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During The 'Decade Of Vaccines,' The Lives Of 6.4 Million Children Valued At $231 Billion Could Be Saved

ABSTRACT Governments constantly face the challenge of determining how much they should spend to prevent premature deaths and suffering in their populations. In this article we explore the benefits of expanding the delivery of life-saving vaccines in seventy-two low- and middle-income countries, which we estimate would prevent the deaths of 6.4 million children between 2011 and 2020. We present the economic benefits of vaccines by using a "value of statistical life" approach, which is based on individuals' perceptions regarding the trade-off between income and increased risk of mortality. Our analysis shows that the vaccine expansion described above corresponds to $231 billion (uncertainty range: $116–$614 billion) in the value of statistical lives saved. This analysis complements results from analyses based on other techniques and is the first of its kind for immunizations in the world's poorest countries. It highlights the major economic benefits made possible by improving vaccine coverage.

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Policy makers are interested not only in the number of lives saved and illnesses averted associated with a particular health intervention, but also in the economic benefits of that investment. The reason is simple: Policy makers typically have to consider a range of benefits for different interventions when making decisions about which interventions to pursue. They often have to justify their choices on economic grounds, precisely because there are many needs competing for a limited pool of resources.

Our other article in this issue of *Health Affairs* estimates that $151 billion in treatment costs and productivity losses could be averted by expanding the delivery of six life-saving vaccines in seventy-two low- and middle-income countries between 2011 and 2020.[1] This ten-year time frame was labeled the "Decade of Vaccines" by the Bill & Melinda Gates Foundation when they committed to spending $10 billion to help discover, develop, and deliver vaccines to people in the world's poorest countries. This approach of looking at treatment costs and productivity losses is a conventional means of understanding the return on investment in terms of actual dollars saved. This is a very concrete way to look at economic returns, but it's not the only way one can estimate the value of a health intervention that saves lives.

One might, instead, consider developing an estimate of the "value" of reducing threats to human life, independent of an analysis of costs averted through reduced mortality and morbidity, and thereby calculate the value of an intervention that is estimated to save a particular number of lives. In this article we do exactly that: We estimate the benefit of the same vaccine expansion described above considered in terms of the "value" of the lives saved.

Such estimates are different from those obtained by calculating treatment and productivity

costs, because they also capture the value that people place on their own lives. They are no less real, and should not be discounted, because they are derived from individual judgments of trade-offs between financial rewards and increased mortality risk. We present such estimates here, but we first describe more fully the concept of the "value of statistical life."

Value Of Statistical Life

Individuals make trade-offs every day between health and risks of death, such as driving a vehicle, smoking a cigarette, and eating unhealthy food.[2] The value of statistical life is based on the idea that people make trade-offs between risks of death and income.[3] It is generated from the estimated amount of income a typical individual is willing to trade off to reduce the risk of death.[4]

Values are derived from both wage risk studies, which use labor-market data, and stated population preference studies, which ask individuals how much they are willing to pay to avoid certain risks of death.[5–7] The reductions in risks are multiplied across a large population. For example, if each member of a population of 10,000 is willing to pay $670 on average for a one in 10,000 decrease in his or her risk of dying, the value of statistical life is calculated as $6,700,000 ($670 \times 10,000$).

Estimating the value of statistical life helps policy makers determine how much they should spend on programs that prevent deaths in their populations. The results are used widely in economics and regulatory assessments to represent the worth of population-level interventions that reduce the number of expected deaths by one.

An intervention is undertaken if it costs less to prevent one death than the country's specific per capita value of statistical life. For example, if a health program in the United States costs less than the US value of $6.7 million to save a child's life, then it may be considered a worthy investment.

