977	63,054	221,036	27,688	65,027	22,071	49,347
1960	29,267	39,726	93,383	240,188	30,018	78,018	25,765	57,497
1970	27,656	39,436	175,897	297,719	34,401	102,065	28,604	66,633
1980	27,424	35,273	174,749	291,074	34,556	114,580	31,135	68,588
1990	43,910	45,546	182,260	323,635	31,964	127,442	35,213	71,084
2000	64,883	58,343	113,222	370,334	31,398	128,389	42,646	74,140
2010	125,591	88,164	100,540	285,432	36,019	120,677	58,017	84,808
2020	151,431	110,980	80,206	276,589	35,347	115,508	66,593	89,386
2030	169,830	126,952	56,363	255,791	35,529	111,768	78,947	98,168
2040	181,503	138,210	24,224	222,368	36,229	109,962	96,236	109,584
2050	200,644	154,800	0.0	212,861	40,643	112,704	127,586	132,008

Note: Entries in this table are calculated from the per person YLLs reported in Tables A7.1 and A7.2 by multiplying those $YLL^{*} = YLL_{a5} + 0.54YLL_{u5}$ by twice per capita GDP expressed in 1990 International Geary–Khamis dollars.

Annex 7.2

In this chapter, we developed measurements of twentieth-century mortality reductions in terms of reduction in the expected number of years of life lost (YLLs) by a typical individual relative to an idealized norm. The norm chosen in the main text of the chapter is the United Nations' projected mortality profile for Japan in 2050, named "Japan 2050." An alternative to Japan 2050 as a norm is to use the lowest mortality country at any given time as the norm for that time, named frontier country. Annex 7.2 presents all the results obtained under this second assumption. Specifically, Annex Table A7.6 describes the characteristics of countries on this life expectancy frontier. Annex Tables A7.7 through A7.11 are the variants of Annex Tables A7.1 through A7.5. Annex Figure A7.2 compares the YLLs per birth for the less developed regions for the period 1900–2050 for the two different norms, Japan 2050 and frontier country.

Finally, Annex Figure A7.3 illustrates the total money metric value of years of life lost as percent of GDP for selected regions for the period 1900–2050. The biggest decline has taken place in less developed regions where the ratio has fallen from 23% to 12% in the last century and is expected to fall to 7.5% in 2050. The world as a whole has experienced a similar but less drastic development from 23% to 8% in the same period. For more developed regions the ratio has been declining and is expected to reach just 2.2% in 2050.

Table A7.5 Ratio *a* of money metric value of years of life lost (MMVYLL) per lifetime income per capita (LI) (no units), selected countries and regions, 1900–2050

Year	China	India	Japan	USA	Sub-Saharan Africa	More Developed Regions	Less Developed Regions	World
1900	2.4	3.5	1.1	0.9	3.9	1.0	3.0	2.1
1910	2.4	3.5	1.0	0.9	3.7	0.9	2.9	2.0
1920	2.3	3.2	1.0	0.8	3.5	0.8	2.7	1.9
1930	2.1	3.0	0.9	0.7	3.5	0.7	2.6	1.8
1940	2.0	2.9	0.8	0.6	3.3	0.6	2.4	1.6
1950	1.9	2.9	0.7	0.5	3.1	0.6	2.2	1.5
1960	1.6	2.5	0.5	0.4	2.9	0.6	1.9	1.3
1970	1.3	2.2	0.4	0.4	2.6	0.5	1.7	1.2
1980	0.9	1.8	0.3	0.3	2.4	0.4	1.4	1.0
1990	0.8	1.7	0.2	0.3	2.4	0.4	1.3	0.9
2000	0.7	1.5	0.1	0.3	2.3	0.3	1.2	0.8
2010	0.6	1.3	0.1	0.2	2.1	0.2	1.0	0.7
2020	0.5	1.1	0.1	0.1	1.9	0.2	0.9	0.6
2030	0.4	1.0	0.0	0.1	1.7	0.2	0.8	0.6
2040	0.4	0.9	0.0	0.1	1.5	0.1	0.7	0.5
2050	0.3	0.8	0.0	0.1	1.4	0.1	0.7	0.5

Note: Entries in this table are calculated from the money metric value of years of life lost MMVYLL reported in Table A7.4 divided by the lifetime income per capita as defined by equation (7.8) in the main text.

