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The Equity Impact Vaccines May Have On Averting Deaths And Medical Impoverishment In Developing Countries

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ABSTRACT With social policies increasingly directed toward enhancing equity through health programs, it is important that methods for estimating the health and economic benefits of these programs by subpopulation be developed, to assess both equity concerns and the programs' total impact. We estimated the differential health impact (measured as the number of deaths averted) and household economic impact (measured as the number of cases of medical impoverishment averted) of ten antigens and their corresponding vaccines across income quintiles for forty-one low- and middle-income countries. Our analysis indicated that benefits across these vaccines would accrue predominantly in the lowest income quintiles. Policy makers should be informed about the large health and economic distributional impact that vaccines could have, and they should view vaccination policies as potentially important channels for improving health equity. Our results provide insight into the distribution of vaccine-preventable diseases and the health benefits associated with their prevention.

Poverty alleviation has become one of the most important global development targets. The World Bank adopted ending extreme poverty by 2030 and promoting shared prosperity as its twin goals.[1] The first of the United Nations' Sustainable Development Goals, to "end poverty in all its forms everywhere,"[2] acknowledges the importance of eliminating poverty in the next fifteen years. Macroeconomic development is not the only way to address extreme poverty. International agencies and policy makers have long recognized that high out-of-pocket health expenditures were one of the main reasons for household impoverishment.[3,4] In China and India, for example, out-of-pocket spending for health services was a primary factor driving families into poverty.[5–7] In 2010 the World Health Organization reported that the cost of health care prevents many poor people from seeking treatment while simultaneously pushing about 150 million care seekers into poverty each year.[8] Reducing out-of-pocket spending for health care and providing financial risk protection is critical to preventing extreme poverty. One of the targets of Sustainable Development Goal 3 for health calls for all countries to move toward providing health care and financial protection to everyone through universal health coverage, emphasizes the importance of reducing out-of-pocket spending and providing financial risk protection, and focuses on equity in accessing health services across socioeconomic strata.[9]

It is well recognized that vaccines have contributed significantly to the improvement of population health in the past few decades,[10] but their nonhealth impact has been less explored. Given the preventive nature of vaccines, they may play a role in providing financial risk protection by preventing illnesses and its high-cost treatments, and therefore averting medical impoverishment. Similarly, while poor health is strongly associated with poverty,[11] and the World Health Organization's *Global Vaccine Action Plan 2011–2020* listed equity as one of its six guiding principles,[12] limited evidence assessing the distribution of health benefits of vaccines by socioeconomic strata exists.[13–16]

The objective of our study was to model the distributional health and household economic benefits of vaccines across socioeconomic groups. Specifically, we aimed to provide an estimate of the distribution of health and financial risk protection benefits of vaccines for ten antigens in forty-one low- and middle-income countries for the vaccination period 2016–30.

Study Data And Methods

We studied vaccines that prevent diseases caused by the following ten antigens: measles, hepatitis B, human papillomavirus, yellow fever, *Hemophilus influenzae* type b, *Streptococcus pneumoniae*, rotavirus, rubella, *Neisseria meningitidis* serogroup A, and Japanese encephalitis.

We looked at the effects of both routine and campaign immunization programs. A distributional analysis was conducted for each antigen by quantifying, per income quintile, the future health gains and household financial consequences corresponding to the vaccination period of 2016–30 in forty-one low- and middle-income countries eligible for support from Gavi, the Vaccine Alliance. Out of the seventy-three Gavi-eligible countries, we included these forty-one countries (total population: 1.52 billion) in our analysis based on the availability of data from the Demographic and Health Surveys after 2010 (see online appendix A2).[17] The number of countries that have introduced these vaccines as well as the average projected vaccine coverage rates in the period 2016–30 are presented in appendix A3.[17] We examined health gains in terms of the number of averted deaths and household financial consequences in terms of the number of averted cases of medical impoverishment—that is, by the reduction in the number of cases where household income would fall below the World Bank poverty line of $1.90 per day (purchasing power parity–adjusted constant 2011 international dollars) as a result of medical expenditures.