Such estimates are frequently applied in high-income countries to assess investments in preventing road traffic accidents or drowning, or in ensuring clean air and safe drinking water.[9,10] Specifically, the United States has presidential executive orders encouraging the use of value of statistical life in policy evaluation and cost-benefit analyses by the Department of Transportation and the Environmental Protection Agency.[11–14] The value-of-statistical-life concept is similarly used in the context of policy analysis of Canadian programs[15] and is implicitly applied in European countries.[16–18]

In the United States, there has been a reluctance to quantify life savings in money in the health sector. However, value-of-statistical-life methods are starting to be applied in other countries to measure the benefits of health interventions. Some examples of interventions whose value has been estimated this way include a cancer risk prevention program in China,[19] tuberculosis control strategies in sub-Saharan Africa,[8] and voluntary counseling and testing for HIV/AIDS in Tanzania.[20]

Governments and people are already making trade-offs between health and money, either explicitly or implicitly.[21] Informed policy making requires a methodology that allows these trade-offs to be captured and quantified in health policy analyses.

Vaccines are considered among the most cost-effective public health interventions.[22–24] The economic argument for purchasing vaccines is compelling when one considers the costs of vaccination against the immediate benefits of illness averted and treatment costs saved. Although these short-term health benefits are well known, there are many other benefits—especially long-term economic ones—that have been given inadequate consideration. Very few articles to date have measured value-of-statistical life savings from vaccines.[25,26]

This article presents the economic benefits of saving lives from improving coverage of pneumococcal, rotavirus, pertussis, measles, *Haemophilus influenzae* type b (Hib), and malaria vaccines in seventy-two of the world's poorest countries between 2011 and 2020. Our analysis goes beyond the economic benefits brought about by treatment cost savings and productivity losses averted by capturing how people value their lives and would pay to delay pain and suffering from death.

Study Data And Methods

DEATHS AVERTED In this study we used the Lives Saved Tool to estimate the number of deaths averted from vaccines.[27] The Lives Saved Tool is a freely available child survival modeling tool (http://www.futuresinstitute.org).[28,29]

The model estimates the impact of specific public health interventions on cause-specific neonatal, under-five, and maternal mortality. It uses the most current country-specific estimates of demography, mortality rates,[30] causes of death,[31] health status, rates at which interventions are provided, and peer-reviewed effects of interventions.[32] The model accounts for competing risks among interventions.

Our analysis examined the impact of improved childhood vaccination coverage (pneumococcal, rotavirus, pertussis, measles, Hib, and malaria) in the seventy-two countries eligible to receive

Vaccines are considered among the most cost-effective public health interventions.

support from the GAVI Alliance (formerly known as the Global Alliance for Vaccines and Immunization), a global health partnership committed to ensuring access to low-cost immunizations in developing countries.[33] Vaccination coverage estimates for 2009 were obtained from the World Health Organization (WHO).[34]

Based on vaccination targets set by the WHO Global Immunization Vision and Strategy, we increased the rate of immunization linearly to 90 percent by 2015 and held the rate constant between 2015 and 2020.[35] In addition, we assumed that a malaria vaccine with an effectiveness of 45 percent[36] would be introduced in 2015 in malaria-affected countries, with rates of vaccination increasing linearly to 90 percent by 2020 (see details in the online Appendix).[37]

BENCHMARK VALUE OF STATISTICAL LIFE Following the standard rules used by the US Congressional Budget Office[38] and the most recent literature in the field, we adopted a benchmark value of statistical life for the United States of $6.7 million per life saved, in 2009 dollars. This estimate is based on studies of compensating wage differentials among jobs with varying risks of death and interview-based approaches from sixty articles in ten high-income countries,[6,39] adjusted for inflation and real income growth.[4] This figure lies between the value used by the US Department of Transportation ($6.2 million in 2009 dollars)[14] and the estimate adopted by the US Environmental Protection Agency ($8.1 million in 2009 dollars).[40]

BENEFITS TRANSFER To date, there are very few studies from low-income countries on people's willingness to pay for mortality risk reductions. To the extent that they exist, results from low-income country studies provide evidence on an income elasticity of the value of statistical life that accounts for differences in per capita income, development levels, and aversion to risk between the US and each low-income country.[4,8,19,20,25]

The method, known as benefits transfer, uses the income elasticity of the value of life—that is, the sensitivity of mortality-risk aversion to changes in income—to estimate the value of statistical life in low-income countries as some proportion of the United States value of statistical life.

