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The Economic Value of Avoidable Mortality

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INTRODUCTION

Disease burden is commonly measured using a variety of health statistics, including deaths by cause, injury and disease prevalence and incidence, and disability-adjusted life years. While these metrics are meaningful, it is also evident that preventing injuries and diseases has practical economic and social consequences beyond health which have economic value. As part of the World Bank's Healthy Longevity Initiative, this chapter aims to estimate the economic value of avoidable mortality by world regions, sex, and age, between 2000 and 2019, with projection to 2050.

This work lies at the conjunction of three important strands of literature – estimation of the global burden of disease (GBD); estimation of the proportion of that burden that is amenable to intervention or can otherwise be avoided; and estimation of the economic value associated with reducing this burden (OECD 2019; Rutstein 1976; Nolte & McKee 2004). Key to defining the GBD was correcting for the overestimation of deaths by individual causes that resulted from individual disease communities providing estimates for their own disease. In the 1980s, researchers at the World Health Organization (WHO) initiated systematic correction by imposing demographically defined death totals as an envelope within which disease-specific estimates must lie (Hakulinen et al. 1986). This work was extended to include a more detailed list of causes of death and estimates of nonfatal health burden and initially published in the World Bank's 1993 World Development Report, Investing in Health, Appendix B (World Bank 1993; Murray et al. 1994). Earlier than the work on burden of disease, economists had initiated efforts to place value on small changes in mortality probabilities and, quite separately, on estimating the value of mortality reductions relative to increases in GDP in providing a comprehensive estimate of growth in national eco-nomic welfare. Schelling provided early approaches to valuing changes in mortality rates; recent, comprehensive pictures of a now substantially empirical literature are now available (Schelling 1968; Hammitt and Herrera-Araujo 2019; Viscusi 1993; Viscusi and Aldy 2003; Robinson et al. 2019; Hammitt 2020). Usher introduced methods for assessing the contribution of mortality change to growth in economic welfare and provided estimates for selected countries (Usher 1973; Bloom et al. 2004). The Lancet Commission on Investing in Health provided updated estimates of the contribution of mortality reduction to economic welfare change in low- and middle-income countries (Jamison 2013; Chang et al. 2017).

The purpose of this chapter is to bring together these two literatures with the economists' valuation of mortality change and the demographers and epidemiologists' definition of an overall envelope of mortality within which the sum of deaths from individual diseases must lie. The result is an estimate of the economic value of avoidable mortality that points to the monetized benefits from future improvements in health. With our framework, one could answer (albeit tentatively) questions such as: *"For a typical female, age 45, from Colombia: What percentage of their income would they be willing to forgo to live the next year under the lowest possible mortality risk?"*. By systematically applying our framework to a variety of populations, we then characterize the economic value to various groups and regions.

CONCEPTUAL FRAMEWORK

Two fundamental concepts underlie our effort: the definition of avoidable mortality and the economic valuation of mortality risks. This section outlines the conceptual framework adopted in our methodology.

Avoidable mortality

Avoidable mortality comprises deaths that may be prevented through public health or prevention interventions that reduce incidence (preventable mortality) and those that can be avoided through curative health care interventions that reduce case-fatality (treatable or amenable mortality) (OECD 2019; Nolte and McKee 2004; Rutstein 1976). Avoidable mortality is typically estimated as the number of deaths assigned to set of specific causes of death, when they occur below a threshold age (OECD 2019; Rutstein 1998; Nolte and McKee 2004). These deaths are categorized as either preventable or treatable. This list-based approach has several drawbacks for our purposes: first, it requires comparable, detailed, and accurate cause-of-death data, which are not currently available for most countries (WHO 2020). Second, deaths cannot be categorized as exclusively preventable or amenable as some deaths may fit in both categories: a death from road traffic injury could, in many cases, have been prevented (e.g., by traffic calming measures) or avoided by better care (e.g., in the emergency room). We have addressed these issues by implementing a simplified method which is suitable for countries with varying availability and quality in cause-of-death information. Our method estimates avoidable mortality without disaggregation into preventable and treatable mortality. Specifically, we estimate avoidable mortality as the difference between current (estimated or projected) mortality levels and unavoidable, or frontier mortality levels, which are the lowest mortality levels that can be obtained for each age given past and current technologies and knowledge.

Frontier mortality levels are estimated for each time t as the lowest projected or observed mortality rates at each age in either sex at time t. We apply a single age-sex-year-specific frontier to all countries and both sexes. In other words, all countries are compared to the single best-practice frontier, and both females and males are compared to the same frontier. This is built on our belief that all countries, with the right level of financial investment, political will, policies, and technological advancements, have the opportunity to reach the frontier, even though it may be more challenging (and take longer) for some countries than others.

We compared both male and female mortality to the lowest sex-specific mortality rate, which in all cases is a female mortality rate. Most of the sex differences in life expectancy has been shown to be due to non-biological factors, namely gender differences in health behavior and risks, such as smoking, alcohol use, and injuries (Luy 2016). In high-income settings, from which our frontier mortality rates are drawn, excess male mortality is caused by injuries and non-communicable diseases (WHO 2020). Excess injury deaths in males are likely a result of socio-cultural factors rather than innate biological susceptibility. A higher proportion of male non-communicable disease deaths can be attributed to modifiable risk factors, again pointing to the importance of socio-cultural differences causing higher male mortality (GBD 2019). Specialized studies of populations where the gender differences in health exposures are minimized have found that the female longevity advantage is around 1-2 years, far smaller than the 5-year gap between male and female frontier life expectancy in 2019 (Luy 2016).

Economic value of mortality reduction

Reductions in mortality risks lead to improved wellbeing and higher living standards in societies. As such, these reductions are perceived as a benefit to the populations that experience them. But consistent mortality reductions are often the result of costly public interventions. Therefore, governments seeking to make more objective decisions frequently perform quantitative comparisons of the benefits and costs of various interventions before establishing their priorities. While estimating the cost of potential interventions is a relatively straightforward accounting exercise, quantifying the benefits of mortality reductions requires a conceptual framework of economic value.

Leading scholars have developed and applied estimates of the value per statistical life (VSL) to quantify the benefits of mortality reductions (Viscusi 1992; Sunstein 2002; Revesz 2008; Sunstein 2014; Viscusi 2018; Robinson et al. 2019; Chang et al. 2018; Khadka and Verguet 2021). The VSL measures the willingness to pay (or to accept compensation) for a small reduction (increase) in mortality risk. The following example illustrates the concept. Suppose we know that a group of workers is willing to pay $1,000 on average to reduce their individual annual fatality risk by 1/10,000. Then, if exactly 10,000 of those workers reduce their fatality risk by this amount, they statistically avoid one death among them. Therefore, they collectively spend $10 million to save one statistical life – or, equivalently they imply a VSL of $10 million. The VSL as a unit is, empirically, on the order of 10,000 times the value actually measured.

The VSL approach is widely adopted by governments and regulatory agencies in countries that require an economic analysis of potential public sector investments and regulations, including the United States, Norway, United Kingdom, and Canada (Viscusi and Aldy 2003). Before the theoretical and empirical advances that led to the consolidation of the VSL framework, the value of saving lives was usually equated to savings in medical costs and forgone wages. However, this alternative approach based on economic losses had substantial limitations for its use in benefit-cost analyses. For instance, because of the list-based quantification, the calculated value is highly sensitive to omissions and often leads to substantial underestimation. Moreover, measures of cost savings are inherently disconnected from the idea of economic benefits, which are conceptually linked to willingness to pay in the economic theory. As the studies by Viscusi have indicated, policies that incorporate the VSL are much more protective of lives and health than policies that adopt the economic losses approach (Viscusi 2018).

The VSL can be estimated based on two types of data: observed behavior (the revealed preference approach) or surveys about subjects' willingness to pay (the stated preference approach). The empirical VSL literature generally favors estimates based on observed behavior because of the significant challenges in eliciting truthful and consistent answers about willingness to pay from hypothetical scenario.[1] However, inference from observed behavior also poses relevant limitations, such as biases from individuals' misperception of risks or selection into specific behaviors.[2] Estimates following the revealed preference approach frequently infer the VSL based on market data. For instance, these studies can statistically estimate the VSL based on the labor markets, using the differences between wages in occupations with different fatality risks, or safety equipment markets (such as helmets and airbags), using the differences in the demand for various devices with different degrees of risk protection. These inherent uncertainties in empirical estimation imply that findings based on the literature should be viewed more as importantly suggestive than conveying quantitative decision.

The VSL approach is increasingly applied in the global health literature (Robinson et al. 2019; Chang et al. 2018). These applications typically calculate the economic value of reducing mortality by multiplying the VSL by the number of expected lives saved (Jamison et al. 2013 Khadka and Verguet, 2021). However, this approach is appropriate only when mortality risk changes are not appreciably larger than values empirically measured. As indicated above, the VSL is defined and estimated based on small risk changes. When applied to large risk changes, the VSL multiplication approach can lead to substantial overestimation and even to values that exceeds one's income – a direct contradiction with the concept of the income-mortality trade-off that underlies the VSL.