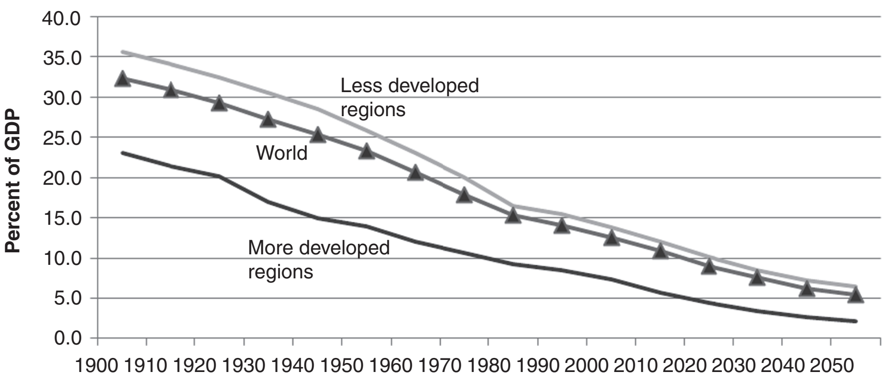


Figure A7.1 *Money metric value of years of life lost (MMVYLL), selected regions, 1900–2050, percent of GDP*

Table A7.6 Characteristics of countries on the life expectancy frontier

Year	Frontier reference (female life expectancy)	e_0 (females)	e_0 (males)	e_0 (both)	e_5 (both)	q_5 (per 1,000 live births)	YLLs under age 5 per birth	YLLs from age 5 per birth	YLLs per birth[a]
Estimates									
1900	New Zealand[b]	60.3	57.8	59.0	60.4	99	5.9	13.3	19.2
1910	New Zealand	63.6	60.6	61.9	61.8	73	4.6	13.0	17.5
1920	New Zealand	65.0	62.4	63.6	62.7	62	5.0	12.7	17.8
1930	New Zealand	68.2	65.5	66.8	64.7	43	2.8	12.4	15.2
1940	New Zealand	69.4	65.8	67.6	65.3	39	2.6	11.9	14.6
1950	Norway	74.4	70.8	72.6	69.8	30	2.2	11.0	13.2
1960	Norway	75.9	71.1	73.5	70.1	22	1.6	10.8	12.3
1970	Norway	77.6	71.3	74.4	70.5	15	1.1	10.9	12.0
1980	Iceland	79.9	73.8	76.8	72.4	8	0.6	11.3	12.0
1990	Japan	82.3	76.2	79.4	74.9	6	0.5	10.6	11.0
2000	Japan	85.1	78.2	81.9	77.2	4	0.3	10.6	10.9
Projections									
2010	Japan	87.2	80.1	83.7	79.0	4	0.3	10.6	10.9
2020	Japan	88.4	81.2	84.9	80.2	4	0.3	10.4	10.8
2030	Japan	89.5	82.2	85.8	81.1	4	0.3	10.3	10.6
2040	Japan	90.5	83.1	86.8	82.0	3	0.3	10.2	10.5
2050	Japan	91.0	83.5	87.2	82.5	3	0.3	10.1	10.4

Sources: Oeppen and Vaupel (2002), Human Mortality Database (www.mortality.org), United Nations (2009).
Note: The e_0 (females, males, both), and e_5 (both) columns are extracted from full life tables for the frontier country.
[a] This column shows YLLs for the frontier country relative to its own survival curve.
[b] The New Zealand estimates are for New Zealand's non-Maori population.