Specifically, to determine the value of statistical life for each low-income country, we first calculated an "adjustment factor" by taking the ratio of that country's income to US income, then raised that ratio to a power of 1.5, which represents the income elasticity of the value of statistical life between the United States and low-income countries. The US value of statistical life was then multiplied by this adjustment factor to provide the low-income country's value of statistical life (the equation is provided in standard mathematical shorthand in the online Appendix).[37]

An income elasticity of 1 assumes that people are willing to pay the same proportion of their income to reduce mortality risk regardless of income level. However, elasticities are often found to be greater than 1 in countries facing earlier stages of economic development. Specifically, studies in low-income countries suggest that people with lower incomes are willing to take on greater occupational mortality risk than those with greater incomes.[4,41]

Therefore, this study used a baseline income elasticity of 1.5 with an uncertainty range between 1 and 2. The higher the income elasticity, the more the value of statistical life in a low-income country is reduced relative to the value of statistical life in the United States.

Value-of-statistical-life adjustments were made using per capita projected gross domestic product figures for the United States and each low-income country. Per capita gross domestic product projections for 2010–15 were adopted from the International Monetary Fund[42] and trended forward for the years 2016–20 based on the past five years. To calculate the overall value-of-statistical-life values, the number of lives saved as a result of scaling up vaccines was multiplied by the value of statistical life for each country.

The sums of these values across seventy-two countries represent the total value-of-statistical-life figures. This can be interpreted as the aggregate amount that families with children at risk of death are willing to pay to lower their risk by improving childhood immunization coverage.

UNCERTAINTY RANGE We conducted sensitivity analyses to show the uncertainty ranges around each value-of-statistical-life estimate in the model. We carried out computer simulations using the Monte Carlo method, varying three key variables: (1) the benchmark value-of-statistical-life value (which varied from $6.2 million to

$8.1 million), (2) the income elasticity (which varied from 1 to 2), and (3) the mortality estimates from the Lives Saved Tool (which varied from 30 percent to 297 percent of the baseline; see details in the online Appendix).[37] A probability distribution was applied to each variable where 10,000 iterations of the model were run using @RISK software (version 5.7).

LIMITATIONS There are important limitations to note with the approach. First, the value-of-statistical-life methodology was developed to measure trade-offs in working-age adults. For this analysis, value-of-statistical-life values had to be applied to vaccines that target children under age five. Although the trade-offs parents make between money and risk of death on behalf of their children may be distinct from those made in the adult wage market, there is no conclusive evidence that the value would be higher or lower for children.[43]

Second, empirical data on the value of statistical life are limited in low-income countries. In addition, differences in the extent of the availability and cost of health services may influence wage-risk trade-offs in these countries. The benefits-transfer method tries to adjust for cross-country differences in per capita income and stages of economic development. However, further empirical studies are needed to elicit and document the actual value of statistical life among targeted populations.

Another limitation is that the approach of estimating statistical lives does not include greater societal benefits such as economic returns from demographic transitions and preventing disease outbreaks. Because the value-of-statistical-life method asks individuals to consider their own trade-offs between money and risks of death, these societal-level benefits that have externalities, or other effects, might not be fully considered. These benefits may be dwarfed by the value-of-statistical-life numbers, but they are still important to consider if one wishes to paint a more accurate picture of vaccine benefits.

The Lives Saved Tool analysis does not capture the so-called herd immunity benefits that accrue among populations older than age five. These are the benefits that result when large groups of people have immunity to a particular disease, and therefore are far less likely to pass the disease to unvaccinated members of the population—thus keeping the "herd" safe.

For example, in countries such as the United States, large disease reductions have been observed among older children and adults from administering pneumococcal vaccine to children under age five.[44] Not capturing these benefits would tend to make our estimates in this article conservative.

By estimating the benefits that may accrue from scaling up vaccines, our analysis provides a benchmark for policy makers.

Finally, although this analysis estimated the potential benefits of vaccination, it did not estimate the costs of scaling up the vaccine programs (including vaccine purchases). However, by estimating the benefits that may accrue from scaling up vaccines, our analysis provides a benchmark for policy makers to consider.

