Standardized Sensitivity Analysis in BCA: An Education Case Study

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September 2017 Review Draft

Guidelines for Benefit-Cost Analysis
Working Paper No. 5

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Summary

Benefit-cost analysis of education in low- and middle-income countries have historically used the effect of education on future wages as an estimate of its benefits. In addition to wage increases, strong evidence points to (female) education reducing both under-five and adult mortality rates. A full BCA for education would add the value of mortality reduction to wage increases. In this note, we aim to utilize the multiple plausible approaches to valuing mortality deduction provided by the BCA literature in performing a health-inclusive cost-benefit assessment of education investments.

The Gates-funded BCA reference case aims to recommend a 'standardized sensitivity analysis' or SSA for BCAs of interventions affecting the mortality outcomes. A widely-agreed SSA would serve at least three purposes: It would provide a short menu of plausible options that analysts could choose among for their headline analysis; second, others could see whether results differ if they use their own preferred assumptions enabling wider use of a single analysis and third, comparable results could be accumulated over time. This BCA of education investment proposes and applies the following approaches to SSA.

We propose two alternative ways of valuing different ages of death: (i) all deaths have the same value, or (ii) all life years lost (YLLs) have the same value. Furthermore, we propose three alternatives to valuing a one-year change in mortality probability of 10^{-4}: (i) this value should equal 0.013 times per capita income expressed in 2015 PPP US $ (equivalently VSL to income ratio of 130); (ii) this value should be adjusted for the ratio of the country's PPP GNI per capita to a typical high-income value of $50,000 with an elasticity of 1.2; or (iii) this value should be the same for everyone (this assumption allows comparison of standard health cost-effectiveness with the SSA).

Our SSA is for one additional year of schooling in lower-middle-income countries incremented to their current mean number of years of schooling. Our SSA shows a range of BCA values from 4 to 5.8. However, the range in values for the mortality reduction component is much larger since more than half of the benefits of education come from increased wages. An advantage that BCA has over CEA is that BCA aggregates different outcomes—in this case wages together with mortality reduction. Thus, in our note, CEA component of SSAs results in a dashboard that shows costs, wage benefits, deaths averted and YLLs averted. In a BCA of investments yielding only health outcomes, the CEA variant would show costs per death or YLLs averted.

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[1] This case study was drafted before the related methods papers were completed, so does not necessarily reflect their recommendations. It will be updated to incorporate the final recommendations, after the methods papers are reviewed and revised.

In addition to SSA on age and income adjustments, we also perform sensitivity analysis of BCAs with respect to discount rates. Furthermore, since low- and middle-income countries have large numbers of still births (around 3 million per year), we explore the effect of including the impact of education on reductions in stillbirths in addition to reductions in under-five and adult mortality in a separate analysis.

A Introduction

In 2016 the International Commission on Financing Global Education Opportunity published its report, *The Learning Generation: Investing in Education for a Changing World* (The International Commission on Financing Global Education Opportunity 2016). The Commission, chaired by former UK Prime Minister Gordon Brown, utilized benefit-cost analyses (BCA) to underpin its conclusion that a major acceleration of education is now warranted. Standard BCA methods from the economics of education were used to show a high internal rate of return (IRR) to education investments by weighing costs of schooling (and the opportunity cost of student time) against estimates of education-related wage gain over the individual's working lifetime (Psacharopoulos, Montenegro, and Patrinos 2017). The Commission also pointed to a diverse and substantial literature relating higher levels of education to lower levels of mortality, and to improved health more generally (Filmer and Pritchett 1999; Gakidou et al. 2010; Baird et al. 2012; Kuruvilla et al. 2014; Wang et al. 2014; Jamison, Murphy, and Sandbu 2016). The Commission requested that a team (assembled by SEEK Development in Berlin) extend standard approaches to BCA in education to include explicit valuation of reasonable estimates of the impact of education on mortality and headlined the results of that assessment in the executive summary of the Commission Report. Pradhan et al. (2018) report those finds—and the methods on which they are based—in detail.

A notable shortcoming of the Pradhan et al. (2018) analysis lies in how difficult it is to compare its approach to valuing mortality reduction to other approaches in a now extensive literature. Broad agreement holds (at least among economists) on a conceptual approach to valuing small changes in mortality (the so-called VSL approach) and a substantial empirical literature reports findings from different approaches to measurement (Viscusi and Aldy 2003; Aldy and Viscusi 2007; Krupnick 2007; Hammitt and Robinson 2011; Hammitt 2017; Robinson 2017). That said, huge variation remains on how one might plausibly apply existing results in a broad range of environments, particularly in low-income or high mortality environments. The Pradhan et al. study selected reasonable values of parameters from the literature, but the other analysts could have reasonable chosen different parameters. This indeterminateness limits the utility of most BCAs for two reasons:

    (i) It can be hard to judge how sensitive the study's findings are to methods chose, and, therefore, to judge how believable they are; and

    (ii) Individual BCA results cannot be added up over topics and over time to generate a solid corpus of comparable findings. (This problem applies equally to assessment of the economic burden of diseases or risk factors.)

Analysts from several governmental and international organizations and researchers have proposed varying approaches for improving standardization. Chang, Horton, and Jamison (2018) provide a brief account of some options that have been considered. The Bill and Melinda Gates Foundation then funded development of a BCA reference case (Robinson et al. 2017) to address these problems in a way broadly consistent with a cost-effectiveness reference case they had previously funded (Wilkinson et al. 2016).

One suggested approach to improving credibility and comparability was that of developing a 'standardized sensitivity analysis' (SSA) to be reported routinely within both BCAs and assessments of the economic burden of diseases and risk factors. The analyst might choose a particular choice from the SSA for use in the analysis undertaken. Or, for any of a variety of reasons, the analyst might choose to headline a different approach but to undertake the SSA as well. The SSA would both enable judgement on the robustness of the findings of the analysis and enable comparison of those findings with an accumulating literature. The value of developing a reference case lies importantly in proposing a reference case that claims broad acceptance and that, therefore, can be on accumulation point for comparable analyses.

Our purpose in this case study is to illustrate how SSAs might reasonably be done. The analysis pertains to the costs and benefits of education investments in lower-middle-income countries from a health perspective where we estimate the economic returns to education from reductions in under-five and adult mortality in addition to any increases in earnings. We develop a case study that starts with the Pradhan et al. (2018) findings, but then reanalyze those findings into a 6 cell SSA structured in two dimensions.