Table A7.7 Years of life lost per person under 5 (YLL_{u5}) (in years), selected countries and regions, 1900–2050 (variant of Table A7.1)

Year	China	India	Japan	USA	Sub-Saharan Africa	More developed regions	Less developed regions	World
1900	14.4	21.5	7.1	4.9	23.6	5.3	18.6	13.9
1910	14.9	24.2	7.3	5.4	23.6	5.7	20.0	14.9
1920	13.0	20.7	5.3	5.5	20.9	5.8	17.3	13.3
1930	14.1	20.1	6.1	2.5	21.3	2.8	17.7	12.5
1940	12.5	16.7	4.5	1.3	18.7	1.5	15.2	10.5
1950	11.9	14.3	3.4	0.4	17.5	2.1	13.7	10.0
1960	9.4	12.9	0.8	0.6	16.5	1.1	11.9	8.6
1970	6.8	11.4	0.1	0.7	15.5	1.0	10.0	7.5
1980	4.2	10.0	0.1	0.4	14.7	0.8	8.8	7.8
1990	2.7	8.4	0	0.3	14.2	0.5	7.4	6.7
2000	2.3	7.1	0	0.3	12.8	0.4	6.6	6.0
2010	1.8	5.8	0	0.2	10.8	0.3	5.6	5.1
2020	1.4	4.8	0	0.2	8.8	0.2	4.7	4.2
2030	1.1	4.0	0	0.2	7.0	0.2	3.8	3.4
2040	0.9	3.4	0	0.2	5.4	0.2	3.0	2.7
2050	0.8	3.1	0	0.2	4.7	0.2	2.7	2.4

Table A7.8 Years of life lost per person above 5 (YLL_{a5}) (in years), selected countries and regions, 1900–2050 (variant of Table A7.2)

Year	China	India	Japan	USA	Sub-Saharan Africa	More developed regions	Less developed regions	World
1900	5.2	3.3	1.7	1.2	2.4	1.4	3.9	3.9
1910	5.6	3.9	1.9	1.4	3.0	1.3	4.0	4.0
1920	6.0	3.9	2.0	1.0	3.9	0.8	4.6	4.2
1930	6.5	4.6	2.2	1.6	6.0	1.6	5.4	5.2
1940	6.4	6.5	1.9	1.0	6.7	1.2	5.6	5.2
1950	8.8	11.0	3.8	2.4	9.8	3.0	7.6	7.4
1960	7.0	9.1	2.0	1.6	8.7	2.4	6.6	6.1
1970	4.8	7.0	0.5	1.3	7.4	1.6	5.2	4.5
1980	3.5	5.6	0	1.1	7.0	2.1	4.6	3.7
1990	4.8	7.1	0	2.0	9.1	3.1	5.8	4.9
2000	4.9	7.9	0	3.4	11.3	3.9	6.6	5.8
2010	4.6	7.6	0	2.1	11.6	3.2	6.5	5.7
2020	4.5	7.2	0	2.0	11.6	3.0	6.4	5.6
2030	4.4	6.9	0	1.9	11.3	2.7	6.3	5.6
2040	4.3	6.7	0	1.8	11.0	2.6	6.3	5.6
2050	4.4	6.7	0	1.8	10.8	2.5	6.4	5.7

Table A7.9 Total years of life lost per person, selected countries and regions, 1900–2050 (variant of Table A7.3)