In short, if the expected costs of scaling up are less than or equal to the projected benefits, then the program can be considered to convey net benefits. Additional work on the costs of scaling up, and especially the distribution of these costs among payers, would be a useful adjunct to this analysis.

Results

Overall, improving coverage of a package of life-saving childhood vaccines in seventy-two GAVI-eligible countries to 90 percent coverage between 2011 and 2020 would prevent the deaths of approximately 6.4 million children under age five and would represent $231 billion (uncertainty range: $116–$614 billion) in the value of statistical lives. In other words, we estimate the benefits of averting 6.4 million vaccine-preventable child deaths in the Decade of Vaccines to be worth $231 billion to those who are at risk of death.

The value-of-statistical-life benefits are perhaps easier to appreciate on an annual basis. The average benefit over the decade was $23 billion per year, corresponding to an average of 640,000 lives saved per year. The benefits increased over the years, ranging from a low of $3.5 billion in 2011 to a high of $40 billion in 2020. This corresponds to saving 130,000 children's lives in 2011 and 970,000 children's lives in 2020 with improved immunization rates across the seventy-two GAVI-eligible countries.

The largest value-of-statistical-life benefits were from pneumococcal and Hib vaccines, contributing $105 billion (uncertainty range:

$52–$270 billion) from pneumonia and $14 billion ($7–$36 billion) from meningitis cases. Rotavirus vaccine ($54 billion; $27–$138 billion) and malaria vaccine ($28 billion; $14–$76 billion) were the next-largest contributors to value-of-statistical-life estimates.

Malaria vaccine savings increased rapidly assuming its introduction in 2015 (see Exhibit 1). Scaling up the two remaining vaccines yielded value-of-statistical-life benefits of $16 billion ($8–$44 billion) from pertussis and $14 billion ($7–$38 billion) from measles. When the share of eligible people vaccinated is estimated to reach 90 percent for all of these vaccines in 2020, one year of vaccination is estimated to contribute aggregated value-of-statistical-life benefits of $16 billion from averting pneumonia, $9 billion from malaria, and $8 billion from diarrhea.

On a regional basis, Africa and South and East Asia accounted for 88 percent of value-of-statistical-life benefits. Within sub-Saharan Africa, total value of statistical life ranged from $28 million in Lesotho to $42 billion in Angola over this ten-year period. The ranges were even greater in South and East Asia, with $16 million value-of-statistical-life benefits in Timor-Leste compared to $68 billion in India.

At the country level, the highest benefits of vaccination were found in India ($68 billion; uncertainty range: $33–$184 billion), Angola ($42 billion, $24–$85 billion), Nigeria ($36 billion, $17–$98 billion), and Indonesia ($21 billion, $11–$47 billion). Angola also had the highest benefit per vaccine-targeted cohort of $5,000 with one of the highest per capita gross domestic products among the seventy-two countries. Many smaller countries also gained more than $500 in value-of-statistical-life benefits per surviving infant; these included Azerbaijan, Bhutan, Congo, Indonesia, Nigeria, and Sudan.

To help decision makers appreciate what one year's worth of benefits would be, we prepared estimates centered on benefits that would accrue just in 2015, when most vaccines are scaled up to the point that 90 percent of the target population has been vaccinated (except for the malaria vaccine). In 2015 there would be $7.5 billion (uncertainty range: $3.5–$20.6 billion) value-of-statistical-life benefits from India, $4.1 billion ($2.3–$8.5 billion) from Angola, $3.6 billion ($1.7–$10 billion) from Nigeria, and $2.4 billion ($1.3–$5.5 billion) from Indonesia.

Comparing the values in 2015, we see that countries such as Angola have high total value of statistical life because of high value of statistical life per capita ($326,300) but fewer lives saved (12,700). By contrast, other countries such as India have many lives saved (181,300) with low value of statistical life per capita ($41,100) (Exhibit 2).