The VSL multiplication (or fixed VSL) approach can overestimate economic values because it is a linear approximation which holds constant the economic value of risk change. Such approximation results in negligible errors when risk changes are small and of the same order used for the empirical estimation of the VSL. However, as the mortality risk increases, each subsequent risk reduction plausibly has a smaller value – a principle commonly referred to as the decreasing marginal value. Intuitively, this principle also holds because as individuals trade off more and more of their resources for reduced mortality, they need to forgo other uses of their income in increasing order of value. The linear extrapolation in the fixed VSL approach fails to account for the changing nature of this substitution rate. Therefore, in cases where mortality risk changes can be large, such as the case of eliminating avoidable mortality, it is necessary to adjust the value of risk reductions to stay consistent with the underlying VSL framework (Hammitt and Herrera-Araujo 2019; Cardoso and Dahis 2024; Bressler 2022).

In this chapter, we apply the more plausible approach that regards estimates of the value of mortality change as reasonable approximation for modest changes around the baseline mortality levels. Then, we approximate the value of larger changes based on assumed functions that respect income and resource constraints, thus never exceeding one's means in their valuation of mortality reduction.

METHODS

Estimating avoidable mortality

We define avoidable mortality as the difference between current (estimated or projected) mortality levels and unavoidable, or frontier mortality levels, which are the lowest mortality levels that can be obtained for each age given current technologies and knowledge.

Frontier mortality rates are selected from countries with high-quality death registration data to avoid selecting incorrectly estimated mortality rates. Specifically, we selected the frontier mortality rates

1 For further details, see discussions in Hammitt, James and Graham (1999); and Andersson and Treich (2011).

2 For an extensive discussion of these limitations, see Viscusi and Aldy (2003)

from lifetables included in the Human Mortality Database (HMD), which are derived from populations where death registration and census data are virtually complete (Barbieri et al. 2015; Wilmoth et al. 2021; Human Mortality Database 2023). We took two steps to reduce the effect of stochastic variability on frontier mortality: (1) we selected the lowest mortality rates for each age range and year from 5x5 mortality tables (5 years of age by 5 calendar years), and we excluded countries with a population of 1 million or less in 2019.

Formally, we define

$$ {}_{n}a_{x,\,i,s,t} = {}_{n}m_{x,i,s,t} - {}_{n}f_{x,t} \qquad [1] $$

where ${}_{n}a_{x,\,i,s,t}$ is avoidable mortality rate in deaths/1000 population in the age range $[x,x+n)$ in country i, sex s, and year t, ${}_{n}m_{x,i,s,t}$ is the observed/projected mortality rate in deaths/1000 population in the age range $[x,x+n)$ in country i, sex s, and year t from the World Population Prospects (WPP) 2022, and ${}_{n}f_{x,t}$ is the lowest reliably observed mortality rate of any population-sex unit, obtained from populations included in the HMD of age range $[x,x+n)$ in year t or projected as described below (Human mortality database, 2023; UNDESA, 2022).

We compared both male and female mortality to the lowest sex-specific mortality rate, which in nearly all cases is a female mortality rate. In high-income settings, from which our frontier mortality rates are drawn, excess male mortality is caused by injuries and by non-communicable diseases (2). Excess injury deaths in males are likely a result of socio-cultural factors rather than innate biological susceptibility. A higher proportion of male non-communicable disease deaths can be attributed to modifiable risk factors (3), again pointing to the importance of socio-cultural differences causing higher male mortality. We carry out a sensitivity analysis where we construct separate frontiers for males and females, however, this sensitivity analysis is expected to underestimate avoidable mortality in males.

The HMD includes historical data as soon as they are available, up to the 2022 calendar year, but does not include projections. Frontier (or highest observed) life expectancy has been shown to increase linearly at around 2.5 years per decade (Oeppen and Vaupel 2002; Vaupel et al. 2021). We projected log age-specific frontier mortality rates linearly for the years 2022-2050 on the basis of observed mortality rates from all complete 5-year periods in the HMD from the 1980-1984 to 2015-2019. This is a commonly used approach for projecting mortality that results in a projected rate of increase of frontier life expectancy of 1.8 years/decade, lower than predicted by Vaupel and colleagues but consistent with historical increases in our derived frontier life expectancy (webappendix Figure 1) (Oeppen and Vaupel 2002). Frontier mortality rates for each age were then interpolated to obtain annual estimates for the years 2000-2021. An implication of this approach is that frontier mortality rates continue to decline in 2020 and beyond, despite the COVID-19 pandemic. This is consistent with continued declines in mortality in some of the lowest-mortality countries in 2020. In 2020, Japanese women's life expectancy increased 0.3 years to 87.7, and South Korean women's life expectancy also increased 0.2 years to 86.5 years in 2020 (Human Mortality Database, 2023). These increases were similar to the historical annual increase in frontier life expectancy, and they occurred in the populations that set the frontier for some age groups prior to 2020.

Avoidable deaths are computed as the product of age-country-sex-year avoidable mortality rates (${}_{n}a_{x,\,i,s,t}$) and age-country-sex-year population totals from WPP2022.

To provide context and asses the feasibility of achieving the frontier mortality rates, we calculated the historical average annual rate of change for all country-year-sex-age combinations between 2000 and 2019 and identified the top 10th percentile performers. We consider these observed changes to be fast but plausible, and created a scenario (named "rapid progress") in which countries experience such rates from the present to 2050. We compare this scenario to the frontier for 2050 to assess the feasibility of achieving the frontier mortality rates by 2050.

Estimating the economic value of avoidable mortality

The economic value of avoidable mortality in a given year is measured as the percentage of annual income an individual is willing to forgo to live that year at the frontier survival probabilities. We assign economic values to changes in the mortality risk using VSL estimates from the literature (Robinson et al. 2019).

We follow the literature in assuming that individuals are willing to forgo part of their available resources—usually consumption, wealth, or income—for a lower mortality risk (Schelling 1968; Viscusi 1993). Specifically, we assume that the value of income is modeled with a logarithmic function – the simplest nonlinear member of the family of functions typically used to relate utility to income. Function $F_a(\boldsymbol{S}, y)$ represents the discounted expected value of remaining lifetime income for an individual at age a, where $\boldsymbol{S} = \{S_0, S_1, S_2, \dots\}$ represents the vector of current annual survival probabilities at ages $a = \{0,1,2,3,\dots\}$ and y is annual income. For simplicity, we model one country-representative individual for each age group. Moreover, annual income is constant over time and equal to the gross national income per capita (denoted by $\bar{y}$). Then, we can write $F_a(\boldsymbol{S}, y) = f(\bar{y})L_a(\boldsymbol{S})$, where $f(\bar{y}) = ln(\bar{y}) + k$ is the value attributed to living one year with income level $\bar{y}$ and k is a normalization constant, $L_a(\boldsymbol{S}) \equiv \sum_{t=0}^{\infty}(1+\rho)^{-t}S_{a,t}$ is analogous to a discounted remaining life expectancy, ρ is the annual discount rate, and $S_{a,t}$ is the probability of surviving from age a until age $a+t$.

Let $\tilde{S}_{\boldsymbol{a}}$ represent the frontier one-year survival probability at age a. Then, the economic value of avoidable mortality is implicitly defined by $F_a(\boldsymbol{S}, \bar{y}) = \tilde{S}_{\boldsymbol{a}} f(\bar{y} - v_a\bar{y}) + \tilde{S}_{\boldsymbol{a}}(1+\rho)^{-1}F_{a+1}(\boldsymbol{S}, \bar{y})$. This equality says that an individual at age is indifferent between continuing under the status quo and a hypothetical scenario where she forgoes a proportion v_a of this year's income in exchange for higher survival probability (no avoidable mortality) that year.

Using the equality above, we can obtain the expression to calculate $v_a(S_a, \tilde{S}_a, \boldsymbol{S})$: the proportion of income that corresponds to the value of avoidable mortality. However, this procedure solves for a family of functions. To pin down an exact solution, we use empirical estimates of the VSL. This is possible because the VSL contains information about the value of income relative to small mortality risk changes (see webappendix A1 for details). Solving for v_a allows us to derive an expression for the value of eliminating avoidable mortality, which is given by

$$v_a(S_a, \tilde{S}_a, \boldsymbol{S}) = 1 - exp\left(-\hat{\lambda}\frac{\tilde{S}_a - S_a}{\tilde{S}_a}\frac{L_a(\boldsymbol{S})}{S_a}\right) \quad [2]$$

where $\hat{\lambda}$ is a country-specific parameter grounded on empirical estimates of the VSL and background risk. Parameter $\hat{\lambda}$ is defined as $\hat{\lambda} = \hat{V}S_{\hat{a}}^2/\bar{y}L_{\hat{a}}(\boldsymbol{S})$, where $\hat{a}$ denotes reference age for the typical worker $\hat{a}$ and $\hat{V}$ is the estimated VSL.[3] This parameter is analogous to the Value per Statistical Life-Year (VSLY) for the typical worker adjusted for background risk.

Equation (2) characterizes the key elements of our framework to calculate the economic valuation of large mortality risk changes. We can check that when a country is at the frontier, there is no mortality change ($\tilde{S}_a = S_a$), so the value is zero. As the distance between the frontier mortality ($\tilde{S}_a$) and a country's mortality (S_a) increases, the value also increases. At first, S_a increases faster, with a rate governed primarily by the VSL-based parameter $\hat{\lambda}$. As the distance between $\tilde{S}_a$ and S_a becomes larger, v_a goes towards 1 (full income) but never exceeds it (see webappendix A1 for a detailed discussion of this equation).