METHODS A flow diagram outlining each step of our approach is presented in appendix exhibit A6.[17] To estimate the number of vaccine-averted deaths for each antigen, we applied methods described elsewhere[18] for four of them: measles, *Streptococcus pneumoniae*, rotavirus, and human papillomavirus. We quantified the contribution of sets of risk and prognostic factors, defined as behaviors and characteristics of a person that can be used to estimate the likelihood of contracting and dying from each disease. This model leveraged the differences in the prevalence of risk and prognostic factors across socioeconomic strata (available in the Demographic and Health Surveys) to estimate the distribution of cases and deaths.[19] For example, risk factors such as wasting and vitamin A deficiency were used to determine how measles deaths could be distributed, based on different prevalence rates observed across income groups. A detailed explanation can be found in appendix A4.1.[17]

For the remaining six antigens— hepatitis B, yellow fever, *Hemophilus influenzae* type b, rubella, *Neisseria meningitidis* serogroup A, and Japanese encephalitis —there is a lack of established evidence regarding the risk and prognostic factors of their associated diseases and their distribution across socioeconomic strata. Therefore, we conservatively assumed that the cases were distributed equally across the income quintiles. To estimate the distribution of disease-specific deaths, we applied two coverage gradients across quintiles: Quintile-specific vaccine coverage rates from the Demographic and Health Surveys were applied to determine the number of disease cases in the presence of vaccine programs; and quintile-specific treatment coverage rates from the surveys on the percentages of people seeking care from a health care provider for events such as diarrhea, cough, and fever were applied to determine the number of disease-specific deaths averted.[19] Details on the prevalence and relative risks of the risk and prognostic factors, as well as assumptions on vaccine coverage and care access rates, can be found in appendix exhibit A7.[17]

Several mathematical models have recently been used to generate disease- and country-specific estimates of vaccine impact. From each of these disease-specific models,[20–22] we were given national estimates of the numbers of future deaths and cases averted over the lifetime of cohorts vaccinated in the period 2016–30. For example, all of the future deaths and cases (that is, those occurring after 2016) averted by vaccines administered in 2016 would be considered to be attributable to vaccination year 2016.

Finally, we calculated the number of deaths averted per million people vaccinated using the number of people vaccinated in Gavi's Strategic Demand Forecast.[23]

To calculate the number of cases of medical impoverishment averted for each antigen, we

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used estimates of out-of-pocket spending amounts for direct costs (treatment of the disease and transportation) derived from treatment provider costs in previously published literature,[21,24–27] and the share of out-of-pocket spending as a percentage of total health spending from the World Bank;[28] and on indirect costs that reflect the forgone earnings associated with care seeking.[29] We defined the latter as the lost income of the main household member due to the time lost for either seeking care or taking a sick child to care (appendix exhibit A8).[17] Specifically, they are defined as the product of hospitalization or outpatient duration and the hourly wage for each country. When the illness affects children, indirect costs correspond to the time needed to take a child for inpatient or outpatient care; when the illness affects adults, indirect costs correspond to the time needed to seek inpatient or outpatient care.

We simulated monthly household incomes based on each country's gross domestic product per capita (adjusted for purchasing power parity) and Gini coefficient,[30] and we estimated the number of households that would fall below the World Bank poverty line with the incurred costs listed above. A household is considered to be in poverty when monthly household income per capita minus the household's incurred costs falls below the World Bank poverty line of $1.90 (purchasing power parity–adjusted constant 2011 international dollars) per day. This definition avoided counting households that would have been in poverty before the costs were incurred. We then aggregated the number of cases from each country to obtain the total number of cases of medical impoverishment. These measures of household economic well-being are routinely used by the World Health Organization and the World Bank to evaluate the financial impact of health policies on households.[31] More details can be found in appendix A4.2.[17]

OUTCOMES AND SCENARIOS For each country, we first estimated the number of potential deaths that would have occurred in each income quintile if no immunization were available (our counterfactual scenario). Second, we assessed the impact of vaccine programs on this distribution. Third, we estimated the change in the distribution of deaths by comparing the results from the first two steps.

We applied quintile-specific vaccine coverage rates derived from methods described in appendix A4,[17] scaled up as projected by the Strategic Demand Forecast developed by Gavi.[23] In most countries, the lowest (poorest) quintile has the lowest vaccine coverage rate, and the highest (richest) quintile has the highest rate. By definition, each quintile represents 20 percent of the households in the population. However, household size (for example, the number of children) may vary across quintiles. We therefore applied country- and quintile-specific total fertility rates (assumed to be constant over time) to account for the differences in the number of susceptible people in each quintile, which would affect how the disease cases were distributed. To test the influence of total fertility rates on our results, we conducted a sensitivity analysis by removing the adjustment for the total fertility rates.

We generated country-specific outcomes (listed in appendix exhibit A9),[17] and we present the aggregate findings in the "Study Results" section below.