The first dimension of the SSA is concerned with how the analysis values mortality reductions at different ages, and we select two prominent alternative approaches. The second dimension is concerned with how the analysis treats variation across country income levels in how the ratio of the value of a unit of mortality reduction to GNI varies with GNI: we suggest that the SSA report on these alternatives—(i) the ratio of VSL to GNI remains constant (at 130); (ii) the ratio of VSL to GNI has an income elasticity of 1.2; (iii) and the value of a unit of mortality reduction is constant with respect to GNI. Having the value of mortality reduction be independent of income results in cost-effectiveness analysis as a special case of BCA thereby enabling the SSA to make comparisons with the (very large) CEA literature.

The case study proceeds as follows. The next section describes the 6-cell (3x2) approach to SSA that we suggest. Following the methods section, section C describes the BCA undertaken for the Brown commission, in particular the one estimating a benefit: cost ratio in lower-middle-income countries for one year of schooling incremental to the current mean. Section D presents results of the SSA, and section E discusses the findings and study limitations.

B   Methods

The development of an SSA requires both the specification of a reference country and of the specific variant approaches to generating key parameters for that country and for other countries in terms of that country's parameters.

B.1 Reference Country

The 'reference country' is an idealized country with:

      i)   PPP GNI per person (y_r) = 50 (in thousands of 2015$).

[Note: PPP GNI per person for US in 2015 was $57.5 and the high-income country average was $46.1. Source: World Development Indicators 2017, (World Bank 2017)]

      ii) Life expectancy at birth (L_r) = 75 years

          Life expectancy at age 35 (L35$_r$) = 45 years

[Note: In World Population Prospects 2017 (United Nations, Department of Economic and Social Affairs, Population Division 2017), the 2015-2020 life expectancy for 'Europe' was 78.1 years. When US life expectancy at birth was 78.3 years, life expectancy at age 35 was 45 years (Jamison et al. 2013).]

B.2 Value of Mortality Reduction

      i)   The value of statistical life, or 'VSL' for the reference country:

$$\text{VSL}_r(y_r, 35) = \text{VSLR}_r \times y_r \tag{1}$$

where VSLR_r = the reference ratio of VSL to per capita PPP GNI at age 35 in the reference country.

[Note: For the SSA, we assume $\text{VSLR}_r = 130$, and hence $\text{VSL}_r(50, 35) = 130 \times \$50,000 = \$6.5\text{M}$.]

      ii) Value of standardized mortality unit (VSMU) for reference country:

$$\text{VSMU}_r (50, 35) = \text{VSL}_r (50,35) \times 10^{-4} = \$650. \tag{2}$$

[A standardized mortality unit (SMU) is a mortality rate of 10^{-4} per year over one year or, about equivalent, an instantaneous mortality probability of 10^{-4}. A typical empirical estimation of the mortality risk / income tradeoff typically estimates values for mortality risks on the order of magnitude of one SMU. Many interventions likewise have effect sizes measured on the order of magnitude of the SMU, making it a convenient metric. Cameron (2010) discussed these and other considerations for nomenclature around valuation of change in mortality risk.]

B.3 How the value of mortality reduction depends on age

i) Valuing an intervention in the reference country

Consider an intervention in the reference country. The effect of that intervention is to change the survival curve in that country $S_r(a)$, by an amount $\delta(a)$ where $\delta(a)$ is measured in SMUs and (by convention) a positive value of δ denotes a reduction in mortality. $S_r(a)$ and $\delta(a)$ are functions of age a.

Example: For 100,000 children under one, measles immunization reduced the country's infant mortality rate from 200 per thousand live births to 199. This is approximately equivalent to:

$$\delta(a) = \begin{cases} 10 \text{ SMUs} & 0 \leq a < 1 \\ 0 & a \geq 1 \end{cases}$$

Benefit using VSMU, with each SMU valued at $650:

$\text{VSMU} = 10 \text{ SMUs} \times \$650 /\text{SMU} \times 10^5 = \$6.5 \times 10^8 /\text{year}.$

Or,

Benefit using VSL, with value of a statistical life at $6.5M:

$\text{VSL} = 1 \text{ death averted} /1000 \text{ children} \times 10^5 \text{children} \times \$6.5 \times 10^6 = \$6.5 \times 10^8 /\text{year}.$

The measles immunization costs $200 per child. Hence,

$\text{cost} = \$200 \times 10^5 = \$2.0 \times 10^7 /\text{year}.$

The benefit-cost ratio (BCR) = 32.

More generally: if $\delta(a)$ SMUs/year is the annual age-specific benefit of the intervention in mortality reduction, and $\eta(a)$ is the age distribution of the population to which the intervention applies, then:

$$V(I) = \text{value of intervention (in \$/year)} = \int_0^\infty \delta(a)\text{VSMU}(50, a)\eta(a)da \qquad (3)$$

Note that change in mortality rates had the units of SMUs, which will typically have the (convenient) values close to small integers.

If C(I) is the cost of the intervention per year then the BCR is V(I)/ C(I).

However, at this point, we have only VSMU (50,35), which is equal to $650. To complete the analysis, we need to generate the function VSMU (50, a). (We are still working with the reference country and its income of $50,000 2015 PPP $ per year.)

ii) Standardized sensitivity analysis with respect to age

The purpose of having *standardized* BCAs is to allow comparability of all studies that have undertaken the same standardization procedure. (Of course, the headline analysis of a study may differ from any of the standardized variants, and typically will need to do so in order to respond to the sponsor's needs.) We take it as given that the standardized sensitivity analysis will have the following two variants with respect to how VSMU depends on a in the reference country with y per capita income of $50,000/ year.

Variant 1 (From the BCA literature):

VSMU (50, a) = constant = $650 (4)

Variant 2 (From CEA literature):

$$\text{VSMU (50, a)} = \frac{L(a)}{L(35)} \left[\text{VSMU}(50,35)\right]$$ (5)

Where L(a) is life expectancy at age a.

(N.B: Both L(35) and L(a) are calculated from the survival curve of the country for which the analysis is done, not the reference country. A variant on this variant, would be to replace the age 35 referent with a reference age for which the remaining life expectancy in the country is 45.)

The value of mortality reduction at age a is the ratio of life expectancy at age a to life expectancy at age 35 times the value of a unit of mortality reduction at age 35.

