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Title: Benefit Cost Analysis in *Disease Control Priorities, Third Edition*

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Introduction

Role of Benefit-Cost Analysis in the Health Sector

A variety of economic methods is used for analysis in the health sector. Other chapters in this volume summarize the findings from Disease Control Priorities (third edition) (DCP3) concerning cost-effectiveness analysis (CEA) and extended cost-effectiveness analysis (ECEA) (Horton 2018; Verguet and Jamison 2018). This chapter summarizes the findings concerning benefit-cost analysis (BCA).

BCA has long been used for the analysis of public policy. The U.S. Secretary of the Treasury first used it in 1808, and its use became mandatory for the U.S. Army Corps of Engineers in 1936. The U.S. Bureau of the Budget first issued guidelines for its use in 1952. Mills, Lubell, and Hanson (2008) suggest that BCA became less well used for analysis of malaria eradication around 1980, when CEA methods were becoming well developed. More recently, there has been a resurgence of interest in applying BCA to assess the viability of public investment programs and to set priorities among a list of interventions (Jamison, Summers, and others 2013; Ozawa and others 2016; Jha and others, 2015).

BCA tends to be relatively readily understood by the general public, because the private sector uses analogous concepts. However, BCA also tends to raise controversies because it assigns monetary values to outcomes (such as small changes in annual mortality probabilities) that cannot be monetized according to many individuals.

We observe that BCA and CEA in the health sector represent two distinct cultures. The metric for value in CEA can accommodate real health outcomes, such as child deaths averted, and aggregate measures, such as quality-adjusted life years (QALYs) or disability-adjusted life years (DALYs), as well as more granular measures, such as malaria cases correctly treated. When health benefits are measured in life years, both the ages of the individuals and their remaining life expectancies are implicitly factored into the analysis. In contrast, in BCA, health benefits are often measured in terms of the number of statistical lives; ages and remaining life expectancy of individuals are often not considered. BCA involves an additional step of assigning monetary value to health benefits; analysts are required to explicitly assume a certain relationship between the proportional change in this monetary value and the differences in countries' income levels, namely, income elasticity. This factor is often not considered in CEA. The choice of applying CEA or BCA to evaluate economic benefits depends on the type of outcomes produced by the health interventions. For some interventions, the main benefits include reduced mortality, improved quality of life, or reduced morbidity or disability. For these outcomes, CEA works well and allows comparisons with other health interventions. Many health interventions also affect future health care requirements; preventive interventions, in particular, can reduce future health care costs. In CEA, these future cost reductions can be subtracted from current costs of the intervention before comparing net costs to the health benefits.

Other interventions may improve health, but their key outcomes are more easily expressed in monetary terms. For example, supplementation or food fortification with iron or iodine produces modest health benefits in the form of reduced anemia and cretinism. However, the most pervasive benefits accrue via improved human capital—in this case, cognition and education—and thus BCA is more appropriate. The eradication of a disease, such as smallpox, improves health but can also save a substantial amount of money through elimination of future prevention and treatment costs. Hence, BCA may be the most effective way to provide evidence of and advocate for this as a policy intervention.

A third group of interventions undertaken in sectors outside health (for example, improvements in road safety, safety regulations for vehicles, or water and sanitation) are more naturally assessed by BCA methods. The investment decisions are made in sectors that are accustomed to using BCA, and the investments with health benefits are being compared to other investments with outcomes that are assessed by BCA. CEA is more frequently used for comparisons within the health sector; it has been refined for specific policy purposes, such as the decision whether to allow insurance coverage of a particular new drug, technique, health technology, or diagnostic test within a country, or for the prioritization of the use of donor funds when international assistance is involved.

BCA, CEA, and ECEA are complementary techniques; each has value in addressing specific circumstances or specific policy questions. This chapter summarizes the BCA findings from DCP3. It then examines the existing methods for valuing life and considers possible improvements and ends with concluding comments.

Contribution of Disease Control Priorities (Third Edition) to BCA in the Health Sector

The approaches in the DCP3 chapters and DCP-supported literature take many forms. Some directly report benefit-cost ratios from existing literature, while others conduct their own BCA using primary data. Key BCA findings and the methods applied are summarized in tables 9.1 and 9.2.

Most of the benefit:cost ratios reported in tables 9.1 and 9.2 range from 1 to 10. Only one reported ratio is below 1 (likely owing to publication bias), a small number are in the 11–30 range, and a few outliers have higher ratios. In part, this variation in results may stem from variations in the methodologies adopted. Some studies use methods of value per statistical life (VSL) based on willingness to pay (for example, Alkire, Vincent, and Meara 2015; Cropper and others 2017). Others assign dollar values to morbidity and mortality averted (for example, Jamison, Jha, and others 2013; Jha and others 2013; Stenberg and others 2016) or to mortality risk reduction (Fan, Jamison, and Summers 2018; Jamison, Summers, and others 2013), using productivity or cost of illness averted to value years of life lost. Of those assigning a value to mortality averted, only Stenberg and others (2016) include an explicit intrinsic value to life in excess of an assumed contribution to, or share of, GDP. These methods are described in more detail in the next section.

Several studies examine health interventions that improve human capital and value the outcome according to higher wages. These include interventions in early child development and preschool (Horton and Black 2017), school feeding and deworming (Fernandes and Aurino 2017**)** and programs to educate school-age children and adolescents in health prevention (Horton and others 2017). Other studies include future wages and averted future health care costs in regard to malaria elimination (for example, Mills, Lubell, and Hanson 2008) and improvements in sanitation (Hutton 2013; Whittington and others 2009).