The poorest quintiles would gain the most from vaccine programs because they have the most to gain, in both health and economic terms.

LIMITATIONS There were several major limitations to this study. First, our model inputs—including projected vaccine coverage rates, numbers of people vaccinated, total numbers of deaths averted, rates of health care use, and costs incurred—were obtained from various different models[20,21,23] containing a number of important assumptions that affected our findings. An important feature of the disease models is that all diseases are considered as noncompeting risks, which means that the sum of deaths across all diseases might be greater than the actual number of all-cause deaths. We also adopted a simple static approach to understand the impact of different combinations of factors in a straightforward way. This approach has limitations, such as not accounting for herd immunity (additional protective effect at the population level when a large percentage of population becomes immune) and dynamic transmissions (the changes in the nature of disease transmissions with varying numbers of people becoming susceptible, infected, and recovered over time).[32,33] In addition, nonspecific effects of vaccines, such as their effect on overall mortality,[34] as well as the timeliness of receiving the vaccines,[35,36] were not taken into account. We believe that including these factors would lead to a more skewed distribution of averted deaths and impoverishment cases toward the poor.

Second, disease-specific cases and deaths are related, even though the inputs for the relative risks of prognostic factors used here captured the impact of these factors among the healthy population unaffected by disease (that is, not among disease cases). However, given the lack of data on the relative risks of prognostic factors among cases, we had to assume that these relative risks were for cases as well.

Third, we calculated the absolute number of averted deaths and their distribution across income quintiles, not how the remaining deaths were distributed after removing the averted deaths. It is possible that the distribution of deaths not averted by vaccines was skewed toward the poor. In other words, achieving greater reduction in deaths among the poorest groups does not necessarily equate with improving health equity. We also applied the income quintiles assigned by the Demographic and Health Surveys, and we acknowledge that the living conditions of people in the poorest quintile in one country may differ vastly from those of people in the poorest quintile in another country.

Fourth, we considered the effects of vaccines only on mortality, not morbidity. The potentially large impact of Japanese encephalitis and *Neisseria meningitidis* serogroup A vaccines on reducing morbidity, such as brain damage and neuropsychiatric sequelae, is therefore not reflected in our results.

Fifth, data on out-of-pocket expenditures and medical impoverishment by disease cause are scarce. Therefore, we had to rely on imputed modeled data and information available for a small set of countries.

Sixth, estimated deaths and averted cases of medical impoverishment that we report correspond to the future benefits over the lifetime of cohorts vaccinated in the period 2016–30. However, we did not discount these future benefits or account for growth in simulated household incomes, even though some disease-specific benefits might occur either earlier (for example, in the cases of rotavirus and measles) or later (for example, in the cases of hepatitis B and human papillomavirus) over that lifetime.

Finally, we recognize that there may be tradeoffs between keeping program costs low and achieving affordability and equity goals. While we found that vaccine programs could be more *effective* in averting deaths in the poor by a large magnitude, the programs might not be the most *cost-effective* policy—given that reaching the poorest quintiles could be substantially more expensive than reaching the richest.

Study Results

In this section we present the projected numbers of averted deaths and medical impoverishment cases, compared to the counterfactual scenario if no immunization were available. Detailed results from the main analysis and the sensitivity analysis are presented in appendixes A5 and A6.[17] All costs are expressed in 2011 international dollars.

DEATHS AVERTED The number of future deaths averted corresponding to the cohorts vaccinated in 2016–30 for all ten antigens in forty-one low-

EXHIBIT 1

Numbers of deaths and cases of medical impoverishment averted by vaccines to be administered in 41 low- and middle-income countries, 2016–30

Antigen	Deaths averted (thousands)	Number of deaths averted (per million people vaccinated)	Medical impoverishment cases averted (thousands)
Measles	22,204	11,339	4,787
Hepatitis B	6,639	10,751	14,034
Human papillomavirus	2,522	11,990	112
Yellow fever	1,804	4,551	835
Hemophilus influenzae type b	1,242	1,998	1,054
Streptococcus pneumoniae	782	1,337	248
Rotavirus	454	819	242
Rubella	355	897	141
Neisseria meningitidis serogroup A	137	81	2,684
Japanese encephalitis	13	35	8