(Note also that this can be put in VSLY terms: Define a VSLY to be VSL/L35. Then VSMU (50, a) is simply the life expectancy at age a times the VSLY times 10^{-4}.)

In the reference country for a 10-year-old,

VSMU (50,10) is about 1.53 x $650 or $995. For a 75-year-old, the ratio is 0.27, i.e. VSMU (50.75) = 0.27 x $650 = $175

So, for the standardized sensitivity analysis, either variant 1 or variant 2 allows the BCR to be calculated from equation (1). These, then, are the two approaches to dealing with how BCA varies with age in the SSA.

B.4 How the value of mortality depends on income

We propose that three variants of this relationship be used in an SSA. Recall that VSLR is the ratio of VSL to income, and for our reference country, $\text{VSLR}_r = 130$.

Income variant 1 (Constant VSLR, or constant ratio of VSL to income):

VSLR (y, 35) = 130 for all y. $\qquad$ (6)

i.e., VSL (y, 35) = $130 \times$ y.

Likewise, VSMU (y, 35) = $0.013 \times$ y.

Income variant 2 (The income elasticity of VSL is constant (and equal to 1.2)):

From (Hammitt and Robinson 2011), we have:

$$\text{VSL} = \text{VSL}_r \times \left(\frac{\text{GNI per capita}}{\text{GNI per capita}_r}\right)^{\text{elasticity}} .$$

Working out the algebra of this gives

$$\text{VSMU (y, 35)} = \text{VSL}(y_{US}, 35) \times \left(\frac{y}{y_{US}}\right)^{\text{elasticity}} \times 10^{-4}. \qquad (7.1)$$

Or, we have, $\text{VSLR} = \text{VSL}/\,y = \frac{\text{VSL}(y_{US}, 35)}{y} \times \left(\frac{y}{y_{US}}\right)^{\text{elasticity}} .$

$$\text{VSLR} = \text{VSL}(y_{US}, 35) \times \frac{y^{\text{elasticity}-1}}{y_{US}^{\text{elasticity}}} . \qquad (7.2)$$

Hence, for LMICs with GNI per capita PPP at $6,430,

$$\text{VSMU (1.2, 35)} = \$6.5 \times 10^6 \times \frac{6{,}430^{1.2}}{50{,}000^{1.2}} \times 10^{-4} = \$55.$$

Or, $\text{VSLR (1.2, 35)} = 6.5 \times 10^6 \times \frac{6{,}430^{0.2}}{50{,}000^{1.2}} = 86.$

Income variant 3 (All lives or life years of equal value):

VSL (y, a) = 1 for all y. $\qquad$ (8.1)

VSMU (y, a) = 1 for all y. $\qquad$ (8.2)

Note that VSL (y, a) and VSMU (y, a) in equations (8.1) and (8.2) are dimensionless.

B.5 The standardized sensitivity analysis thus contains 6 entries in a 2x3 matrix

[TABLE 1 HERE]

Our case study is for lower-middle-income countries as a group. Their per capita GNI in 2015 was $6430 in PPP (current international $) (WDI 2017). This allows us to fill in the relevant values of column 1 of Table 1 (since values in column 1 are independent of the age distribution of mortality change given a total).

(1.1, 1) = $ 840,000 x Δ lives, where VSL = 130 x $6430

(1.2, 1) = $84 x Δ SMUs, where VSMU = 0.013 x $6430

(2, 1) = $550,000 x Δ lives, where VSL (with income elasticity of 1.2) = 86 x $6430

[For (2,1), please note: y = 6430, VSLR = VSL/ y = 86, VSMU (6430, 35) = $55]

(3,1) = 10,000 x Δ SMUs

There is a particular value in including row 3 in the SSA. Row 3 constitutes, essentially, two main variants of health-related cost-effectiveness analysis.

Variant (3,1) shows the expected number of deaths averted (or deaths averted per year) by the intervention, given the cost (or cost per year) we have CEA in terms of costs per death averted.

Variant (3,2) shows the number of years of life lost (YLLs) that are averted divided by the life expectancy at age 35. The cost per YLL averted, another common cost-effectiveness metric, is then the intervention cost divided by L(a) times entry (3,2) times 10,000.

C   Cost-benefit analysis of additional schooling

Analysis prior to Pradhan et al. (2018) have estimated the returns to education which uses household and labor market survey data, and mainly focuses on the private and 'social' returns of education. Social rate of return incorporates the full cost of schooling whereas private returns estimate assumes that the cost of schooling is borne by the government, and the only cost of schooling to the individual is the opportunity cost of wage forgone by attending school. Both these estimates traditionally only consider the wage benefits of increased schooling.

Pradhan et al. (2018) expands on the benefit-cost analysis by including health gains to increased schooling in addition to the earnings return, and estimates the benefit-cost ratios (BCRs) of investing US$1 in education in low-, lower-middle-, and upper-middle-income countries. This case study presents a proposed set of standard sensitivity analysis on BCRs of an additional year of schooling in lower-middle-income countries. We also used updated data sources for our analysis, as tabulated in Annex A.

The methods for benefit-cost analysis of additional schooling are briefly summarized below:

Pradhan et al. uses a hierarchical linear model to estimate the impact of increased female schooling on under-five mortality, adult male mortality and adult female mortality controlling for technological progress (proxied by time period categories) and income. Further, we allow the impact of time/ technological progress to vary every five years, hence allowing a country-specific impact of technological progress on health.

From these regression results, the study estimates the level of mortality reductions resulting from one more year of female schooling. For example, the average years of schooling in lower-middle income countries is six years. The BCR calculations then assume the benefits and costs of increasing female schooling from six years on average, to seven years per pupil.

The mortality reductions are then valued using base VSLR of 130, and provide upper and lower bounds of the benefit cost ratios varying VSLR from [100, 180], and discount rates from [3%, 5%]. The study combines the expected health value with the earning benefit of increased schooling using smoothed age-earnings profiles received from (Psacharopoulos, Montenegro, and Patrinos 2017).

The direct cost data was provided by International Commission on Financing Global Education Opportunity, which is the cost of teacher time, facilities rent and consumable items such as textbooks, and the opportunity cost was derived from the age-earnings profile. The opportunity cost is the earnings forgone by the additional year of schooling, such that the earnings for the age of entry for additional year of schooling is negative. Direct cost of schooling is only incurred in the additional year; it is zero for ages higher than age at which the additional schooling occurs. Similar to direct costs, the opportunity costs of schooling at ages higher than age of additional year of schooling is also zero.