BCA findings were not surveyed and analyzed systematically in all volumes (unlike CEAs), and thus we can draw only tentative conclusions as to the areas where BCA is used most often. It is widely used in injury prevention and environmental health areas, and volume 7 (Mock and others 2017) has very few examples of CEA. Similarly, the analyses of pandemics and elimination or eradication of infectious diseases lend themselves to BCA. BCA is underrepresented in volume 2, because space did not permit the inclusion of BCAs on nutrition, an area with many BCAs already (Black and others 2016). BCAs are scarcely visible in volume 3 (Gelband and others 2015) and volume 5 (Prabhakaran and others 2017). The focus of these particular areas of noncommunicable diseases is on health interventions more relevant to individuals than populations and on treatment and screening of those individuals, which may make CEA methods more appropriate.

The next section considers the issues around the variation in methodology and associated effects on the magnitudes of BCA reported.

Use of the Value per Statistical Life in Estimating BCA in the Health Sector

Several of the *DCP*3 chapters and related articles build on the concept of the VSL to estimate the intrinsic value of health improvements. The VSL is defined as the marginal rate of substitution between money and mortality risk in a defined time period. It is typically calculated by dividing individuals' willingness to pay for a small change in their own risks in a defined time period by the risk change. For example, individuals have a VSL of US$9 million if they are willing to pay US$900 for a 10^{-4} reduction in mortality risk in the current year. Note that money is used as a measure to reflect the trade-offs individuals are willing to make, and it is not itself important. Jamison, Summers, and others (2013) argue that terminology should be used in cases where the risk change units are close to those actually measured so that one avoids the occasionally contentious interpretations of value of life (Chang and others 2017). They propose that risk be measured in source measure units (SMUs), or units of 10^{-4}. Rather than referring to the value of a statistical life, they propose referring to the value of an SMU (VSMU). In the example just provided, the risk change was 1 SMU and the associated VSMU was US$900. Most published VSL studies focus on the risks of accidental deaths, mainly among adult populations in high-income settings (Lindhjem and others 2011; Robinson and Hammitt 2015b; Viscusi 2015; Viscusi and Aldy 2003).

Far fewer VSL studies are conducted in low- and middle-income countries (LMICs), and the quality of the papers varies widely (Bhattacharya, Alberini, and Cropper 2007; Guo and Hammitt 2009; Hammitt and Zhou 2006; Hoffmann and others 2012; Shanmugam 2001; Simon and others 1999; Tekeşin and Ara 2014; Vassanadumrongdee and Matsuoka 2005). Under this limitation, analyses that value health improvements in LMICs often rely on studies from high-income countries (HICs) as their base VSL estimates, and these are adapted on the basis of some characteristics of the population of interest. This section discusses the common practices, as well as the challenges, that analysts face in using previously established values for another setting of interest (also known as *benefit transfer*) and provides an alternative to existing methods.

Current Practice of Benefit Transfer in Global Health

Selection of Base VSL or VSL-to-Income Ratio

Benefit transfer often begins with selecting a base VSL or a VSL-to-income ratio (VSLr). We consider the VSL estimates produced by major U.S. regulatory agencies and the Organisation for Economic Co-operation and Development (OECD) as two reasonable starting points. In the

United States, a simple average of the values applied by three regulatory agencies is US$9.3 million (Robinson and Hammitt 2015b; U.S. DOT 2015; U.S. EPA 2014), which translates into a VSLr of roughly 180. OECD (2012, 2014) proposed a VSL of US$3.6 million and a VSLr of roughly 100, which is much lower than the U.S. estimates.

Several considerations need to be made when extrapolating existing estimates to other populations. The VSL is expected to vary, depending on the characteristics of those affected (for example, health status, age, life expectancy, and income) and the characteristics of the risks (for example, latency, morbidity before death, voluntariness, and controllability). However, the effects of many of these characteristics need further research. There are significant inconsistencies and gaps in the available literature, even for HICs (Hammitt 2017; Robinson and Hammitt 2015b; Viscusi and Masterman 2017). The most commonly adjusted characteristic is income, possibly because both theoretical and empirical evidence are readily available (although consensus on the magnitude of adjustments one should make between countries with varying income levels is still lacking). Other important characteristics, such as the average age or remaining life expectancy of those affected, are often ignored.

Relationship to Income

Research on the relationship between income and the VSL generally indicates that the VSL increases as income increases. However, the proportional change in the VSL in response to a change in real income—its income elasticity—is uncertain (Robinson and Hammitt 2015a). Income elasticity is of particular importance in estimating the VSL for lower-income countries because changing the elasticity can affect the resulting VSL by orders of magnitude (equations 9.1 and 9.2) (Hammitt and Robinson 2011).

$$\mathrm{VSL}_{\mathrm{country\ x}} = \mathrm{VSL}_{\mathrm{US}} \times \left(\frac{\mathrm{GDP\ per\ capita}_{\mathrm{x}}}{\mathrm{GDP\ per\ capita}_{\mathrm{US}}}\right)^{\mathrm{elasticity}} \quad (9.1)$$

$$\mathrm{VSL}_{\mathrm{r}} = \frac{\mathrm{VSL}_{\mathrm{country\ x}}}{\mathrm{GDP\ per\ capita}_{\mathrm{country\ x}}} =$$

$$\frac{\mathrm{VSL}_{\mathrm{US}} \times \left(\frac{\mathrm{GDPpc}_{\mathrm{country\ x}}}{\mathrm{GDPpc}_{\mathrm{US}}}\right)^{\mathrm{elasticity}}}{\mathrm{GDPpc}_{\mathrm{country\ x}}} = \mathrm{VSL}_{\mathrm{US}} \times \frac{\mathrm{GDPpc}_{\mathrm{country\ x}}^{(\mathrm{elasticity}-1)}}{\mathrm{GDPpc}_{\mathrm{US}}^{\mathrm{elasticity}}} \quad (9.2)$$