We closely followed the recommendations made by the Harvard Benefit Cost Analysis Reference Case for conducting benefit cost analysis in global health in choosing the base VSL, setting the level of income elasticity, placing a floor constraint on VSLr — the ratio between VSL and annual income per capita—, and conducting the recommended sensitivity analysis scenarios (Viscusi and Aldy 2003). As a starting point, we set the VSLr at 160 (the ratio comes from a United States VSL of $9.4 million and GNI per capita of $57,900), and income elasticity of 0.8 when extrapolating across countries with higher GNI per capita than the United States, and 1.2 for countries with lower GNI per capita. We apply a lower bound constraint for the VSLr at 20. We choose to estimate income using GNI per capita expressed in 2017 international dollars and adjusted for purchasing power parity (PPP), as recommended by the reference case. Data on GNI per capita (PPP constant 2017 International $) between 2000-2021 came from the World Bank (World Bank 2021); income levels for 2050 are projected using OECD's projected country-specific growth rates between 2021 and 2050 for listed countries (OECD and G20 countries), and the world average growth rate during the same time period for all remaining countries. The initial VSLr for all ages are set as equal. The annual discount rate is 3 percent. The economic value of avoidable mortality is presented as percentage of annual income for both sexes, and females and males separately. Following the common approach in the literature, we used the same VSL for both sexes due to two reasons: lack of good data on sex-specific VSL, and that females likely have lower VSL due to lower labor income. For example, Aldy & Smyth estimated about 13 percent lower VSL for American females than males, reflecting a combination of females' higher life expectancy (increase in VSL) but lower labor market compensation

3 Using a reference value of 40 years based on VSL estimates for the United States, the VSLY = VSL / 40.

(decrease in VSL) than males (Aldy and Smyth 2014).

We present the estimated avoidable mortality and its associated economic value by the World Bank's geographic regions, with China and India presented separately. We focus on the years 2000, 2019, and 2050, which represent the beginning of the era of major international investment in global health, current conditions just prior to the COVID-19 pandemic, and future projections. We also discuss estimates for 2021, which is the latest observed year available from WPP2022 and reflects the unique mortality profile during the COVID-19 pandemic.

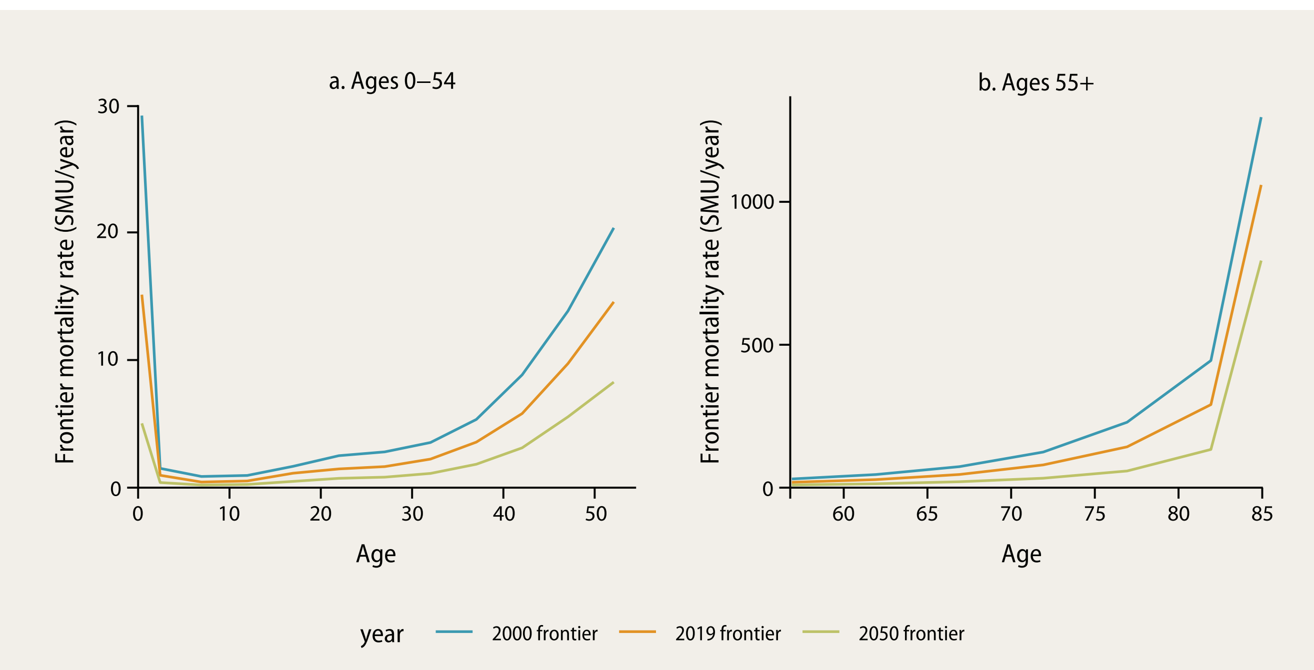
Sensitivity analyses

Six sets of sensitivity analyses were conducted. In estimating avoidable mortality, we first replaced the mortality frontier with sex-specific frontiers. In other words, we applied the lowest frontier mortality levels for each sex separately to estimate avoidable mortality by sex. Second, we compared mortality under the rapid progress scenario to business-as-usual WPP2022 projections and the 2050 frontier. In estimating the value of mortality reduction, in addition to the three sets of standard sensitivity analyses proposed by the Harvard Benefit Cost Analysis Reference Case (on income elasticities, discount rates, baseline VSL-to-income ratio), we further test different value-of-income functions (linear, reciprocal).

RESULTS

During the four five-year periods between 2000-2019 and considering 19 age groups (76 age-period categories), Japanese women had the lowest observed mortality rate for 22 age-period categories; the next most frequently appearing population was Hong Kong SAR, China women (15 age-period categories; webappendix Table A1). Other populations that set the frontier for at least two age-period categories were women from Denmark, Finland, Italy, Slovenia, South Korea, Spain, Sweden, and Switzerland. Combining these age-specific mortality rates, frontier life expectancy was estimated to increase from 84.8 in 2000 to 88.5 in 2019, and was projected to reach 94.2 in 2050 (webappendix Figure A7), an increase of 1.8 years per decade. Frontier mortality rates for years 2000, 2019, and 2050 are depicted in Figure 3.1, and the gap between the frontier life expectancy at birth and observed or projected life expectancy is listed in Table 3.1.

FIGURE 3.1 Frontier mortality rates from 2000, 2019, and 2050



Note: The scale of the y-axes for the two graphs are different. SMU = standardized mortality unit, deaths per 10^{-4} per year

TABLE 3.1 Gap between observed and frontier life expectancy at birth in years, 2000, 2019 and 2050, globally and by region

	World	China	Euroasia & Mediterranean	High-income	India	Latin America & Caribbean	Sub-Saharan Africa
Males							
2000	20.7	15.0	21.9	10.1	23.0	17.1	35.4
2019	18.3	13.2	19.7	9.7	18.9	16.9	29.5
2050	19.4	11.9	20.0	10.5	18.0	16.2	29.8
Females							
2000	15.9	10.5	15.7	3.8	21.1	10.5	32.4
2019	13.1	7.5	13.4	4.3	16.0	10.5	25.8
2050	14.4	8.1	14.0	6.2	14.1	10.9	24.9

Note: estimated life expectancies at birth were compared to frontier life expectancies at birth, which were 84.8 in 2000, 88.5 in 2019, and 94.2 in 2050.

Avoidable mortality as percentage of total mortality was approximately 69 percent in 2019, equivalent to 40 million deaths. Nearly half of avoidable deaths occurred in Euroasia & Mediterranean (10.7 million) and Sub-Saharan Africa (8.9 million). The percentage of deaths that were avoidable was lowest and highest in High-income countries (42 percent) and sub-Saharan Africa (91 percent), respectively (Figure 3.2, Table 3.2). More than 70 percent of mortality in every age group under age 80 was avoidable.

For the oldest age group – adults aged 80 years and older – avoidable mortality as a percentage of total mortality ranged from 26 percent of deaths in High-income to 64 percent in sub-Saharan Africa. Avoidable mortality in the oldest ages account for an increasing proportion of overall avoidable mortality, with avoidable mortality in ages 80 and over contributing 17 percent of avoidable mortality globally in 2019 and anticipated to contribute 34 percent of avoidable mortality in 2050.