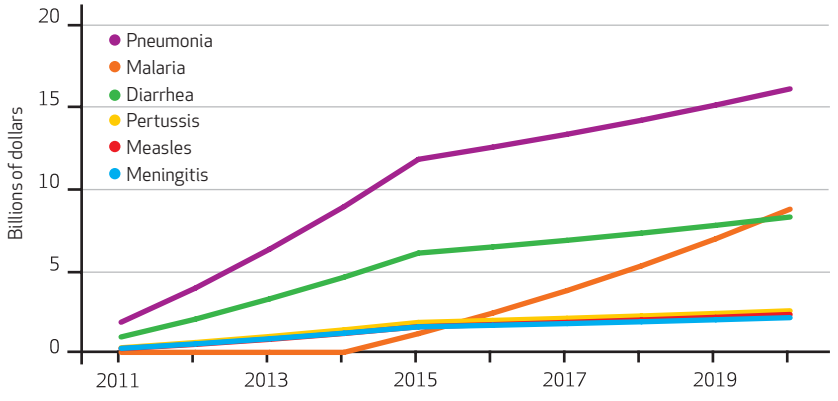
The per capita value-of-statistical-life values in the seventy-two GAVI-eligible countries in 2015 ranged from $550,000 in Cuba to $1,700 in Burundi. These values were derived from countries' respective per capita gross domestic product—$10,500 in Cuba and $225 in Burundi—forecast for 2015. Among the GAVI Alliance countries in 2015, child deaths prevented from scaling up vaccines ranged from 181,300 in India to 11 in Cuba.

In 2015 the average total value-of-statistical-life benefit for a country in sub-Saharan Africa was $298 million across thirty-six countries, compared to an average of $1.2 billion across nine countries in South and East Asia. On the whole, most countries observed between $100 million and $1 billion (31 countries, 43 percent) or between $1 billion and $10 billion (24 countries, 33 percent) in total value-of-statistical-life benefits over the decade (Exhibit 3).

Sensitivity analysis found that income elasticity contributed the most to the uncertainty around the value-of-statistical-life estimate, ranging the estimate from $72 billion to $929 billion. The next contributor was the mortality estimates from the Lives Saved Tool, ranging the value of statistical life between $79 billion and $517 billion. The uncertainty around the mortality estimates was driven by a number of inputs such as the under-five mortality rate, vaccine efficacy, and percentage of deaths due to pneumonia and diarrhea. Lastly, the benchmark value of statistical life ($6.7 million) varied the value-of-statistical-life estimate between $219 billion and $250 billion. In a computer simulation, we combined these uncertainty ranges to estimate a total value-of-statistical-life uncertainty range between $116 billion and $614 billion (see the

EXHIBIT 1

Annual Value-Of-Statistical-Life Savings, By Vaccine-Preventable Disease, 2011–20



SOURCE Authors' analysis.

EXHIBIT 2

Top 10 Countries With Value-Of-Statistical-Life (VSL) Savings For 2015

Rank	Country	GDP per capita	VSL per capita	Vaccine-preventable child deaths	Total VSL saved (millions of US$)	
					Estimate	Range
1	India	1,860	41,100	181,300	7,451	(3,544–20,646)
2	Angola	7,390	326,300	12,700	4,139	(2,272–8,484)
3	Nigeria	1,800	39,300	91,100	3,578	(1,696–9,985)
4	Indonesia	4,440	152,000	15,900	2,411	(1,260–5,473)
5	Pakistan	1,350	25,600	26,700	683	(321–1,999)
6	Sudan	2,440	62,100	8,900	552	(276–1,414)
7	Bhutan	2,810	76,500	6,100	467	(237–1,164)
8	Afghanistan	780	11,300	28,400	320	(140–1,065)
9	Kenya	1,480	29,300	9,300	274	(130–785)
10	Cameroon	1,260	23,000	11,200	258	(121–767)