r: ratio (ratio of VSL to GDP per capita); pc: per capita

Empirical studies comparing VSL estimates from HICs and middle-income countries (MICs), as well as between higher- and lower-income groups in the United States, support the use of elasticity greater than 1.0 when applying VSL across income levels (Biausque 2012; Costa and Kahn 2004; Hammitt and Ibarrarán 2006; Kniesner, Viscusi, and Ziliak 2010). However, similar research has not been conducted in low-income countries (LICs). Nevertheless, the global meta-analysis in Lindhjem and others (2011) and OECD (2012) for OECD countries yielded the estimate of 0.8 (range 0.7–0.9). Figure 9.1 illustrates the relationship between VSLr and income when an income elasticity of 1.2 is applied across countries, using the U.S. VSLr of 180 as the base. If elasticity of 1 were applied, all countries would face the same VSLr of 180. With greater income elasticity, countries with greater GDP per capita will behave a higher VSLr, with the highest occurring in Qatar at 217. For LMICs, the VSLr drops exponentially, with the lowest VSLr occurring in the Central African Republic at 73.

One issue with extrapolating the VSL from a higher- to a lower-income setting is that the VSL may fall below the expected income or consumption in the relevant period in the lower-income country. Theory suggests that the VSL will exceed the present value of future earnings and of future consumption, both of which vary by age, because it reflects the intrinsic value of living in addition to an individual's productivity or consumption. Accordingly, the VSL is expected to at least equal the present value of future income, as well as consumption, discounted to the age at which the risk reduction occurs (Hammitt and Robinson 2011).

Relationship to Age and Life Expectancy

Because the VSL cannot be directly estimated from market measures such as earnings or consumption, researchers instead rely on revealed or stated preference studies. The former estimates the value of risk reductions based on related market transactions or behavior, often on the relationship between wages and occupational risks in the case of the VSL. Some of these studies found an inverse U-shaped relationship; the VSL increased in young adulthood, peaked in middle age, and then declined, consistent with the patterns of income and consumption predicted under the lifecycle models (Rosen 1988; Shepard and Zeckhauser 1982, 1984). Others find that the values for older adults may decrease or remain constant (Evans and Smith 2006; Krupnick 2007). One limitation of the revealed preference method is that it addresses only working age populations. Stated preference methods instead involve surveying respondents to determine their willingness to pay for risk reductions of various types. Some stated preference studies suggest that adult willingness to pay to reduce risks to children is likely to be larger than the value adults place on reducing risks to themselves, although the magnitude of the difference varies across studies. For example, Hammitt and Haninger (2010) found that willingness to pay for risk reduction is nearly twice as large for children than for adults. To date, we are unaware of a general consensus in the BCA community on how to adjust the value of risk change for differences in age.

Age and life expectancy are related but distinct concepts. As Sanderson and Scherbov (2007) stated, a person has two different ages: the retrospective age, which is a measure of how many years one has already lived, and the prospective age—remaining life expectancy—which reflects how many years a person will live. For example, a person age 35 years in 1960 and a person age 35 years in 2015 likely would have different levels of willingness to pay for mortality risk reduction, because they would have had different perceptions of how much longer they will live. This distinction is important in transferring base VSL from an HIC to an LIC. Comparing the remaining life expectancies of persons at age 35 years in 2015 in Lesotho (the lowest life expectancy at birth), the United States, and Japan (the highest life expectancy at birth), one finds that the average person in Lesotho faced a 26-year life expectancy, while a person in the United States and Japan faced 45 years and 49 years, respectively (UNDP 2015**).** Intuitively, all else equal, we would expect lower willingness to pay among people in Lesotho, given the lower number of years remaining. However, no empirical data support this claim.

As an illustration, in figure 9.2 we estimate the VSLr for all countries, based on the ratio of the remaining life expectancy at age 35 years of persons of a selected countries and of the United States (equation 9.3). The figure shows a narrower range of the VSLr across countries, because the differences among remaining life expectancies are smaller than among income levels. The lowest VSLr occurs in Lesotho, the country with the lowest life expectancy, at a VSLr of 101, and highest in Japan, at 194.

$$\mathrm{VSL}_{\mathrm{r\ country\ x}} = \mathrm{VSL}_{\mathrm{r\ US}} \times \left(\frac{\text{remaining life expectancy }(35)_{\text{country x}}}{\text{remaining life expectancy }(35)_{\text{US}}}\right) \qquad (9.3)$$

r: ratio (ratio of VSL to GDP per capita)

Alternative Approaches

Given the limited theoretical and empirical evidence on the appropriate framework to account for transferring the value of mortality risk reduction to populations with different characteristics, we propose five simple and defensible alternative approaches to incorporate these key characteristics. We start with the two VSLr described earlier as the starting point (VSLr = 180 and 100), and we estimate the VSLr for each World Bank income group in table 9.3.[1]

The first approach ([1] in table 9.3) is to not apply any adjustments based on income or age and to assume that the VSLr remains the same across all populations.

The second approach ([2] in table 9.3) makes income adjustments by applying an elasticity of 0.8 for HICs and 1.2 for all other countries, based on equation 9.2, to the VSLr. We use 2013 GDP per capita in U.S. dollars (PPP) for each income group.