Year	China	India	Japan	USA	Sub-Saharan Africa	More developed regions	Less developed regions	World
1900	19.7	24.8	8.9	6.0	26.0	6.8	22.6	17.8
1910	20.5	28.1	9.2	6.8	26.6	7.0	24.0	18.9
1920	19.0	24.6	7.3	6.6	24.8	6.5	21.9	17.5
1930	20.7	24.7	8.3	4.1	27.3	4.5	23.1	17.8
1940	19.0	23.2	6.4	2.3	25.4	2.6	20.8	15.7
1950	20.7	25.3	7.2	2.8	27.2	5.2	21.4	17.3
1960	16.5	22.0	2.8	2.2	25.2	3.5	18.5	14.7
1970	11.6	18.4	0.6	2.0	22.9	2.7	15.3	12.0
1980	7.6	15.6	0	1.5	21.7	2.8	13.4	11.5
1990	7.5	15.5	0	2.3	23.3	3.6	13.3	11.6
2000	7.1	15.0	0	3.7	24.1	4.3	13.3	11.8
2010	6.5	13.4	0	2.3	22.4	3.5	12.1	10.7
2020	6.0	12.0	0	2.2	20.4	3.2	11.1	9.8
2030	5.5	10.9	0	2.1	18.3	2.9	10.1	9.0
2040	5.2	10.1	0	2.0	16.4	2.8	9.3	8.3
2050	5.2	9.8	0	2.0	15.5	2.6	9.1	8.2

Note: Values in this table are the sum of the values in the corresponding columns of Tables A7.7 and A7.8.

Table A7.10 Money metric value of years of life lost (MMVYLL), selected countries and regions, 1900–2050 ($) (variant of Table A7.4)

Year	China	India	Japan	USA	Sub-Saharan Africa	More developed regions	Less developed regions	World
1900	14,195	17,838	13,177	30,485	15,631	16,656	14,231	22,449
1910	15,091	23,637	15,127	42,644	16,729	20,083	16,426	27,579
1920	14,555	19,105	16,436	43,200	17.076	21,012	15,972	28,213
1930	16,008	22,422	20,218	35,544	20,770	16,758	18,589	32,184
1940	14,838	21,258	24,765	23,141	20,660	10,649	17,880	30,745
1950	13,658	23,167	21,507	48,725	24,855	24,327	18,308	36,640
1960	16,039	24,238	19,092	41,479	27,113	22,755	20,724	41,029
1970	13,153	22,784	10,816	49,263	30,893	25,998	21,882	44,670
1980	12,062	20,173	0	47,273	32,745	34,497	25,330	51,554
1990	23,394	30,425	0	96,596	32,809	53,976	30,215	58,898
2000	41,594	44,379	0	192,245	34,396	74,604	41,101	69,988
2010	83,412	70,117	0	139,174	39,745	72,822	57,542	82,495
2020	114,007	93,291	0	159,886	39,404	78,644	69,083	91,248
2030	140,065	112,921	0	174,357	39,889	85,297	84,826	103,942
2040	167,924	131,815	0	187,828	41,549	99,320	107,831	121,273
2050	200,644	154,800	0	212,861	47,012	112,704	148,850	154,638

Note: Entries in this table are calculated from the per person YLLs reported in Tables A7.7 and A7.8 by multiplying those $YLL^{*} = YLL_{a5} + 0.54YLL_{u5}$ by twice per capita GDP expressed in 1990 International Geary–Khamis dollars.

Table A7.11 Ratio *a* of money metric value of years of life lost (MMVYLL) per lifetime income per capita (LI) (no units), selected countries and regions, 1900–2050 (variant of Table A7.5)

Year	China	India	Japan	USA	Sub-Saharan Africa	More developed regions	Less developed regions	World
1900	0.9	1.4	0.2	0.2	1.6	0.2	1.2	0.7
1910	1.0	1.6	0.3	0.2	1.6	0.2	1.2	0.8
1920	0.9	1.4	0.2	0.2	1.6	0.2	1.2	0.7
1930	1.0	1.5	0.2	0.1	1.8	0.1	1.3	0.8
1940	1.0	1.5	0.2	0.1	1.7	0.1	1.2	0.7
1950	1.1	1.8	0.2	0.1	2.0	0.2	1.3	0.8
1960	0.9	1.5	0.2	0.1	1.8	0.1	1.1	0.7
1970	0.6	1.3	0.1	0.1	1.6	0.1	0.9	0.6
1980	0.4	1.0	0	0.0	1.6	0.1	0.8	0.5
1990	0.5	1.1	0	0.1	1.7	0.1	0.8	0.6
2000	0.4	1.1	0	0.1	1.9	0.2	0.9	0.6
2010	0.4	1.0	0	0.1	1.8	0.1	0.8	0.5
2020	0.4	0.9	0	0.1	1.7	0.1	0.7	0.5
2030	0.4	0.9	0	0.1	1.6	0.1	0.7	0.5
2040	0.3	0.8	0	0.1	1.4	0.1	0.7	0.5
2050	0.3	0.8	0	0.1	1.4	0.1	0.7	0.5