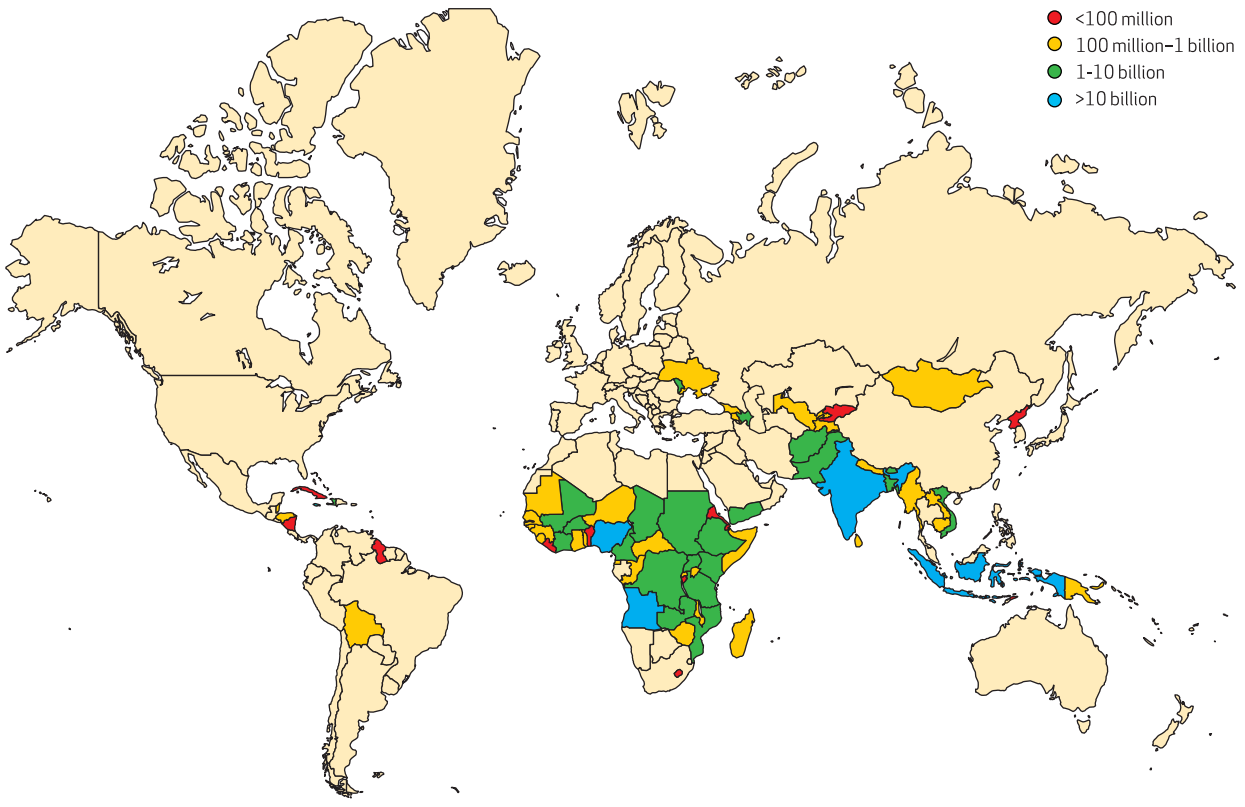
SOURCE Authors' analysis. **NOTES** Gross domestic product (GDP) per capita is rounded to the nearest tenth. VSL per capita and vaccine-preventable child deaths are rounded to the nearest hundred.

online Appendix).[37]

We also computed the total value of statistical life for the extreme ends of our income-elasticity range (1.0–2.0). If income elasticity were changed to 1 from 1.5, $115 billion would be saved per year on average annually (Exhibit 4), resulting in ten-year value-of-statistical-life benefits of $1.2 trillion. On the other hand, if income elasticity were set at 2 as a conservative measure, annual value-of-statistical-life benefits would be