FIGURE 3.2 Avoidable mortality as percentage of total mortality, year 2019

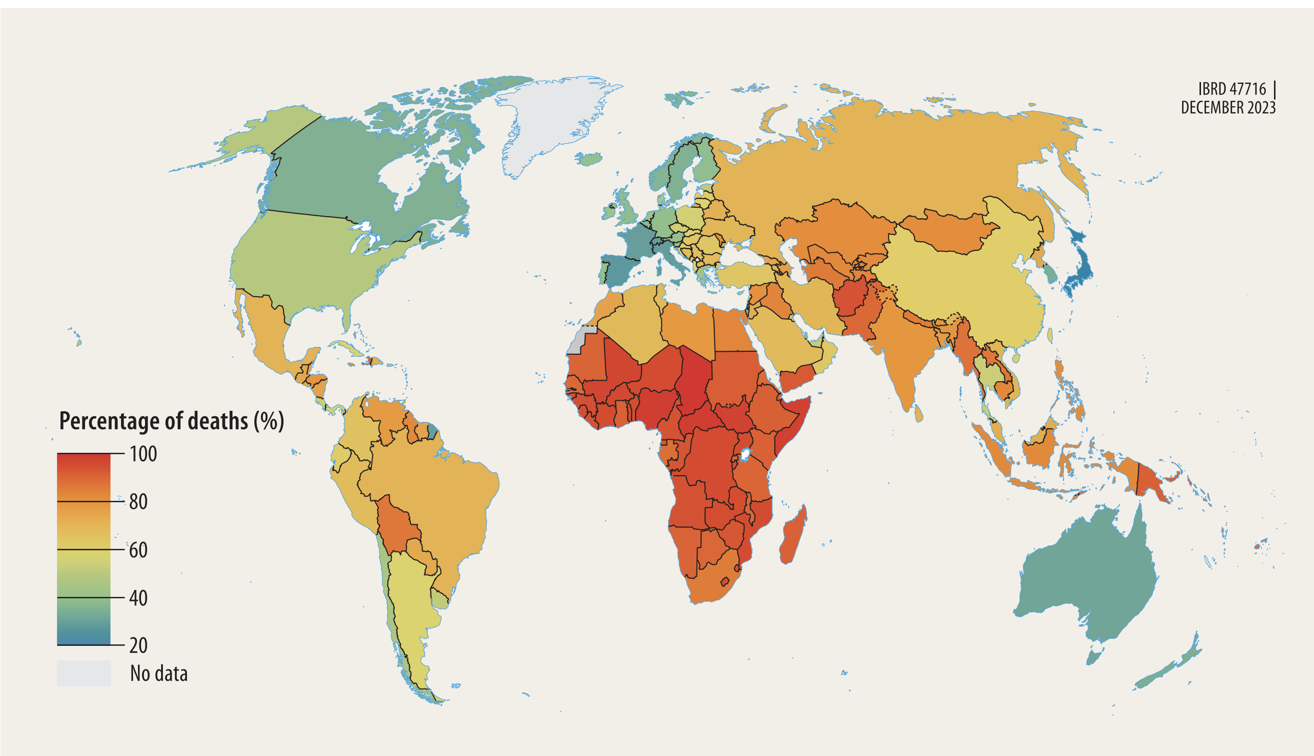


TABLE 3.2 Total mortality and percentage of mortality that is avoidable in 2019, globally and by region, for all ages and by age

	World		China		Euroasia & Mediterranean		High-income		India		Latin America & Caribbean		Sub-Saharan Africa	
	total deaths (millions)	% avoidable	total deaths (millions)	% avoidable	total deaths (millions)	% avoidable	total deaths (millions)	% avoidable	total deaths (millions)	% avoidable	total deaths (millions)	% avoidable	total deaths (millions)	% avoidable
All ages	58.1	69	10	62	14.2	75	10.6	42	9.3	78	4.1	69	9.7	91
Infants	4.0	95	0.1	77	1.0	94	0.1	64	0.7	95	0.1	90	2.0	97
1-9 years	2.1	96	0.05	79	0.3	93	0.02	54	0.2	94	0.04	87	1.4	99
10-19 years	1.1	91	0.06	79	0.2	88	0.03	64	0.2	88	0.06	85	0.6	97
20-39 years	4.0	88	0.3	72	0.9	86	0.2	71	0.7	87	0.3	86	1.5	95
40-59 years	9.2	77	1.4	64	2.5	79	1.0	61	2.0	83	0.7	76	1.5	89
60-79 years	21.4	75	4.5	71	5.8	80	3.7	58	3.8	81	1.6	74	2.0	86
80 and over	16.3	43	3.7	48	3.5	55	5.6	26	1.7	50	1.2	51	0.7	64

Across regions, mortality rates have converged in absolute terms over time, but the percentage of mortality that is avoidable has changed little. Avoidable mortality rates were estimated and projected to decline, with a few exceptions (webappendix Figure A9). Regional trends in the percentage of deaths that are avoidable in each age group are a mixture of stable or, especially after 2010, increasing, indicating that relative gains in frontier mortality rates have been and are projected to outpace gains in mortality in many countries (Figure A10). Despite increases in the percentage of deaths avoidable at each age, the percentage of all deaths that were avoidable changed little globally and in each region because average ages are increasing everywhere, and the percentage of deaths that are avoidable declines with age (Figure 3.3). Avoidable mortality as percentage of total mortality was approximately 72 percent in 2000, 69 percent in 2019, and projected to be 70 percent in 2050 (Figure 3.3). Across all regions, the lowest proportions of avoidable mortality were found in the high-income region, with 42, 42, and 45 percent in years 2000, 2019, and 2050, respectively. The highest proportions were found in sub-Saharan Africa (92, 91, and 92 percent in years 2000, 2019, 2050), India (82, 78, 75 percent), and Euroasia & Mediterranean (77, 75, 76 percent).

FIGURE 3.3 Avoidable mortality globally and by region, year, and age group

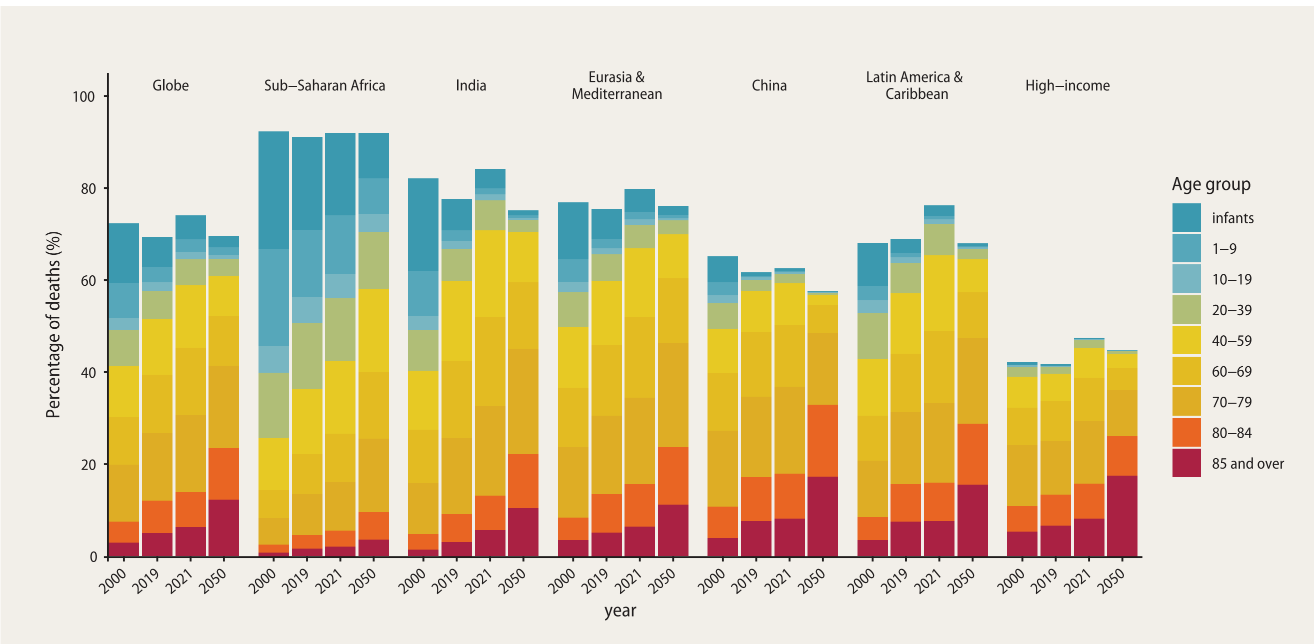
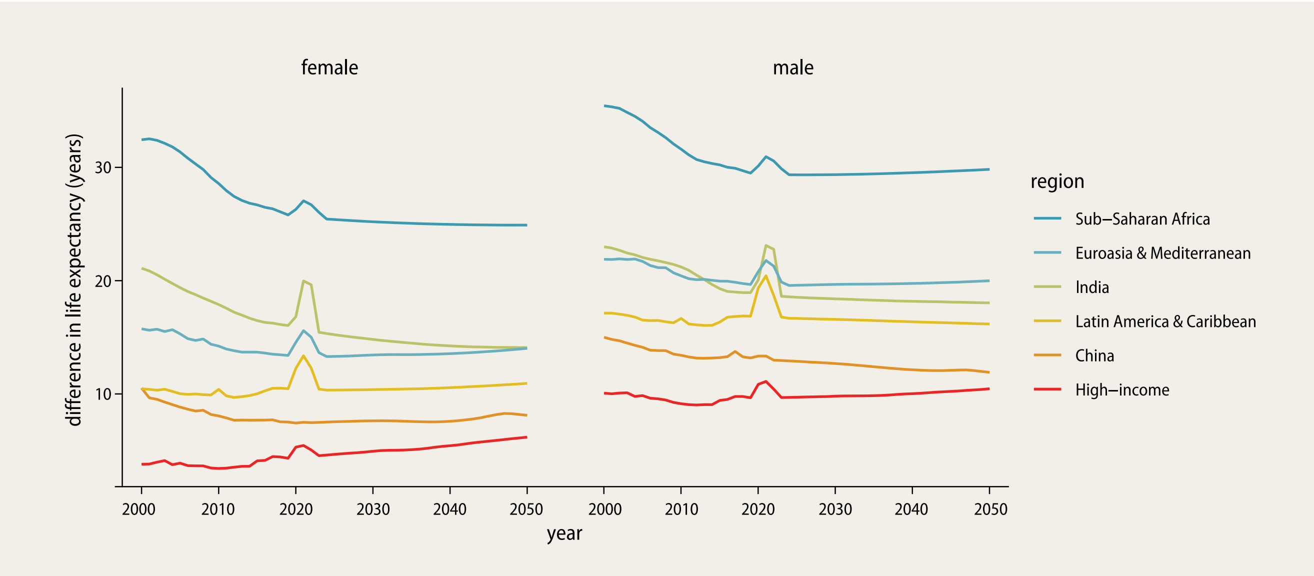