The third approach applies age and life expectancy adjustment ([3] in table 9.3) by assuming that the value decreases proportional to remaining life expectancy. This method reflects common practices in the health economics literature, and specifically in CEA in the health sector, in which the units of health benefits are in life years, rather than, for example, lives saved. These analyses implicitly assume that the VSL decreases in proportion to remaining life expectancy and that saving the life of a younger person with higher remaining life expectancy has a greater yield than saving the life of an older person. To estimate the changes in VSLr, we first collected the most recent (2010–15) age-specific death rates for all four income groups (UNDP 2015) and used the 2015 world population distribution to create age-standardization for the distribution of deaths. Assuming that the value of risk reduction decreases proportional to remaining life expectancy, we then applied a ratio of the remaining life expectancy at that age and at age 35 years for each age group (equation 9.4).

$$\text{Age} - \text{adjusted VSLr}_\text{j} = \text{Base VSLr} \times \frac{\sum_{\text{i}=0}^{21} \text{world population size}_\text{i} \times \text{death rate}_\text{ij} \times \frac{\text{e(a)}_\text{ij}}{\text{e(35)}_\text{j}}}{\sum_{\text{i}=0}^{21} \text{world population size}_\text{i} \times \text{death rate}_\text{ij}} \qquad (9.4)$$

where j is income group, i is age group (0, 1–4, 5–9, and so on up to 95+), e(a)_ij is the remaining life expectancy at age a in age group i in the jth income group, and e(35)_j is the remaining life expectancy of 35 year olds in the jth income group.

The fourth approach combines the second and third approach to adjust for both differences in income and in age and life expectancy ([4] in table 9.3).

The fifth and final approach involves using an alternative functional form that incorporates different characteristics. This varies substantially from the previous four approaches, which are all built on the same functional form commonly applied in the VSL literature (equation 9.2). In searching for an appropriate functional form to calculate the VSLr for countries, we set the following criteria that we consider important when transferring VSLr from one country to another:

1. The base VSLr is set roughly at the U.S. average of 180 or the OECD's estimate at 100 (for purpose of illustration, we use the former in the calculation that follows equation 9.5).
2. Following the income elasticity literature, we apply an elasticity of roughly 0.8 for HICs and 1.2 for LMICs.
3. All VSLr should be above the income floor, namely, the VSLr should not be lower than the discounted remaining life expectancy.

We found that the sine function can approximately meet these criteria and could therefore be an appropriate functional form to represent the relationship between VSLr and income. For example, one function form that meets the criteria is as follows:

$$\mathrm{VSLr}(\mathrm{y}) = 115 + 70\sin(\mathrm{y}_n) \tag{9.5}$$

where y_n is the normalized 2013 GDP per capita in U.S. dollars (PPP).

$$\mathrm{y}_n = \frac{x-a}{b-a} \tag{9.6}$$

where x is the country's income level. We set a (i.e., where $\sin(y_n) = 0$) as the average income of upper-middle-income countries and b as the average income of non-OECD HICs. We excluded the following small countries with very high income levels to simplify the analysis: Qatar, Luxembourg, Kuwait, and Singapore. We present this relationship between VSLr and income level under the scenario in figure 9.3 and the implied VSL as a function of income under this analysis in figure 9.4. We constrained the U.S. VSLr to be approximately at 180. The lowest VSLr occurs in the Central African Republic, an LIC with a 2013 GDP per capita of US$603, and the highest VSLr occurs in several HICs, including Iceland and the Netherlands, with the 2013 GDP per capita ranging from US$42,000 to US$46,000. Under this formulation, the income elasticities in LMICs and HICs are approximately 1.2 and 0.9, respectively.

Conclusions

This chapter reviews estimates of B/C ratios from *DCP3* and illustrates the large number of applications of the technique to the health sector. Two major streams of methods are used within the health sector for B/C estimation in *DCP3*. One uses willingness to pay and the VSL concept. The other uses a human capital measure, analyzing costs of lost productivity because of morbidity and mortality or improved productivity associated with improved cognition. The literature on VSL is evolving, and we have presented current thinking on how that evolution might continue. The following research priorities are recommended for future examination.

First, standardization of the assumptions within each methodology would be useful. Currently, actual differences across alternative interventions are obscured by variations in methods and assumptions. Disagreements about how the VSL should vary with population characteristics are built on both empirical and normative arguments. The human capital side lacks consistency of rules for valuing future years of human life: Do we use current GDP? Do we use rates of actual growth per capita of countries? Do we use a common measure of expected growth, for example, 2 percent per capita per annum? This lack of consistency makes the comparison of estimates challenging. Estimates made in different sectors with different traditions is part of the problem. The development of a reference case would help. Such a reference case is being supported by the Bill & Melinda Gates Foundation, in part as a follow-up to *DCP3*. A possible proposal is that each BCA (or economic burden of disease assessment) would select its own values for key parameters while also reporting standardized sensitivity analyses to enable accumulation of comparative knowledge.

Second, more empirical VSL estimates from low- and middle-income countries are needed. The current practice of benefit transfer does not adequately reflect the different characteristics between populations, and we believe this inadequacy leads to inaccurate estimations of the population's willingness to pay. Having empirical estimates of VSL from a diverse set of populations will fill an important research gap in this field.

Third, advances in BCA also need to be harmonized with the evolution in thinking about thresholds for cost-effectiveness. We know that VSL methods tend to assign large values to health because they focus on willingness to pay without specific reference to ability to pay. At the same time, recent studies (Claxton and others 2015; Ochalek, Lomas, and Claxton 2015) have shown that the public tends to undervalue public dollars spent on health care, acting as if a DALY (one year of enjoyment of full health) is worth only 50 percent of per capita GNI at the margin. If this methodological issue is not resolved, health policy makers will overspend on health interventions assessed by BCA (for example, environmental interventions, injury prevention, and human capital promotion) and underspend on those assessed primarily by CEA (used to decide between many curative interventions). This is an important area for future work.