Note: Entries in this table are calculated from the money metric value of years of life lost MMVYLL reported in Table A7.10 divided by the lifetime income per capita as defined by equation (7.8) in the main text.

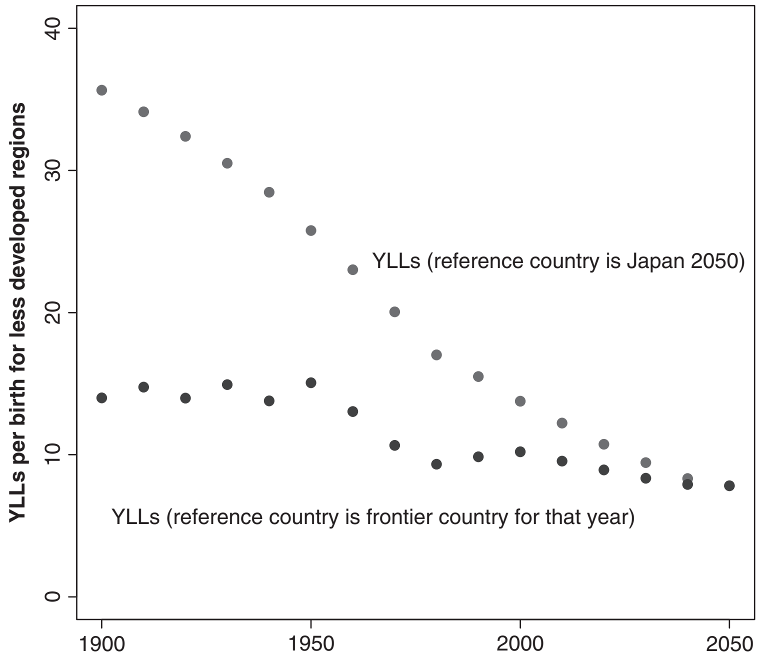


Figure A7.2 *Years of life lost (YLLs) per birth; reference country is either frontier country or Japan 2050, less developed regions, 1900–2050*

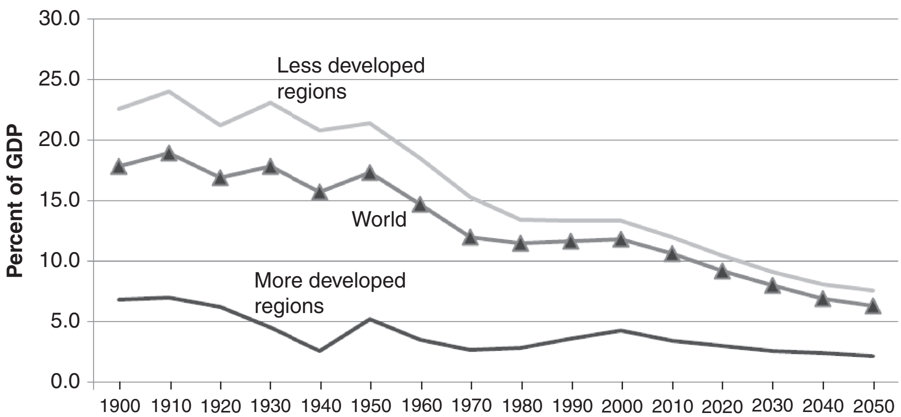


Figure A7.3 *Money metric value of years of life lost (MMVYLL), selected regions, 1900–2050, as percent of GDP*