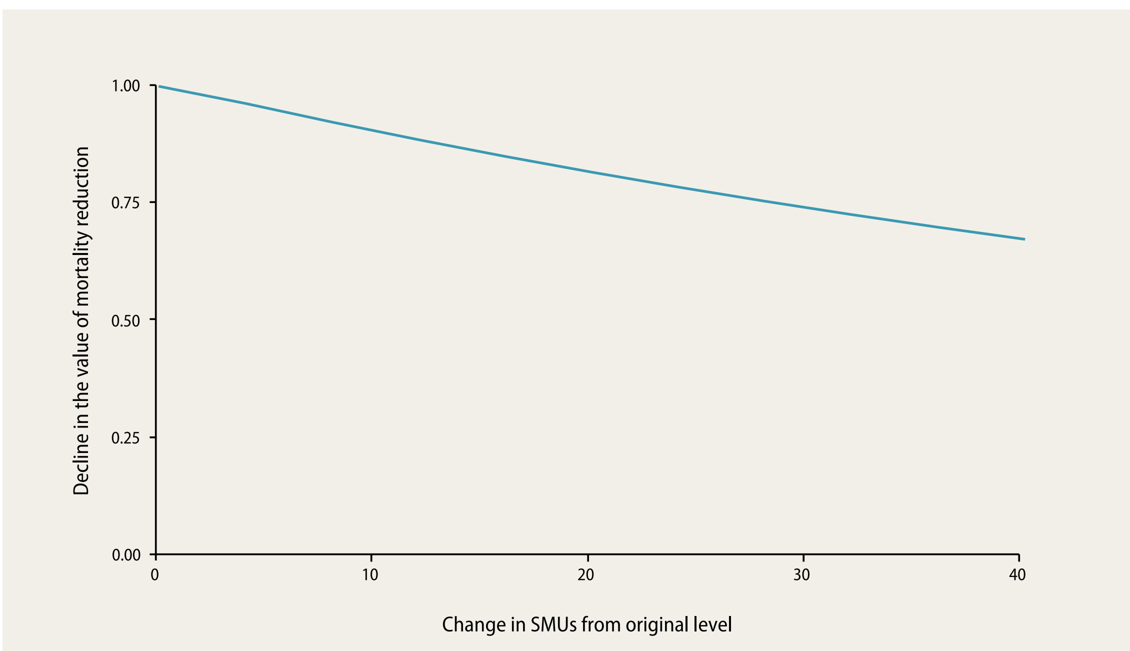
Figure 3.4 depicts the gap between regional life expectancy and frontier life expectancy. From 2000-2010, this gap was decreasing for most regions. However, the gaps between frontier and projected life expectancy are expected to change little after 2025 due to the projected deceleration of reductions in avoidable mortality at all ages. In some populations, including women in high-income countries, this gap is projected to grow as women in some countries fall behind the frontier. Because males have higher mortality rates, avoidable mortality in males is larger than in females, both in percentage of deaths and number of deaths, in all regions and years (webappendix Figures A9 and A10).

FIGURE 3.4 Gap in life expectancy at birth between observed/projected life expectancy and frontier life expectancy



Based on the estimated levels of avoidable mortality presented above, we calculated the economic value of avoidable mortality as percentage of annual income by region, year, and sex. First, we illustrate the relationship between the size of mortality risk change and the decline in marginal economic value assigned in Figure 3.5, using the example of age group 0-1 in the United States in 2019. As the decay curve shows, our model assigns lower marginal economic value (VSMU) with increasing size of mortality risk reduction.

FIGURE 3.5 Ratio of average VSMU to initial VSMU, for United States age group 0-1

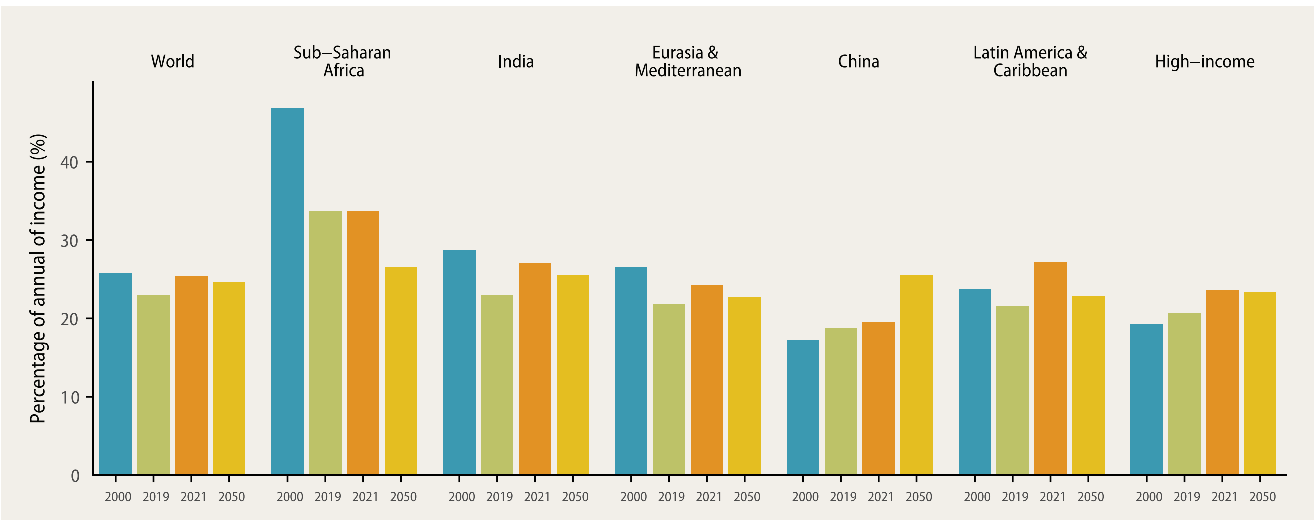


Note: An SMU (standardized mortality unit) is a mortality rate of 10^{-4} per year. The y-axis represents the ratio of the value of SMU (VSMU) associated with small increment from initial mortality level to applied VSMU for active change in mortality level. In this example, we show the decline in the average VSMU with the change in SMUs for age group 0-1 in the United States.

TABLE 3.3 **Value of avoidable mortality in 2019 globally and by region and age group**

	World	China	Euroasia & Mediterranean	High-income	India	Latin America & Caribbean	Sub-Saharan Africa
Economic value (2017 international billion dollars, PPP)	29320	4249	5080	12344	2077	1878	1380
Economic value as percentage of annual income	23%	19%	22%	21%	23%	22%	34%
Distribution by each age group (%)							
Infants	6	3	7	2	7	6	10
1-9 years	10	2	7	1	8	4	27
10-19 years	6	3	5	1	6	5	12
20-39 years	18	11	18	11	20	22	25
40-59 years	26	28	29	26	30	29	16
60-79 years	28	43	28	44	26	28	9
80 and over	6	10	5	15	4	6	1