The health-inclusive internal rate of return ($hPVNR(r_h)$) is the value of annual rate of return (r_h) such that the health-inclusive net present value of an additional year of schooling is zero. As described above, we consider annual direct costs $c_1(a)$ and opportunity costs of schooling $c_2(a)$, and the health benefits $hv(a)$ and earnings benefit $ev(a)$ when estimating the rate of return. Equation (9) gives the net present value of health-inclusive costs and benefits of an additional year of schooling for ages A through 65. Age A is the age of entry for the additional year of schooling at the mean years of schooling (7th grade), which is at 14 years for LMICs.

$$hPVNR(r_h) = \sum_{a=A}^{65} \frac{ev(a) + hv(a) - c_1(a) - c_2(a)}{(1 + r_h)^{a-A}} \tag{9}$$

Hence, the health-inclusive rate of return (r_h) is the value of r_h where the net present value ($hPVNR(r_h)$) equals zero.

Similarly, the benefit-cost ratio is estimated by applying an annual discount rate (r) to all costs and benefits. For annual costs and benefits described above, equation (10) shows the health-inclusive benefit cost ratio (hBCR) of one additional year of schooling.

$$hBCR(r) = \frac{\sum_{a=A}^{65}[e(a)(1+r)^{A-a}+h(a)(1+r)^{A-a}]}{\sum_{a=A}^{65}[c_1(a)(1+r)^{A-a}+c_2(a)(1+r)^{A-a}]} \qquad (10)$$

The details of the estimation process of benefit and cost streams are explained in Annex B, and Annex C describes the age- and income-adjusted benefit streams used for the SSA.

D   Results of BCA for education: standardized sensitivity analysis

Table 2a shows the present dollar value of reduction in mortality due to an additional year of schooling in lower-middle income countries, with varying assumptions of the dependency of value of a standard mortality unit (VSMU) on income elasticity and years of life lost (YLLs), and table 2b shows the benefit-cost ratios and internal rates of return (IRRs) for the same.

[TABLE 2a HERE]

Our results show that adjusting the VSMUs for YLLs yields higher values of mortality reduction benefits, benefit cost ratios and internal rates of return. For every dollar invested in schooling in LMICs would return five dollars in earnings and reductions in under-five and adult mortality when not adjusting the returns for age (and when assuming the ratio of VSL to GNI per capita is constant). However, adjusting the VSLs for years of life lost, the benefit cost ratio is 16% higher, at $5.8 in benefits accrued per dollar spent on schooling. We also find that adjusting VSL for income elasticity yields lower IRRs and BCAs for lower-middle-income countries as the income of the reference country is about 8 times higher than the GNI per capita of LMICs at $6430.

[TABLE 2b HERE]

In figure 1, we graph the undiscounted age-specific health returns of an additional year of schooling for constant VSLR (income variant 1), and compare the benefit streams when VSMU is independent of age to when the value is dependent on YLLs. The age-adjustment yields higher returns to additional year of schooling in early years, and lower in older ages compared to returns not adjusted for age. Note that the age-adjustment of the higher value of reduced under-five death is reflected during women's reproductive period, annually distributed from ages 20-39. The benefit streams are tabulated in Annex E.

[FIGURE 1 HERE]

Figure 2 presents the sensitivity of benefit cost ratios to income elasticity of VSL. This scenario assumes that VSL is independent of age, and the future benefits and costs are discounted at the rate of 3%. Benefit cost ratios and IRRs for LMICs decrease when we assume VSL is income-elastic as the income per capita of the reference country is higher than the income per capita of LMICs. We find that the BCR ranges from [2.3,5] when changing the income elasticity of VSL from 2.0 to 1.0.

[FIGURE 2 HERE]

In adherence with the BCA guidelines, we also report our BCAs for discount rates lower and higher than 3% (Table 3). The lower discount rate of 1% might be of particular import as the time horizon for the analysis is 51 years, from the age of 14 which is the average age of entry for the additional year of schooling in LMICs, to retirement at the age of 65. Comparing the age-unadjusted, income variant 1 scenario across the discount rate of 1% with the standard rate of 3%, we find that the lower discount rate yields a substantially higher benefit-cost ratio at $8.3 in benefits for every dollar spent in schooling in LMICs—this estimate is 66% higher than the BCR estimated at 3%.

[TABLE 3 HERE]

In the discussion around table 1 we pointed to the entries in row 3 as "generating the special case when BCA becomes CEA." CEAs in health cannot, however, aggregate across health outcomes and non-health outcomes (undertaking such aggregation is, of course, one important reason for doing BCAs). When all the outcomes of an intervention are mortality reduction, then all six entries in the SSA reflect only value of mortality reduction—and the entries in row 3 become cost-effectiveness analyses. However, in BCAs like the one reported in this note, the benefits of intervention include increased wages from higher levels of education. A CEA can only separately record this dimension of outcome as well as the mortality reduction benefit. That inherent characteristic of CEA carries over to our SSA in education. All we can do in this case is to provide a dashboard of outcomes from, say, investing in one additional year of education for 100,000 children (Table 4).

[TABLE 4 HERE]

The cost of investing in one additional year of schooling for 100,000 children is estimated at $13 million, and the present value of increased earnings at $25 million. Furthermore, an additional year of schooling for 100,000 children is likely to avert 20 under-five and 27 adult deaths. Hence, the cost of an additional year of schooling in LMICs is valued at $277,000 per death averted, excluding the wage benefits.

E   Conclusions

[To follow]

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Tables and Figures

Table 1: The six outputs of a Standardized Sensitivity Analysis[a]

Variation of value with GNI per capita	Variation of value with age	
	1. None	2. Proportional to remaining life expectancy
1.1 Constant VSL to GNI per capita ratio (=130)	(1.1,1)	(1.1,2)
1.2 Constant VSMU to GNI per capita ratio (=0.013)	(1.2,1)	(1.2,1)
2. Constant elasticity of VSL with respect to income (=1.2)	(2,1)	(2.2)
3. None [VSMU (y, a) constant with respect to y = 10^4]	(3,1)	(3,2)

[a]The outputs are the value of the benefits of intervention as specified in equation (3).