Finally, both CEA and BCA entail implicit ethical judgments. An approach using BCA that incorporates considerations of future wages gives a larger weight to individuals who are of working age, to those with higher labor force participation rates (men compared to women), and to urban populations as compared to rural populations. These same groups (working-age population, men, urban residents) also tend to have higher health-care expenditures and, hence, also receive greater weight in benefit calculations of future health expenditures averted. Because benefits measured in CEA are denominated in years of health, they are less subject to bias by gender, higher income, and residence. However, they share similar ethical concerns as do measures of the global burden of disease. Years of life saved for someone who suffers from a disability or mental illness are valued less than those for someone who is free of disability, for example. For these reasons, a common compromise between CEA and BCA methods is to assign the same VSL to everyone within a country. These topics may be usefully examined in future research.

Notes

World Bank Income Classifications as of July 2014 are as follows, based on estimates of gross national income (GNI) per capita for 2013:

- Low-income countries (LICs) = US$1,045 or less
- Middle-income countries (MICs) are subdivided:
    a) lower-middle-income = US$1,046 to US$4,125
    b) upper-middle-income (UMICs) = US$4,126 to US$12,745

- High-income countries (HICs) = US$12,746 or more.

1. These scenarios build on conversations among an informal group of researchers interested in developing standardized VSL sensitivity analyses to enhance the comparability of assessments of global health and development issues. The group was initially convened by Dean Jamison and Maureen Cropper in February 2016 and ultimately grew to include over 30 participants as of April 2016. Major contributors included Kenneth Arrow, Nils Axel Braathen, Angela Y. Chang, Rob Dellink, James K. Hammitt, Michael Holland, Alan Krupnick, Elisa Lanzi, Urvashi Narain, Ståle Navrud, Lisa A. Robinson, Rana Roy, and Christopher Sall, among others. The analysis presented here uses these discussions as a starting point, but it has not been reviewed or approved by that group.

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Tables and Figures

Table 9.1 Economic Burden of Disease, BCA, and Investment Cases in *DCP3*

Subject	DCP3 reference	Summary of key findings	Method of valuing health or changes in mortality
Essential Surgery	Volume 1, chapter 21	• B/C of cleft lip and palate repair were 42 (income elasticity = 1.0) and 12 (income elasticity = 1.5), respectively. • The median B/C of cesarean-section delivery for obstructed labor across countries is 4.0 (income elasticity = 1.5), ranging from 0.3 for the Democratic Republic of Congo to 76 for Gabon (Alkire, Vincent and Meara 2015).	• The base VSL was set at $7.4 million (2006 US$), and income elasticities of 1.0 and 1.5 were applied when extrapolating to other countries. Age adjustment was applied, with the highest value of VSLY occurring at two-thirds of life expectancy. A 3 percent discount rate was applied.
Reproductive, Maternal, Newborn, and Child Health	Volume 2, chapter 16	• Additional investments of $5 (2011 US$) per person per year in 74 countries with 95 percent of the global maternal and child mortality burden would yield a B/C of 8.7 by 2035. • B/C in low-, lower-middle-, and upper-middle-income (excluding China) countries are 7.2, 11.3, and 6.1, respectively, at 3 percent discount rate (Stenberg and others 2016).	Values for changes in mortality and morbidity and in consequences of decline in fertility and unintended pregnancies were estimated using human capital methods. No age adjustment was applied. • Mortality averted: The authors assigned an average benefit of 1.0 times the GDP per capita for the direct economic benefits in terms of increased labor supply and productivity and an additional 0.5 times the GDP per capita for the social value of a life year. • Morbidity averted: A morbidity-to-mortality ratio of disability weights (namely, severity) was applied to estimate the social value of morbidity averted. • Positive economic and social consequences of decreases in fertility and reductions in unintended pregnancies: The economic benefit (expressed as percentage of GDP per capita) of this category was calculated by assuming different levels of decline in total fertility rate

			(TFR) and applying the model by Ashraf, Weil, and Wilde (2013) to calculate the effect of TFR reduction on GDP per capita.
Major Infectious Diseases: Malaria	Volume 6, chapter 12	• B/C of malaria elimination programs surveyed by Mills, Lubell and Hanson (2008) range from 2.4 in the Philippines to 4.1 and 9.2 for control in India, 17.1 for elimination in Greece to almost 150 in Sri Lanka. • B/C of global malaria reduction and elimination between 2013 and 2015 is estimated at 6.1 (Purdy and others 2013) • B/C of malaria eradication efforts between 2015 and 2040 is estimated to be 17 (Gates and Chambers 2015). • **Shretta and others 2017**	Various methods are used to value benefits (varies by study): • Elimination of costs required to control malaria • Productivity gains (labor, land, or both) • Modeled macroeconomic growth benefits
Major Infectious Diseases: NTDs	Volume 6, chapter 17	• B/C of interventions to end NTDs is 25 between 1990 and 2030. The benefits include health expenditure and lost wages averted, estimated at around $657 billion (international dollars) between 2011 and 2030. Total cost of the investment is estimated at US$27 billion. A discount rate of 3 percent per annum was applied for both benefits and costs (Fitzpatrick and others2017)	• The benefits of the interventions include only health expenditure and lost wages averted. No value was assigned to the intrinsic value of mortality risk reduction.
Injury Prevention and Environmental Protection: Environment	Volume 7, chapter 9	B/C from Hutton (2013) and Whittington and others (2009): • Networked water and sewerage services: 0.7 • Deep borehole with public hand pump: 4.6 • Total sanitation campaign (South Asia): 3.0 • Household water treatment (biosand filters): 2.5 • Improved water supply: 2.0 • Improved sanitation: 5.5 • Hutton and Chase 2017	• Health estimates based on direct health costs (treatment of water- and sanitation-related disease), productivity losses during illness, and mortality losses were measured using human capital. • Estimates also include reduced travel and access time for water and sanitation owing to improvements.
Injury Prevention and	Volume 7, chapter 13	B/C of installing flue-gas desulfurization units at every coal-fired power plant in India is greater than 1, for all	• Empirical estimates of the VSL in India range widely, from US$50,600 (Bhattacharya, Alberini,