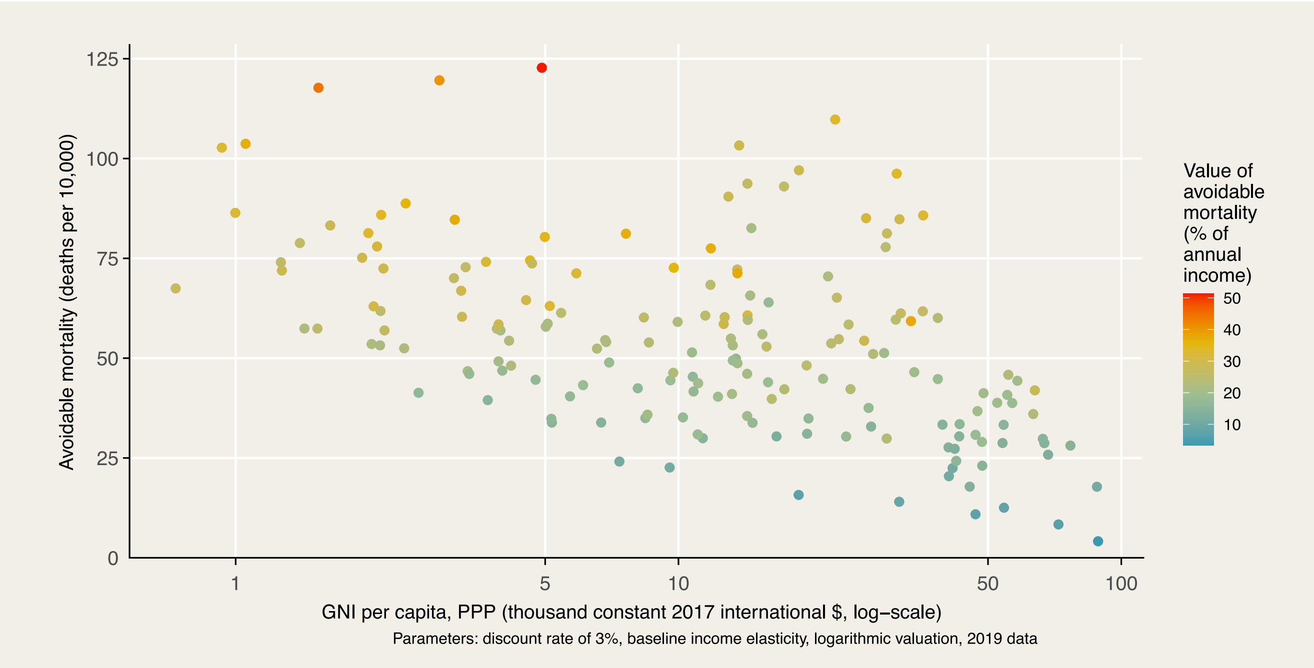
FIGURE 3.6 **Value of avoidable mortality as percentage of annual income for years 2000, 2019, 2021, and 2050 (projected)**



Globally in 2019, the economic value of avoidable mortality (mean value, weighted by population) is estimated at about 29.4 trillion international dollars (2017, PPP-adjusted), representing approximately 23 percent of annual global income (Table 3.3, Figure 3.6). We estimated the highest percentages in sub-Saharan Africa (34 percent annual income), followed by India (23 percent), Euroasia & Mediterranean (22 percent), Latin America & Caribbean (22 percent), High-income (21 percent), and China (19 percent). The relationships between the levels of avoidable mortality, income, and the value of avoidable mortality are shown in Figure 3.7. Higher avoidable mortality rate reflects the combined effect of older population age structure (because older ages tend to have higher mortality) and relatively higher rates of avoidable mortality across all ages. As shown in the figure, at the same income level, countries with higher avoidable mortality rate have higher value of avoidable mortality as percentage of annual income.

Different time trends are observed across regions (Figure 3.6). In sub-Saharan Africa, Euroasia & Mediterranean, and India, we estimate the value (as percentage of annual income) to decrease over time. In sub-Saharan Africa, for example, the value was 46 percent in 2000, decreased to 34 percent in 2019, and projected to decline further to 27 percent by 2050—nearly halved in 50 years. In Euroasia & Mediterranean and India, large declines were seen

FIGURE 3.7 Relationship between avoidable mortality rate, GNI per capita, and value of avoidable mortality



Parameters: discount rate of 3%, baseline income elasticity, logarithmic valuation, 2019 data

between 2000 and 2019, but the value is projected to increase slightly by 2050. In comparison, the values for the other regions increased over time. The largest increases are seen in China: from 17 percent in 2000, 19 percent in 2019, to 26 percent in 2050, reflecting the large projected increases in income and the proportion of older population. While China had the lowest values in 2000 and 2019, it is expected to surpass many other regions in 2050. In contrast, Euroasia & Mediterranean is expected to have the lowest value (at 23 percent) in 2050.

Global and regional values of avoidable mortality are unevenly distributed among different age groups in all years. The two left-most columns in Figure 3.8 show that infants (age 0) and ages 60 and above account for a proportion of the total value that is larger than their population weights. Globally in 2019, ages 60 and above account for about 34 percent of the total value despite representing 13 percent of the population. Similarly, age 0 contributes to 6 percent of the value while being less than 2 percent of global population. The disproportionate contribution to value from these age groups reflects both their high avoidable mortality rates, especially for infants, and large absolute reductions in elderly mortality rates if avoidable mortality is eliminated (see Figure 3.3). On the other hand, children, adolescents, and younger adults (ages 10 to 39) comprise almost half of the global population (47 percent) but only account for 24 percent of the total value of avoidable mortality.

Regional differences in population age structure led to substantially different age group contributions to the total value of avoidable mortality, as evidenced in Figure 3.8. In sub-Saharan Africa, approximately 37 percent of the value comes from ages 0–9, which accounts for 30 percent of the population. Moreover, ages 60 and above represent about 10 percent of the value and only 5 percent of the population. The distribution of contributions is markedly different in regions with older populations. For instance, in High-Income countries, ages 60 and above account for 60 percent of the total value and represent 24 percent of the population. Furthermore, with low infant mortality rates, age group 0–9 accounts for only 3 percent of the value while being 11 percent of the population.

Looking at the differences by sex, Figure 3.9 shows that the global value of avoidable mortality in 2019 is estimated at 19 and 27 percent of annual income for females and males, respectively. Hence, the value of avoidable mortality is approximately 40 percent higher for males, reflecting the higher avoidable mortality rates of males relative to females

FIGURE 3.8 Age-group contributions to the total value of avoidable mortality and population composition by age in year 2019

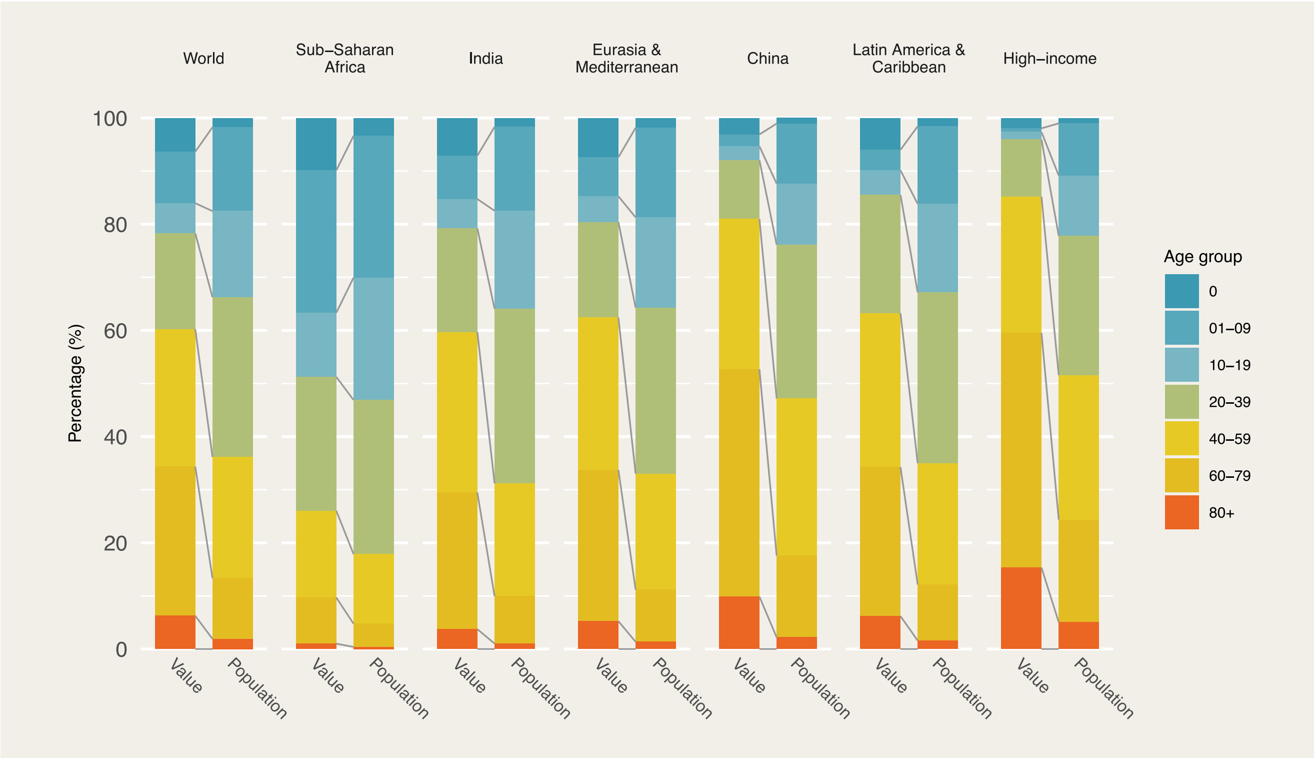
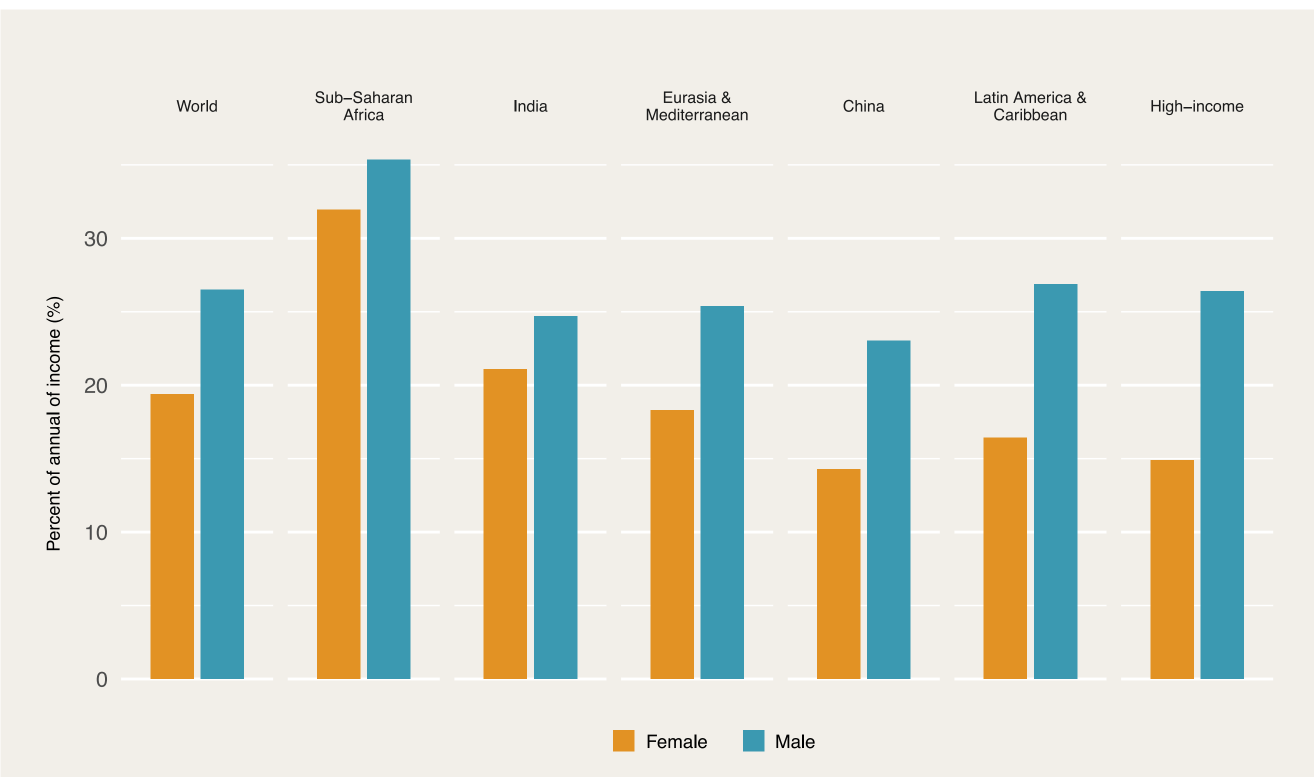