EXHIBIT 3

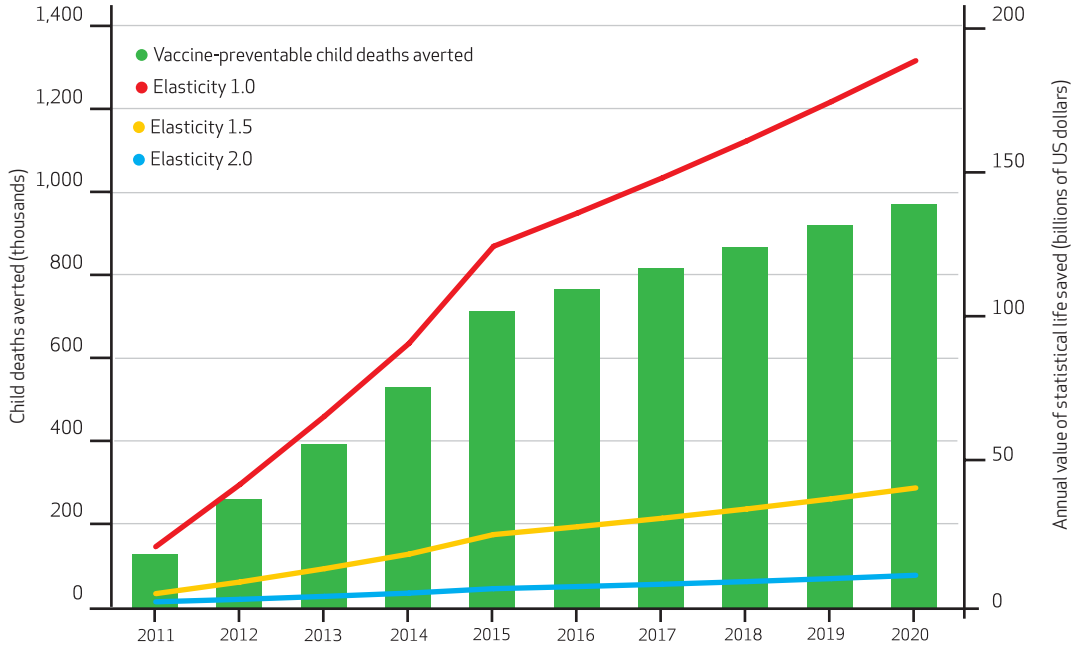
Value-Of-Statistical-Life Savings In Seventy-Two Countries, By Region



SOURCE Authors' analysis.

EXHIBIT 4

Value Of Statistical Life Saved And Vaccine-Preventable Child Deaths Averted, By Year, 2011–20



SOURCE Authors' analysis. **NOTES** Green bars denote deaths averted and relate to the left-hand *y* axis. Red, yellow, and blue lines denote annual value of statistical life saved, with varying elasticities, and relate to the right-hand *y* axis.

$5.3 billion, leading to cumulative benefits of $53 billion over the Decade of Vaccines. Even with conservative income-elasticity figures, the value-of-statistical-life benefits are in the tens of billions of dollars.

Discussion

This is the first study to present the economic benefits of vaccines by using the value-of-statistical-life approach for diseases that primarily affect children under age five in developing countries. It highlights the major benefits made possible by investing in vaccines and suggests that the global community should be willing to pay up to an estimated $231 billion ($116–$614 billion) to avert 6.4 million child deaths during the Decade of Vaccines (2011–20) in seventy-two of the world's poorest countries. This is equivalent to an investment of $2.3 million for a one in ten thousand annual risk reduction of vaccine-preventable deaths.

Whose money is this $231 billion? This analysis presents the value that people place on children's survival based on ordinary trade-offs they make. These benefits are based on the ability and willingness of the world's poor to pay money to help their children stay alive. If local governments and the global community lower their children's death risks, the world's poor derive a benefit equal to what they would have been willing to pay to lower their own children's death risk by the same amount. In essence, a global investment in the Decade of Vaccines could give the world's poor a health benefit for which they would have paid $231 billion.

The value-of-statistical-life benefits are perhaps more tangible at the vaccine or country levels. They highlight the value of improving global rates of immunization especially with pneumococcal, Hib, and rotavirus vaccines to prevent pneumonia, meningitis, and diarrhea cases. Introduction of the malaria vaccine would add further economic benefits in malaria-endemic countries.

At the country level, most countries' value-of-statistical-life benefits ranged between $100 million and $10 billion (55 countries, 76 percent), thereby illustrating vaccines' staggering ability to thwart mortality risks worth millions and sometimes billions of dollars. These are values that global and national decision makers choosing to introduce new vaccines or invest in improved immunization coverage may want to consider when making vaccine-related policy decisions.