Environmental Protection: Environment		reasonable VSL estimates applied (Cropper and others 2017).	and Cropper 2007) to US$362,000 (Madheswaran 2007) (2007 US$). • Transferring the U.S. VSL to India at current exchange rates, using an income elasticity of 1, suggests a VSL of US$250,000 (2006 US$).
Child and Adolescent Health and Development: Early childhood	Volume 8, chapter 24	B/C for the following interventions: • Videos on early childhood development shown to parents with children age 2 years and younger waiting in health centers, followed by group discussion: 5.3 (Walker and others 2015) • Responsive stimulation and nutrition intervention (sprinkles) for children age 2 years and younger: 1.5 (López Boo, Palloni, and Urzua 2014) • Home visiting program that educates mothers with children age 2 years and younger in child development: 2.6–3.6 (Berlinski and Schady 2015) • Preschool programs for children ages 3 to 5 years: generally exceed 3 (Berlinski and Schady 2015) • Nutritional add-on to preschool: 77 (Psacharopoulos 2014) • Overall, B/C of a well-designed and well-implemented early childhood program is in the range of 2 to 5. • Horton and Black 2017	• Benefits include improved cognition and greater school grade attainment, which translate into higher wages and employment. Same pathway exists for all interventions (except sprinkles, which reduce anemia and then also has same effects). • Psacharopoulos (2015) study does not fully incorporate the cost of all interventions, hence the incredibly high B/C ratio.
Child and Adolescent Health and Development: school-age children	Volume 8, chapter 25	• School feeding programs with micronutrient fortification had estimated B/C of 3 and 7 for low- and lower-middle-income countries, respectively (2012 US$, discount rate 3 percent). The average cost of school feeding is US$56 in low- and lower-middle-income countries (Fernandes and Aurino, 2017**)**	• Benefits are assumed to be gained through improved education outcomes over the lifetime of targeted children and to translate into improved productivity and contributions to GDP. No intrinsic value of health improvements was included.
Child and Adolescent Health and	Volume 8, chapter 26	B/C for adolescent health in high-income countries is as follows:	• Benefits included health care costs averted, human capital gains (via education, reduced

Development: adolescents		• Education sessions with children ages 11–12 years and parents and other interventions for alcohol use in the United States: range of 5 to 100 (McDaid and others 2014) • School-based smoking programs in Germany: 3.6 (McDaid and others 2014) • Programs to promote mental well-being in the United States: range of 5 to 28 (McDaid and others 2014) • Programs for reduced drug dependency, smoking, and delinquency in the United States: 25 (McDaid and others 2014) • Horton and others 2017	mortality), and reduced costs of crime (for alcohol and drug interventions).
Disease Control Priorities: Improving Health and Reducing Poverty: Pandemic flu	Volume 9, chapter 18	• The total cost of a pandemic is presented as a sum of its effect on income and the intrinsic value of lives prematurely lost and illness suffered (Fan, Jamison, and Summers, 2018). • For the first dimension, the authors estimated the expected annual income losses globally of US$16 billion for moderately severe pandemics and US$64 billion for severe pandemics. • For the second dimension, they estimated the expected annual loss for the whole world from the intrinsic cost as 0.6 percent of global income and variation by income group, from 0.3 percent in high-income countries to 1.6 percent in lower-middle-income countries. • In total, the expected annual inclusive cost, reflecting both dimensions above, amounts to about 0.7 percent (US$570 billion per year) of global income, with income losses accounting for a small fraction of inclusive costs (12 percent) for severe pandemics, but a larger fraction (40 percent) for moderately severe pandemics.	• The values of a 1-in-10,000 mortality risk reduction for one year for a 35-year-old person were set at 0.7, 1.0, 1.3, and 1.6 percent of income per capita for low-, lower-middle-, upper-middle-, and high-income countries, respectively. This amount was then adjusted for ages other than age 35 years in proportion to the ratio of life expectancies at those ages to life expectancy at age 35 years.