Table 2a: Present dollar value of mortality reduction benefits

Income variants	Age variants	
	1. Value independent of age	2. Value dependent on YLLs
1. VSLR = 130	$3,960	$4,970
2. VSL income elastic [b]	$2,630	$3,300

[a] Intervention is one additional year at the current mean of 7 years. Future benefits discounted at the rate of 3% per year.

[b] Since income is $6430 per year, VSLR is 86 given an income elasticity of 1.2.

Table 2b: BCA for an additional year of education in lower-middle-income countries: A standardized sensitivity analysis [a]

Income variants	Age variants			
	1. Value independent of age		2. Value dependent on YLLs	
	B:C [b]	IRR	B:C [b]	IRR
1. VSLR = 130	5.0	13%	5.8	16%
2. VSL income elastic [c]	4.0	10%	4.5	13%

[a] Intervention is one additional year at the current mean of 7 years.

[b] B:C ratios calculated using a discount rate of 3% per year.

[c] Since income is $6430 per year, VSLR is 86 given an income elasticity of 1.2.

Figure 1: Health benefit stream from one additional year of schooling in LMICs ᵃ
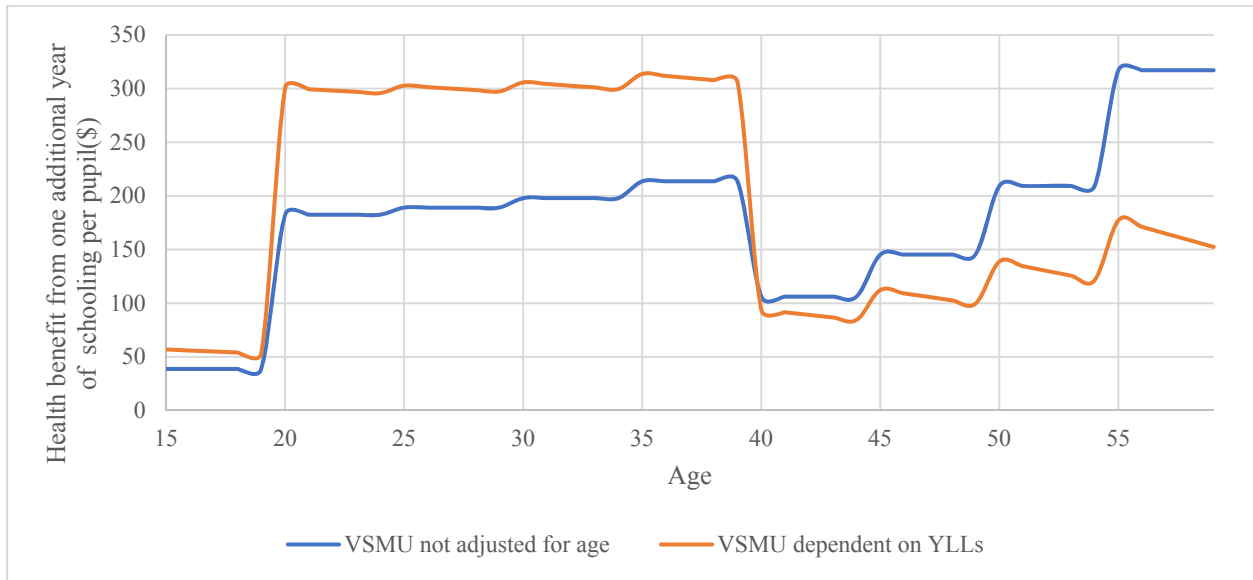
ᵃ Intervention is one additional year at the current mean of 7 years. Benefit streams shown are undiscounted, and are estimated for income variant 1, or when VSLR is constant (and =130).

Figure 2: Relationship between benefit cost ratio of an additional year of schooling and income elasticity of VSL [a]
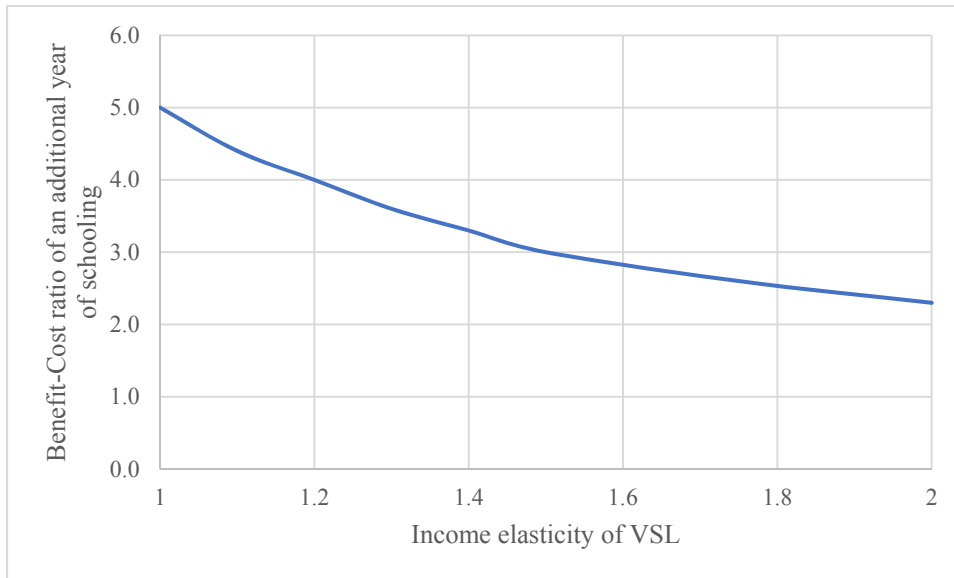
[a] Intervention is one additional year at the current mean of 7 years. Benefit-cost ratios are estimated for age variant 1, or the case in which VSMU/VSL does not depend on age.

Table 3: Benefit-cost ratios for an additional year of schooling: Sensitivity analysis on discounting rates [a]

Income variants	Age variants			
	1. Value independent of age		2. Value dependent on YLLs	
	r = 1% [b]	r = 5%	r = 1%	r = 5%
1. VSLR = 130	8.3	3.3	9.0	4.0
2. VSL income elastic [c]	6.7	2.6	7.1	3.0

[a] Intervention is one additional year at the current mean of 7 years.

[b] r = annual discount rate

[c] Since income is $6430 per year, VSLR is 86 given an income elasticity of 1.2.

Table 4: Outcomes associated with one year of education for 100,000 children in LMICs [a]

Outcome	Cost	Value of increased wages	Effect on under-five mortality	Effect on adult mortality
Deaths averted	$13 million	$ 25 million	20	27

[a] Intervention is one additional year at the current mean of 7 years. Future wages and deaths averted discounted at 3%. We will also estimate YLLs averted in the next iteration of the work.