FIGURE 3.9 Value of avoidable mortality for females and males as percentage of annual income in year 2019



(see Figure 3.4). Among females, we estimated the lowest values in China (14 percent), High-income (15 percent), and Latin America & Caribbean (16 percent), and the highest values in sub-Saharan Africa (32 percent), India (21 percent), and Euroasia & Mediterranean (18 percent). Among males, the lowest values were found in China (23 percent), India (25 percent), and Euroasia & Mediterranean (25 percent), and the highest values in sub-Saharan Africa (35 percent), Latin America & Caribbean (27 percent), and High-income (26 percent). The largest relative differences between the sexes were found in High-income (male's value is 77 percent higher), Latin America & Caribbean (64 percent), China (61 percent), and the smallest differences in sub-Saharan Africa (11 percent), India (17 percent), and Eurasia & Mediterranean (39 percent).

We observe some changes in the estimated results for 2021 during the COVID-19 pandemic. Globally, avoidable mortality as percentage of total mortality increased from 69 percent in 2019 to 74 percent in 2021, and the gap between frontier and estimated life expectancy at birth increased from 15.7 to 17.9 years. Across regions, the largest increases in the share of avoidable mortality were in Latin America & Caribbean (from 69 to 76 percent), India (78 to 84 percent), and High-income (42 to 47 percent), and lowest in sub-Saharan Africa (91 to 92 percent) and China (62 to 62 percent). The economic value of avoidable mortality increased globally from 23 to 25 percent, with the largest increases in Latin America & Caribbean (22 to 27 percent), India (23 to 27 percent), and High-income (21 to 24 percent), and very little change in sub-Saharan Africa (34 to 34 percent) and China (19 to 20 percent) (Figure 3.6).

Sensitivity analyses

Here, we highlight three key results from our sensitivity analyses; for additional results and details, see webappendix A2. First, replacing the mortality frontier with sex-specific frontier reduced the estimated avoidable mortality among males (webappendix Figure A1). Globally, this reduced the percentage mortality considered avoidable in 2019 from approximately 69 percent to 59 percent. As previously discussed, this likely underestimates male avoidable mortality because causes of excess male mortality in frontier countries are associated with socio-cultural factors rather than biological differences (e.g., road traffic injuries rather than prostate cancer; see methods). This sensitivity analysis reclassified the largest proportion of deaths in high-income countries and the lowest proportion in sub-Saharan Africa, where around 90 percent of deaths are avoidable regardless of the method used to set the frontier. Nevertheless, regional patterns were similar in the sensitivity analysis vs. the baseline analysis.

Second, to determine the extent to which the frontier mortality levels are achievable, we considered a rapid progress scenario in which countries experience fast and plausible (historically observed) rates of mortality change. Between 2000 and 2019, countries with the fastest 10th percentile decline in age-specific mortality rate experienced reductions between 3.4 percent (ages 85+) and 12.2 percent (ages 5-9) annually (webappendix Table A.2). Between 2019 and 2050, under this scenario, we would expect to see 57 percent lower overall mortality compared to the baseline 2050 mortality rates projected by WPP2022 (webappendix Table A.3). In comparison, if all countries had the same mortality rates as the 2050 frontier, we would expect 70 percent lower mortality level. Under the 10th percentile scenario, females from 30 high-income countries are projected to have mortality rates lower than the 2050 frontier in 80 percent of the age groups.

Third, as expected, applying a fixed VSL (linear extrapolation) yields much larger values of avoidable mortality compared to using our parameters methods that adjust for the effect of large changes in risk. For instance, the global value of avoidable mortality in 2019 using a fixed VSL is 35 percent of annual income (versus 23 percent with a logarithmic function). The overestimation with fixed VSL is more pronounced in regions with higher mortality rates, such as sub-Saharan Africa, where this method yields a value of 58 percent (versus 34 percent with a logarithmic function). These differences are particularly striking within high-mortality age groups and countries, where values estimated with a fixed VSL can far exceed annual income–and sometimes reach up to 1600 percent of income. In comparison, applying a negative reciprocal function—another widely-used non-linear adjustment— only slightly reduces the values; for example, the global value for 2019 is 20 percent of income (versus 23 percent with a logarithmic function).

DISCUSSION

We estimated the economic value of avoidable mortality from 2000-2019 and projected to 2050 by region, age, and sex. In other words, we estimated the perceived economic benefits, measured as percentage of annual income, if countries were to live at the lowest possible (frontier) mortality levels. Using the frontier approach, we first identified countries with the lowest all-cause mortality by age and estimated avoidable mortality for all countries. Then, using the VSL approach with non-linear adjustment, we estimated the proportion of annual income one is willing to forgo to live at the mortality frontier. We highlight five key messages from our findings.

First, a high percentage of mortality is avoidable: Our comparisons of frontier mortality to estimated mortality show that, globally, 69 percent of deaths would have been postponed in 2019 if all countries experienced frontier mortality rates, with the lowest and highest percentages in the High-income region (42 percent) and sub-Saharan Africa (91 percent), respectively. While the absolute level of mortality is projected to decline globally over time, the proportion of avoidable mortality has changed little. Although past illness, injuries, and risk exposures mean that a rapid shift to frontier mortality rates would not be possible, this analysis demonstrates that there are large opportunities for health improvements worldwide, even in higher income countries and among older adults.

Second, it is plausible to significantly reduce the level of avoidable mortality by 2050: Although many countries do not reach frontier mortality levels by 2050 under a fast but plausible mortality decline scenario, the gap between the projected and frontier mortality would narrow significantly. If countries experienced the historical 10th percentile declines in mortality, by 2050, they will have reduced avoidable mortality by 81 percent. We also highlight that historical fast declines were frequently observed in some age groups in non-high-income countries, suggesting that these rates are achievable regardless of income level.

Third, the economic value of avoidable mortality is large: globally in 2019, the economic value of avoidable mortality represented approximately 23 percent of global annual income, with the lowest and highest percentages in China (19 percent) and sub-Saharan Africa (34 percent), respectively. The economic value is approximately 4 percent higher for males than females, reflecting the higher avoidable mortality rates of males. Hence, these results indicate that, on average, regional populations would be willing to give up about one-fifth to one-third of their current income in exchange for a year living at the lowest possible mortality rate, even when considering resource constraints. Two main factors drive these results. First, due to the large differences in mortality rates between the frontier countries and the rest, approximately 70 percent of all mortality was deemed avoidable, and this number does not change much across time. Second, in line with the literature, we placed high monetary value on reducing mortality risk (the VSL-to-income ratio at 160). The combination of these two factors resulted in high values of avoidable mortality.