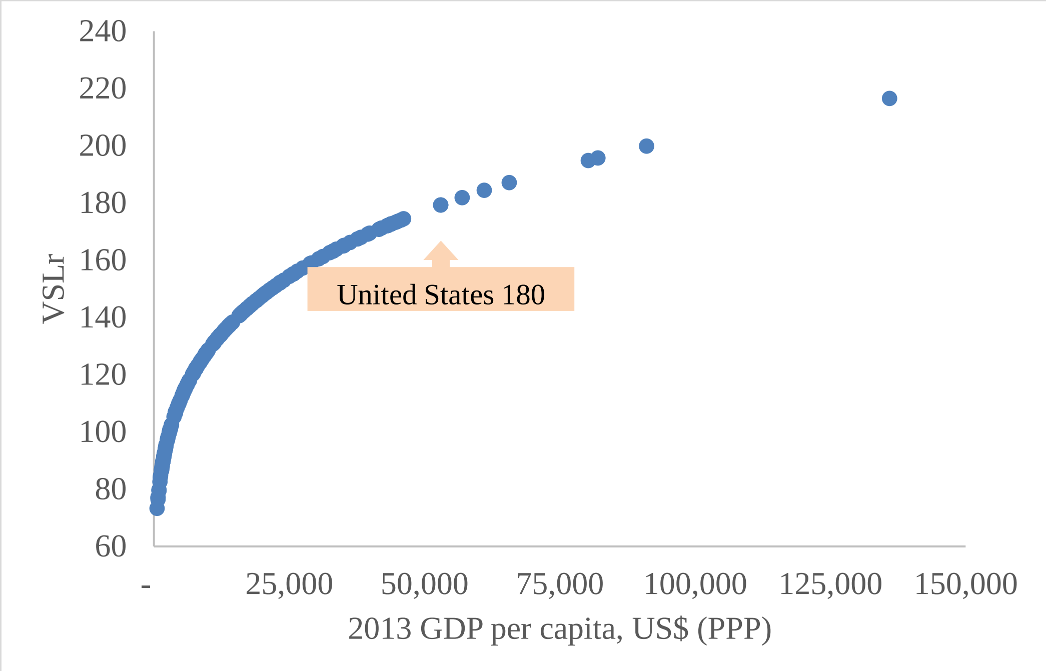
Note: B/C = benefit/cost; GDP = gross domestic product; NTDs = neglected tropical diseases, VSL = value per statistical life; VSLY = value per statistical life year.Table 9.2 Economic Burden of Disease, BCA, and Investment Cases Supported by *DCP3*

Subject	Reference	Summary of key findings	Method of valuing health or changes in mortality
Global Health 2035 grand convergence	Jamison, Summers, and others (2013)	• The recommended set of investments to scale up health technologies and systems in LMICs, compared to a scenario of stagnant investment and no improvements in technology, would yield a B/C of 9 in lower-income countries and 20 in lower-middle-income countries over a 20-year period.	• The value of a 1-in-10,000 mortality risk reduction for one year for a 35-year-old person was set at 1.8 percent of income per capita, assuming an income elasticity of 1.0. This was then adjusted for ages other than age 35 years in proportion to the ratio of life expectancies at those ages to life expectancy at age 35 years, using the historical Japanese life table. • Four different age adjustment scenarios were applied: no adjustment, reducing progress in children under age 4 years by 50 percent, excluding all children under age 10 years from the calculation, and excluding over-70 mortality. Under the second age adjustment scenario, the value of a life year is 2.3 times the per person income.
Infectious disease and maternal health	Jamison, Jha, and others (2013)	Recommended investment solutions and B/Cs are as follows: 1. Tuberculosis: Appropriate case finding and treatment, including dealing with MDR TB—15 2. Malaria: Subsidy for appropriate treatment via Affordable Medicines Facility–malaria—35 3. Childhood diseases: Expanded immunization coverage—20 4. HIV: Accelerated vaccine development—11 5. Essential surgery: Management of difficult childbirth, trauma, and other—10 6. Deworming of schoolchildren: 10	• US$1,000 per DALY was applied to value the health benefits gained; it roughly equals the lower end of the proposed value of a statistical life year of 2 to 4 times per capita income of low-income countries. US$5,000 per DALY was used for sensitivity analysis. • The DALYs were discounted at 3 percent, and the DALY cost of a typical death under age 5 years was reduced by 50 percent. For DALYs accrued near the time of birth, a smoothing formula using the concept of acquisition of life potential was applied to assign greater weights to DALYs resulting from deaths of a fetus.
NCDs	Jha and others (2013)	Key investment priorities and B/Cs are as follows: 1. Tobacco taxation: 40 2. Acute management of heart attacks with low-cost drugs: 25 3. Salt reduction: 20 4. Hepatitis B immunization: 10 5. Secondary prevention of heart attacks and strokes with 3–4 drugs in a *generic risk pill*: 4	• Same method as the Copenhagen Consensus on infectious disease (Jamison and others 2013b) was applied.

Rheumatic heart disease	Watkins and Chang (2017)	Economic burden of RHD found to be approximately US$ 64·8 billion, or an average of US$ 360,000 per preventable death in low- and middle-income countries	• The value of a 1-in-10,000 mortality risk reduction for one year for a 35-year-old person in the U.S. was set at $900. These were adjusted downward for low- and middle-income countries based on average GDP per capita in each region, assuming an income elasticity of 1.0. This was then adjusted for ages other than age 35 years in proportion to the ratio of region-specific life expectancies at those ages to life expectancy at age 35 years. • Sensitivity analyses conducted for income elasticity (0.6 and 1.5), anchoring age (from 35 year olds to ages with remaining life expectancy of 45 years).