Annex A

Table A.1 Data sources used in the note

Variable	Description	Data sources (see reference list)
Educational attainment (mean years of schooling)	Mean years of total schooling among the population aged 25+. Both overall- and sex-specific estimates were used.	Barro and Lee data set, version 2.0
Under-five mortality (5q0)	Probability of dying between birth and exact age 5. Expressed as deaths per 1000 live births.	UN World Population Prospects, 2017 revision
Adult mortality (45q15)	Expressed as deaths under age 60 per 1000 alive at age 15 calculated at current age-specific mortality rates. Both overall and sex-specific estimates were used.	UN World Population Prospects, 2017 revision
Fertility	Total fertility rate (children per woman).	UN World Population Prospects, 2017 revision
Remaining life expectancy at age (a) (L(a))	Average number of years lived subsequent to age (a) by those reaching age (a)	UN World Population Prospects, 2017 revision
GNI per capita	GNI per capita, PPP (current international $)	World Development Indicators, 2017
Age-earnings profile	Age-specific wage return of each level of schooling	(Psacharopoulos, Montenegro, and Patrinos 2017)
Direct cost of schooling	Direct cost of schooling of one pupil per year	(The International Commission on Financing Global Education Opportunity 2016)

Annex B Estimating the impact of an additional year of schooling on changes in standard mortality unit

B.1 Results from the hierarchical model

Pradhan et al. (2018) finds that adjusting for income, technological progress and allowing for the impact of technological progress to vary by each country, one year of increase in average female schooling is associated with 2.2 percent reduction in adult male mortality, 3.7 percent reduction in adult female mortality, and 4.2 percent reduction in under-five mortality.

Table B.1 Impact of female schooling on health outcomes: Results from the hierarchical model

	Dependent Variables		
	Ln [Adult mortality rate], male	Ln [Adult mortality rate], female	Ln [Under-five mortality rate]
Independent Variables			
Mean years of schooling (female)	-0.022 **	-0.037 ***	-0.042 ***
Schooling ratio (male: female)	0.019 *	0.010	-0.009
Ln [GDP per capita]	-0.034 *	-0.079 ***	-0.127 ***

Note: GDP = gross domestic product. Ln[x] denotes natural log of variable x. Period: 1970–2010. Countries: 80. Observations: 688. Standard errors and goodness of fit measures reported in Pradhan et al. (2017), annex 30D. *p < .10; **p < .05; ***p < .01.

B.2 Estimating changes in SMUs from an additional year of schooling (ΔSMU)

(i) Reductions in under-five mortality

The reductions in under-five mortality ($\Delta SMU_{U5}(a)$) are accounted in the benefit stream over a woman's reproductive age, assuming equal benefit at each age [20,39] given the expected number of children over those years.

ΔSMU from reduction in under $-$ five mortality for women at age (a)$= \Delta SMU_{U5}(a)$

$\Delta SMU_{U5}(a) = $ Expected number of children at age (a) $\times$ $\delta(a)_{U5MR}$.

Where, $\delta(a)_{U5MR} = \Delta SMU$ per child $= \frac{gr \times U5MR \times \beta_{U5MR}}{1000} \times 10^4$,

Expected number of children at age (a) $= \begin{cases} TFR/(40-20) & 20 \leq a < 40 \\ 0 & a \geq 40 \end{cases}$

gr $=$ Ratio of girls to boys attending one more year of school

TFR $=$ Total fertility rate at base year

U5MR $=$ Under $-$ five mortality rate at base year

$\beta_{U5MR} =$ Proportion reduction in U5MR because of one additional year of female schooling

(ii) Reductions in adult male and female mortality

ΔSMU from reduction in adult male mortality at age (a) = $\Delta SMU_m(a)$, and

ΔSMU from reduction in adult female mortality at age (a) = $\Delta SMU_f(a)$, and

$$\Delta SMU_m(a) = \frac{gr \times\ _5q_{a,m} \times \tau_m}{5 \times 1000} \times 10^4, \text{ and}$$

$$\Delta SMU_f(a) = \frac{gr \times\ _5q_{a,f} \times \tau_f}{5 \times 1000} \times 10^4$$

where, τ_m = Proportion reduction in male age −
specific mortality rate because of one additional year of female schooling

τ_f = Proportion reduction in female age −
specific mortality rate because of one additional year of female schooling

$_5q_{a,m}$ = Male age − specific adult mortlality between age (a, a + 5)

$_5q_{a,f}$ = Female age − specific adult mortlality between age (a, a + 5)

We derive $\tau_m\ and\ \tau_f$ by minimizing the following equation (for male and female adult mortality separately):

$$\left[1 - (1 - \beta_m) \cdot\ _{45}q_{15} \right] - \left[\prod_{i=15}^{55} \left(1 - (1 - \tau) \times\ _5q_a \right) \right] = 0$$

Where we have,

$_{45}q_{15}$ = probability of a 15 − year

− old surviving up to age 60 conditional on survival until age 15

Or,

$$_{45}q_{15} = 1 - \prod_{a=15}^{55} \left(1 -\ _5q_a \right)$$

$$\left[1 - \left((1 - \beta_m) \times \left(1 - \prod_{a=15}^{55} \left(1 -\ _5q_a \right) \right) \right) \right] - \left[\prod_{a=15}^{55} \left(1 - (1 - \tau) \times\ _5q_a \right) \right] = 0$$

Here,

β_x = Proportion reduction in $_5q_{a,x}$ because of one additional year of female schooling

$_5q_a$ = adult sex and age − specific adult mortality between age (a, a + 5)

Annex C Estimating the costs and benefits of an additional year of schooling for SSA

This section describes our method for estimating costs and benefits of additional year of schooling given the reductions in standard mortality units described in Annex B. We first consider the health benefits, followed by the earnings benefits, then the direct and opportunity costs of schooling. The health-inclusive rate of return and benefit cost ratio consider all these benefit and cost streams.