Explicit in our analysis is variation in parents' willingness to pay to protect their children where incomes vary dramatically across countries (Exhibit 2). We are not assuming that global in-

come disparities and their consequences are desirable. However, what each person's life is worth in practice is what each individual and others are willing to pay to protect it, implicitly or explicitly. Global investments in vaccines actually move the world closer to a point at which all lives have equal value.

The value-of-statistical-life estimates found in our analysis appear comparable to value-of-statistical-life values presented in other papers. Raminan Laxminarayan and colleagues found that the economic benefit of tuberculosis treatment in sub-Saharan Africa was estimated to be $129 billion (uncertainty range: $113–$146 billion),[8] which is in the same ballpark as the benefits we found in our vaccine analysis.

However, this comparison must be made cautiously, because the two studies' results are not directly comparable. There are many differing assumptions, including the number of years of life saved, countries and years of the analysis, and other key assumptions. Note especially that the income-elasticity assumption of 1 used in their analysis has a large impact on the projected value of statistical life per capita, and it generates estimates that are higher than when using an elasticity value of 1.5, as we have done in this analysis.

In examining the benefits of human papillomavirus vaccine in Taiwan, Chih-Hsien Liao and colleagues found that the per capita value of statistical life was estimated at $0.65–$4.09 million for vaccinating daughters and $0.56–$3.16 million for vaccinating mothers.[25] Applying our methodology with Taiwan's per capita gross domestic product, we estimated a per capita value of statistical life of $1.7 million for Taiwan in 2011, which falls within the range presented in this study. Although the two studies assess value-of-statistical-life benefits for very different outcomes and countries, the similar scale of the results reinforces the validity of our findings.

Conclusion

Overall, this analysis provides a robust projection of the potential economic benefits that may be accrued from expanding access to life-saving childhood vaccines during the Decade of Vaccines. In its use of the value-of-statistical-life approach, the study represents the first analysis of its sort for vaccination programs in developing countries. The sensitivity analyses indicate that the benefits accrue to tens of billions of dollars even under the most conservative set of assumptions. They also provide a useful indication of where further empiric validation of estimates would be most valuable. ■

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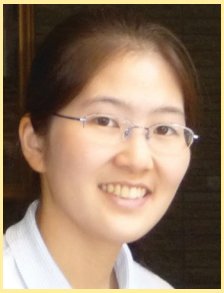

Sachiko Ozawa is an assistant scientist at the Johns Hopkins Bloomberg School of Public Health.

In this issue of *Health Affairs*, Sachiko Ozawa, Meghan Stack, and their coauthors present two papers assessing the benefits of vaccines, focusing on the impact of a $10 billion, ten-year investment by the Bill & Melinda Gates Foundation to expand access to vaccines among children in some of the world's poorest countries.

The paper on which Ozawa is the lead author employs a "value of statistical life" analysis, concluding that expanding access to vaccines would prevent the deaths of 6.4 million children over the next ten years. The paper also estimates a $231 billion benefit in terms of the value placed on the lives of children who would otherwise die.

The paper on which Stack is the lead author uses a more traditional measure of savings in treatment costs and economic output, finding that $6.2 billion in treatment costs and $145 billion in productivity losses would be averted by the expansion of access to vaccines.

Ozawa is an assistant scientist at the Department of International Health, Johns Hopkins Bloomberg School of Public Health. Her research focuses on examining economic benefits of public health interventions, scaling up health financing schemes, and examining the role of trust and social capital in health care systems. In 2010 she was awarded a faculty grant in global health research from the Johns Hopkins Center for Global Health, and a research grant from the Toyota Foundation. She received both her doctorate and master's degrees in health systems from the Bloomberg School, with specialization in international health economics.

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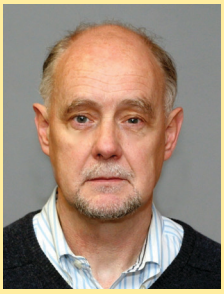

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