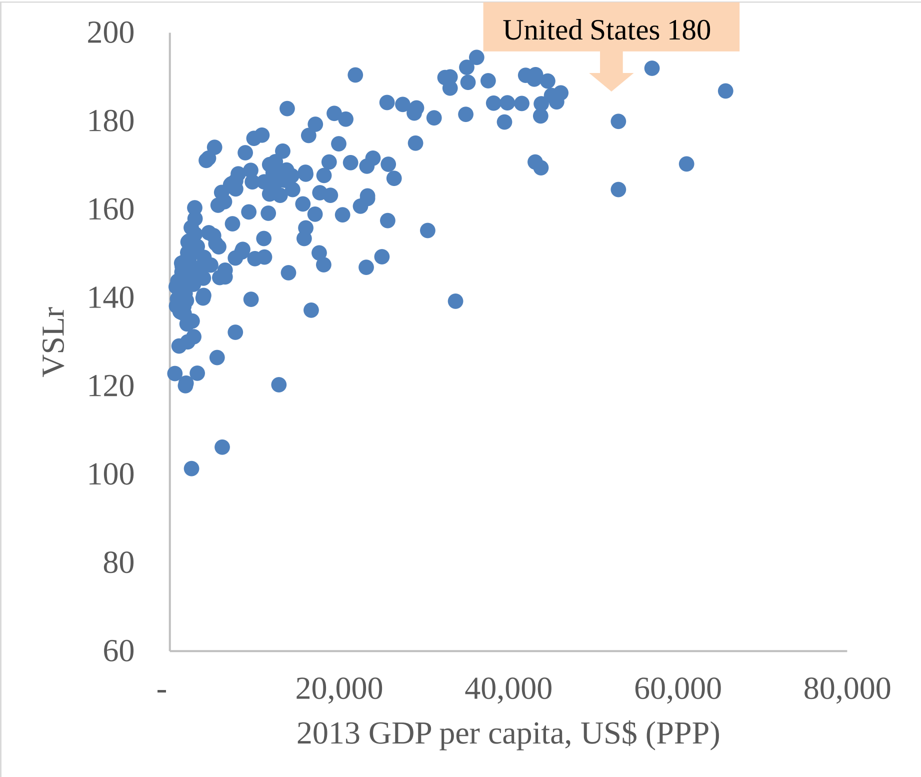
Note: DALY = disability-adjusted life year; HIV = human immunodeficiency disease; MDR = multidrug-resistant; NCDs = noncommunicable diseases; RHD = rheumatic heart disease; TB = tuberculosis.

Figure 9.1 VSLr, with VSL Extrapolated from the U.S. VSL with Income Elasticity of 1.2



Note: GDP = gross domestic product; PPP = purchasing power parity; VSLr = value per statistical life–to–income ratio

Figure 9.2 VSLr Extrapolated with the Ratio of Remaining Life Expectancies at Age 35 Years for Persons in Selected Countries and the United States



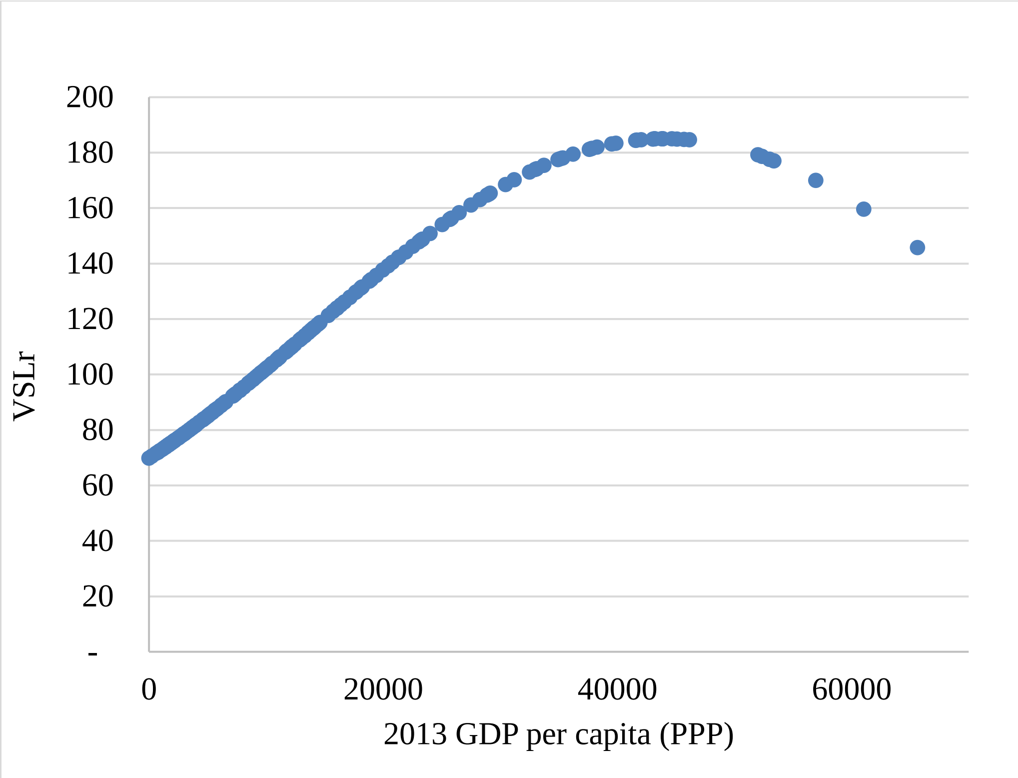
Note: GDP = gross domestic product; PPP = purchasing power parity; VSLr = value per statistical life–to–income ratio

Table 9.3 Estimated VSLr for Four Alternative Approaches, World Bank Income Group

Anchor VSL	Alternative options	HICs	UMICs	LMICs	LICs
US 180	[1] No adjustment	180	180	180	180
US 180	[2] Income adjustment	n.a.	137	115	88
US 180	[3] Age adjustment	80	81	104	117
US 180	[4] Income and age adjustment	n.a.	62	66	57
OECD 100	[1] No adjustment	100	100	100	100
OECD 100	[2] Income adjustment	n.a.	80	67	51
OECD 100	[3] Age adjustment	44	45	58	65
OECD 100	[4] Income and age adjustment	n.a.	31	33	28

Note: HICs = high-income countries; LICs = low-income countries; LMICs = lower-middle-income countries; OECD = Organisation for Economic Co-operation and Development; UMICs = upper-middle-income countries; VSL = value per statistical life; VSLr = VSL-to-income ratio.

Figure 9.3 VSLr Extrapolated with the Sine Function



Note: GDP = gross domestic product; PPP = purchasing power parity;; VSLr = value per statistical life–to–income ratio

Figure 9.4 Implied VSL, Based on the Sine Function Extrapolation of the VSLr