C.1 Benefit stream

The health benefit stream at age (a) of an additional year of schooling (hv(a)) simply accounts for the standard mortality units reduced at each age with the value of the standard mortality unit at each age.

$$hv(a) = \Delta SMU_{U5}(a) \times VSMU^*(y, a) + \Delta SMU_m(a) \times VSMU(y, a) + \Delta SMU_f(a) \times VSMU(y, a)$$

where, $\Delta SMU_{U5}(a) = \Delta SMU$ from reduction in under five mortality for women at age (a),

$\Delta SMU_m(a) = \Delta SMU$ from reduction in adult male mortality at age (a),

$\Delta SMU_f(a) = \Delta SMU$ from reduction in adult female mortality at age (a),

$$VSMU^*(y, a) = \begin{cases} 0.013 \times y_{LMICs} & \text{constant VSMU to } y, \text{VSMU age} - \text{independent} \\ 55^a & \text{Income elasticity of VSL} = 1.2, \text{VSMU age} - \text{independent} \\ (L(2)/L(35)) \times 0.013 \times y_{LMICs} & \text{constant VSMU to } y, \text{VSMU dependent on YLLs} \\ (L(2)/L(35)) \times 0.013 \times 55^a & \text{Income elasticity of VSL} = 1.2, \text{VSMU dependent on YLLs} \end{cases},$$

$$VSMU(y, a) = \begin{cases} 0.013 \times y_{LMICs} & \text{constant VSMU to } y, \text{VSMU age} - \text{independent} \\ 55^a & \text{Income elasticity of VSL} = 1.2, \text{VSMU age} - \text{independent} \\ (L(a)/L(35)) \times 0.013 \times y_{LMICs} & \text{constant VSMU to } y, \text{VSMU dependent on YLLs} \\ (L(a)/L(35)) \times 0.013 \times 55^a & \text{Income elasticity of VSL} = 1.2, \text{VSMU dependent on YLLs} \end{cases},$$

$y_{LMICs} = $ GNI per capita of LMICs, PPP $,

$L(a) = $ Remaining life expectancy at age (a) in LMICs,

[a] from equation (4).

The **total benefit stream** at age (a) then sums the health benefit (hv(a)) above, and earnings benefit (ev(a)) of an additional year of schooling per pupil.

$$ev(a) = \frac{ws(a) - wp(a)}{\# \text{ of years of secondary schooling}}$$

where, $ws(a) = $ Earnings of a secondary school graduate at age (a), and

$wp(a) = $ Earnings of a primary school graduate at age (a).

C.2 Cost stream

We consider the direct cost of schooling (c_1) and opportunity cost of schooling (c_2) of an additional year in our analysis. Both the direct cost and opportunity cost are incorporated for the additional year a pupil enrolls in school. The total cost then is the direct and the opportunity cost combined. We have:

$$c_1(a) = \begin{matrix} c_1 & a = A \\ 0 & a \neq A \end{matrix}, \text{ and } \quad c_2(a) = \begin{matrix} c_2 & a = A \\ 0 & a \neq A \end{matrix}.$$

where,

if a_p = Theoretical age of start of primary schooling ($= 6$), and

s = Mean years of schooling at base year($= 7$),
A = Age of attending one additional year of school $= s + a_p + 1 = 14$ (for LMICs)

Annex D Estimating reduction in standard mortality unit at each age

In this section, we tabulate the changes in standard mortality unit at each age, estimated from equations in Annex B (Table D.1). As seen in table D.1, the under-five mortality reductions are only realized between ages 20-39, and adult male and female mortality reductions between 15 to 59.

Since the value of standard mortality unit is estimated separately for under five mortality reductions versus adult mortality reductions in the case when we assume VSL/ VSMU is dependent on YLLs, table D.2 tabulates the age-adjusted SMUs for under-five and adult mortality reductions. Table D.1 shows the age-unadjusted SMUs. The age-adjusted under-five ΔSMUs are higher than age-unadjusted ΔSMUs and the adult ΔSMUs are higher for ages less than 35 and lower for ages higher than 35 compared to age-unadjusted adult ΔSMUs.

Table D.1: Impact of an additional year of female schooling on changes in standard mortality units (SMUs) at each age(a) [a]

Age (a)	Expected # of children at age (a)	$\delta(a)_{U5MR}$ (SMUs/child)	ΔSMU_{U5}	ΔSMU_f	ΔSMU_m	ΔSMU_{mf}	ΔSMU_{tot}
14	0	0	0	0	0	0	0
15	0	0	0	0.27	0.19	0.46	0.46
16	0	0	0	0.27	0.19	0.46	0.46
17	0	0	0	0.27	0.19	0.46	0.46
18	0	0	0	0.27	0.19	0.46	0.46
19	0	0	0	0.27	0.19	0.46	0.46
20	0.14	11.05	1.56	0.36	0.26	0.62	2.18
21	0.14	11.05	1.56	0.36	0.26	0.62	2.18
22	0.14	11.05	1.56	0.36	0.26	0.62	2.18
23	0.14	11.05	1.56	0.36	0.26	0.62	2.18
24	0.14	11.05	1.56	0.36	0.26	0.62	2.18
25	0.14	11.05	1.56	0.39	0.31	0.70	2.26
26	0.14	11.05	1.56	0.39	0.31	0.70	2.26
27	0.14	11.05	1.56	0.39	0.31	0.70	2.26
28	0.14	11.05	1.56	0.39	0.31	0.70	2.26
29	0.14	11.05	1.56	0.39	0.31	0.70	2.26
30	0.14	11.05	1.56	0.43	0.38	0.80	2.37
31	0.14	11.05	1.56	0.43	0.38	0.80	2.37
32	0.14	11.05	1.56	0.43	0.38	0.80	2.37
33	0.14	11.05	1.56	0.43	0.38	0.80	2.37
34	0.14	11.05	1.56	0.43	0.38	0.80	2.37
35	0.14	11.05	1.56	0.51	0.48	0.99	2.56
36	0.14	11.05	1.56	0.51	0.48	0.99	2.56
37	0.14	11.05	1.56	0.51	0.48	0.99	2.56
38	0.14	11.05	1.56	0.51	0.48	0.99	2.56
39	0.14	11.05	1.56	0.51	0.48	0.99	2.56
40	0	0	0	0.64	0.63	1.27	1.27
41	0	0	0	0.64	0.63	1.27	1.27
42	0	0	0	0.64	0.63	1.27	1.27
43	0	0	0	0.64	0.63	1.27	1.27
44	0	0	0	0.64	0.63	1.27	1.27
45	0	0	0	0.87	0.87	1.74	1.74
46	0	0	0	0.87	0.87	1.74	1.74
47	0	0	0	0.87	0.87	1.74	1.74
48	0	0	0	0.87	0.87	1.74	1.74
49	0	0	0	0.87	0.87	1.74	1.74
50	0	0	0	1.25	1.25	2.50	2.50
51	0	0	0	1.25	1.25	2.50	2.50
52	0	0	0	1.25	1.25	2.50	2.50
53	0	0	0	1.25	1.25	2.50	2.50
54	0	0	0	1.25	1.25	2.50	2.50
55	0	0	0	1.95	1.84	3.79	3.79
56	0	0	0	1.95	1.84	3.79	3.79
57	0	0	0	1.95	1.84	3.79	3.79
58	0	0	0	1.95	1.84	3.79	3.79
59	0	0	0	1.95	1.84	3.79	3.79

[a] Equations in Annex B and C.