The levels and changes in economic value reflect multiple factors beyond the levels and changes in mortality. First, it reflects national income and how it is projected. For example, Poland and Tajikistan show approximately the same proportion of avoidable mortality (81.3 and 82.6 percent, respectively) and annual survival probabilities for males at ages 50–54. Nevertheless, Poland's per capita income is 8.5 times larger than Tajikistan's ($31,800 versus $3,700 in 2017 USD PPP). As a result, the value of avoidable mortality for this segment of their populations is 47.6 percent of annual income for Poland but only 34.8 percent for Tajikistan. Hence, Tajikistan's value is lower both in absolute dollars and relative to national income levels. Second, the estimates are weighed by the age distribution of the population. For illustration, we compare Japan and Morocco, where the economic values of avoidable mortality are estimated at 14.5 and 16.7 percent of annual income in 2019, respectively. Morocco has lower population-weighted economic value of avoidable mortality than Japan despite having much higher level of avoidable mortality across all ages, and especially in older ages, than Japan, where avoidable mortality is close to the frontier for all except among older males. On the other hand, even though Japan's older age groups are assigned lower values (as percentage of income) than Morocco because of its relatively lower mortality, Japan has a much higher proportion of older adults, whose values are higher than younger people. Thus, countries with larger proportions of older populations (like Japan) have higher economic values of avoidable mortality than younger countries (like Morocco) even though the former has lower levels of avoidable mortality across all ages. Third, baseline mortality rates should also be considered. Reducing avoidable mortality by 50 percent in a low-mortality country yields a lower value than the same proportional change in a high-mortality country.

Fourth, avoidable mortality and its economic values vary substantially across age groups: as shown in Figure 3.8, some age groups (ages 0 and 60 and above) contribute disproportionately higher value than others (relative to their population share), as a result of the higher rates of avoidable mortality in those age groups. Previous literature on estimating amenable or preventable mortality that use list-based approaches exclude deaths among age 70 or 75 and above (OECD 2019;Barber et al. 2017). In comparison, our approach estimates avoidable deaths in all age groups. For example, using a list-based approach, OECD found that more than a quarter of deaths in OECD countries—mainly high-income countries with high-quality cause-of-death information—were avoidable in 2019 (OECD 2021). In our analysis, we found that 42 percent of deaths in high-income countries were avoidable in 2019, with more than half of avoidable deaths occurring in ages 75 and over. Thus, our analysis demonstrates that exclusion of avoidable deaths in older adults results in a substantial undercount of overall avoidable mortality.

Fifth, it is necessary to adjust the VSL for large risk change. Existing global health literature seldom considers the issues associated with using linear approximation when extrapolating values with larger mortality changes. For example, we find that linear extrapolation yields a value that is on average 54 percent higher than estimates using a logarithmic value of income function. For certain age groups in countries with high avoidable mortality rates, linear extrapolation results in values that are nearly ten times larger than our estimates. The logarithmic approach also ensures that valuation of mortality reduction does not exceed resource constraints, and we believe future research should consider adopting this method.

Contributions to the literature

We aim to make three important contributions to the literature: (1) creating an envelope for global economic value of mortality reduction; (2) implementing a simplified method to estimate avoidable mortality; and (3) incorporating risk-size adjustments that are necessary to the economic valuation framework in this context.

First, similar to the GBD's approach in creating an "envelope" to ensure the sum of cause-specific deaths do not exceed all-cause deaths, our estimates on the economic value of avoidable mortality could be used as an envelope for the value of mortality reduction from specific causes, interventions or programs.

Second, avoidable mortality is typically estimated as the number of deaths assigned to set of specific causes of death, when they occur below a threshold age (OECD 2019; Rutstein 1998; Nolet and McKee 2004). This list-based approach requires comparable, detailed, and accurate cause-of-death data, which are not currently available for most countries (WHO 2020). We propose a simplified method by computing avoidable mortality as the difference between current observed or estimated mortality and an unavoidable, or frontier, mortality (Mathers et al. 2015). This has several advantages, including application to countries with limited cause-of-death information, allowing for a time-varying frontier based on improvements in knowledge and technology, and inclusion of avoidable mortality in older adults, and avoiding artificial categorization into preventable and treatable deaths.

Third, the global health economics literature using the VSL approach has traditionally relied on existing valuation studies to value mortality risk reduction in various settings. This process, referred to as "benefit transfer" or "value transfer", typically involve extrapolating the VSL from the United States or western Europe to another setting based on differences in the income levels and the assumed level of income elasticity (Robinson et al. 2019; Robinson et al. 2019). This step implicitly assumes that income is the only difference between the settings, such that income adjustment to the VSL is sufficient. However, several other key differences may exist between the original research from which the VSL estimate was derived and the new setting. They may include population age distribution, size of the change in mortality risk, baseline mortality, and whether the risk change is one-time or permanent. There is a lack of empirical evidence on the relationship between these factors and the VSL (with the exception of population age), which may have led to the omission of quantitative adjustments or discussions around them in the global health benefit cost literature. In this chapter, we rely on the theoretical literature and introduce a novel and relatively easy approach to incorporate these factors into the VSL estimate (Hammitt 2020; Cardoso and Dahis 2024). This is especially important in global health research, which often focuses on a wide range of baseline and size of risk reduction across time and region.

Limitations

This study has several limitations. First, mortality and population projections from WPP2022 are uncertain. For many countries, WPP2022 estimates mortality rates by country, age and sex from incomplete death registration data and population-based census or survey data, such as reports of child or sibling survival, as available. The same limitation holds for country-level income data. We therefore focus on the results at the regional level in the main paper to mitigate the effect of outlying country estimates. Second, the medium- and long-term impact of COVID-19 on levels and trends in mortality is uncertain. As populations gain immunity (from past infection and vaccination) and treatments continue to improve, we expect that mortality rates will resume their declines in all populations and our projections for 2050 may be considered informative. Third, we only focused on mortality and not morbidity, suggesting that the results likely underestimate the actual economic value of preventing and treating diseases and injuries. Fourth, our projected results for 2050 are sensitive to some key assumptions, one of which is the projected GNI per capita in 2050. While we relied on the projected growth rates of a reliable source (OECD), the results are highly sensitive to how income levels in 2050 are projected. Fifth, the VSL approach to assigning monetary values to risk reduction is not without its limitations (Viscusi and Aldy 2003). While we have introduced important adjustments when extrapolating the VSL from the United States to other countries, having empirical studies from countries with different income and risk levels is preferred. Finally, our results estimate one's willingness to forgo income for a one-year change in survival. An alternative perspective and approach would be to estimate the exchange between lifetime income and lifetime changes in survival, which could also be insightful for policymaking.

Comparison to previous literature

Previous work on estimating the economic burden of disease has taken different approaches. One approach is using a list-based approach, for example work by Alkire and colleagues provide estimates of amenable mortality, i.e., mortality that can be reduced by the health care system, for 130 low- and middle-income countries between 2015-30 (Alkire et al. 2018). The second approach looked at what specific packages of interventions could be expected to do if more fully implemented than they now are. These assessments have been undertaken in the context of estimating the impact of universal health coverage on mortality (and on health care costs). Two analytic programs, from the WHO and the third edition of the Disease Control Priorities (DCP) Project, respectively, have generated estimates, and both point to a substantial volume of amenable mortality (and are thus consistent with the main conclusion of this study) (Stenberg et al. 2019; Stenberg et al. 2017; Jamison and Alwan 2018; Watkins et al. 2020). In terms of valuing these mortality reductions, Alkire et al. estimate the value of amenable mortality at $6.0 trillion in 2015 (international dollars) for all low- and middle-income countries, and approximately 5 to 20 percent of GDP in different regions Our methodological differences – the three most important being how and which mortality is valued, inclusion or exclusion of ages over 75, and the use of linear versus logarithmic value-to-income functions – make it difficult to compare the estimates directly. Furthermore, putting our numbers into context, while not directly comparable, in 2019 national health expenditure (as percentage of GDP) in all countries were much less than our estimate, suggesting that people may be willing to invest much more in health promotion and health care or other means in exchange for better survival probabilities (World Bank 2022). Studies on primary health care in low- and middle-income countries reported that an additional 3.3 percent of GDP on top of current levels of health expenditure could lead to large gains in health (Stenberg et al. 2019). Another study estimated an additional 4.6 percent of GDP is required to achieve the Sustainable Development Goal 3 by 2030 (Stenberg et al. 2017). The DCP studies concluded costs would be somewhat higher. These numbers are much lower than our estimates of value.

CONCLUSION

As governments worldwide engage in policy dialogues on how and how much to invest in improving population health, our work provides supportive evidence on the high economic value placed on improving health. Furthermore, the disproportionally higher distribution of the economic value of avoidable mortality among older adults also lends support to policies related to healthy aging and interventions targeting non-communicable diseases.

DEDICATION

We dedicate this study to Professor James W. Vaupel (1945-2022) who inspired us and many others with his intellect, vision, and passion for great research.

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