Table D.2: Age-adjusted SMUs [a]

Age	Age − adjusted ΔSMU_{U5}	Age − adjusted ΔSMU_{mf}	Age − adjusted ΔSMU_{tot}
14	0	0	0.00
15	0	0.68	0.68
16	0	0.67	0.67
17	0	0.66	0.66
18	0	0.65	0.65
19	0	0.64	0.64
20	2.76	0.84	3.60
21	2.76	0.82	3.58
22	2.76	0.81	3.57
23	2.76	0.79	3.55
24	2.76	0.78	3.54
25	2.76	0.86	3.62
26	2.76	0.84	3.61
27	2.76	0.83	3.59
28	2.76	0.81	3.57
29	2.76	0.80	3.56
30	2.76	0.90	3.66
31	2.76	0.88	3.64
32	2.76	0.86	3.62
33	2.76	0.84	3.60
34	2.76	0.82	3.58
35	**2.76**	**0.99**	**3.75**
36	2.76	0.97	3.73
37	2.76	0.95	3.71
38	2.76	0.92	3.68
39	2.76	0.90	3.66
40	0	1.12	1.12
41	0	1.10	1.10
42	0	1.07	1.07
43	0	1.04	1.04
44	0	1.01	1.01
45	0	1.34	1.34
46	0	1.31	1.31
47	0	1.27	1.27
48	0	1.23	1.23
49	0	1.19	1.19
50	0	1.66	1.66
51	0	1.61	1.61
52	0	1.56	1.56
53	0	1.50	1.50
54	0	1.45	1.45
55	0	2.12	2.12
56	0	2.05	2.05
57	0	1.97	1.97
58	0	1.90	1.90
59	0	1.82	1.82

[a] L(2) = 67.8 years; L(35) = 38.4 years. Equations in Annex B and C.

Annex E Comparing health benefits at each age across SSA for age and income

This section tabulates the undiscounted health benefits at each age across the standard sensitivity analyses of VSMU/ VSL for age and income (table E.1). As discussed in section D, the benefit streams when assuming VSL is income elastic is lower than when we assume constant VSMU/ VSL to income per capita ratio, and the age-adjustment yields higher benefits to additional year of schooling in early years, and lower in older ages compared to returns not adjusted for age.

Table E.1: Health benefits at each age across SSA for age and income ($)

Variation of value with age	None			Proportional to remaining life expectancy		
Variation of value with GNI per capita	Constant VSMU to income per capita ratio (=0.013)	Constant elasticity of VSL with respect to income (=1.2)	None [VSMU (y, a) constant with respect to y = 10^4]	Constant VSMU to income per capita ratio (=0.013)	Constant elasticity of VSL with respect to income (=1.2)	None [VSMU (y, a) constant with respect to y = 10^4]
Age						
15	39	26	4628	57	38	6804
16	39	26	4628	56	37	6693
17	39	26	4628	55	37	6582
18	39	26	4628	54	36	6471
19	39	26	4628	53	35	6360
20	182	121	21832	301	199	35969
21	182	121	21832	299	199	35824
22	182	121	21832	298	198	35678
23	182	121	21832	297	197	35533
24	182	121	21832	296	196	35388
25	189	125	22625	303	201	36221
26	189	125	22625	301	200	36058
27	189	125	22625	300	199	35894
28	189	125	22625	299	198	35731
29	189	125	22625	297	197	35568
30	198	131	23685	306	203	36588
31	198	131	23685	304	202	36401
32	198	131	23685	303	201	36214
33	198	131	23685	301	200	36027
34	198	131	23685	300	199	35840
35	214	142	25556	314	208	37525
36	214	142	25556	312	207	37297
37	214	142	25556	310	206	37070
38	214	142	25556	308	204	36842
39	214	142	25556	306	203	36615
40	106	70	12693	94	62	11237
41	106	70	12693	92	61	10951
42	106	70	12693	89	59	10665
43	106	70	12693	87	58	10379
44	106	70	12693	84	56	10093
45	145	96	17386	112	74	13433
46	145	96	17386	109	72	13053
47	145	96	17386	106	70	12673
48	145	96	17386	103	68	12293
49	145	96	17386	100	66	11913
50	209	139	25036	139	92	16608
51	209	139	25036	134	89	16085
52	209	139	25036	130	86	15562
53	209	139	25036	126	83	15039
54	209	139	25036	121	81	14516
55	317	210	37941	177	118	21205
56	317	210	37941	171	113	20465
57	317	210	37941	165	109	19724
58	317	210	37941	159	105	18983
59	317	210	37941	152	101	18242

[a] undiscounted. Equations in Annex B and C.

Annex F Considering the impact of schooling on reduction in stillbirths

In this section, we undertake a separate, illustrative sensitivity analysis of how inclusion of stillbirths could affect benefit-cost analysis of education investments (Table F.1). We find that the benefit-cost ratio of education investments increases by 8%, and the present dollar value of mortality reduction by 13% if we consider the impact of education on reduction in still-births in addition to under-five and adult mortality.

Table F.1: Benefit-cost analysis incorporating reductions in stillbirths [a]

Outcome	Value of still birth averted		
	None	20% of value of under-five averted	Same as value of under-five death averted
Present dollar value of mortality reductions	$3,960	$4,060	$4,460
Benefit-cost ratio	5.0	5.1	5.4

[a] Future costs and benefits discounted at 7% a year. Intervention is one additional year at the current mean of 7 years. Number of stillbirths assumed at 30% of the number of under-five births. Analysis performed assuming constant VSMU to income per capita ratio, and independence of VSMU with respect to age.