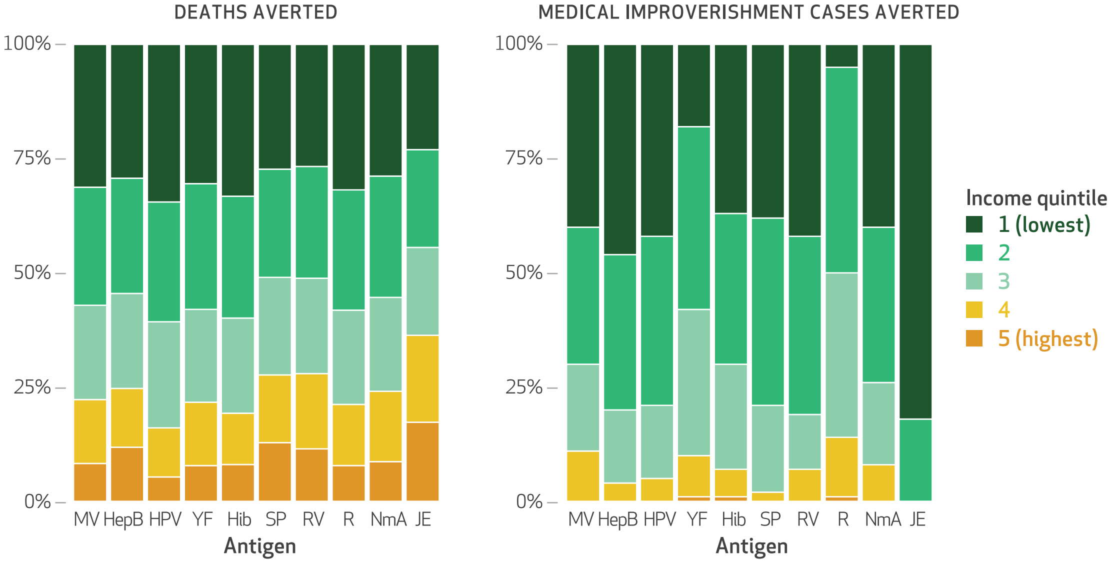
SOURCE Authors' analysis.

and middle-income countries is estimated to be approximately thirty-six million (exhibit 1). Vaccines for measles, hepatitis B, and human papillomavirus accounted for the largest share of averted deaths—61 percent, 18 percent, and 7 percent, respectively. The magnitude of deaths averted by vaccines is primarily a function of the burden of the related disease (measured as total deaths that would have occurred, estimated in the counterfactual scenario), the number of countries that were forecasted to introduce the vaccine and their national immunization coverage, the proportion of people who received care after contracting the disease, and vaccine and treatment efficacy. In addition to the large disease burden in the absence of the related vaccines, by 2016 all forty-one countries are forecasted to have introduced vaccines for measles and hepatitis B, with average coverage rates greater than 80 percent and vaccine efficacy over 85 percent.[23] Human papillomavirus vaccine has high efficacy (close to 100 percent) and is modeled to be introduced in most countries. In contrast, while *Streptococcus pneumoniae* also accounts for a large disease burden, the vaccine has a lower vaccine efficacy and thus contributed to fewer averted deaths.[37] Vaccines for Japanese encephalitis and *Neisseria meningitidis* serogroup A account for a small proportion of averted deaths mainly because they are regional vaccines projected to be introduced in only a limited number of countries. While rubella has a sizable case burden, it has a low case-fatality ratio, so rubella mortality accounts for a relatively small proportion of the averted deaths.

When we examined the counterfactual scenario, we found that more deaths were projected to occur in the poorest quintile for all vaccine-related diseases. The poorest quintile had a high prevalence of risk and prognostic factors, low use of health care, and a high total fertility rate. Consequently, members of this population were more likely than others to develop a case of a vaccine-preventable disease and less likely to recover from a disease once they contracted it. Although the poorest quintiles experienced the lowest vaccine coverage rates, they enjoyed the most health benefits in terms of absolute number of averted deaths: The poorest quintile accounted for the largest share of deaths averted by all vaccines (23–34 percent), and the poorest two quintiles accounted for over half of the deaths averted by most vaccines (exhibit 2). Furthermore, our estimates suggest that the distribution of deaths averted across income quintiles would vary by vaccine. For example, 61 percent and 60 percent of deaths averted by the vaccines for human papillomavirus and *Hemophilus influenzae* type b occurred in the poorest two quintiles, compared to only 16 percent and 19 percent

EXHIBIT 2

Distribution, by income quintile, of deaths averted and cases of medical impoverishment averted by vaccines to be administered in 41 low- and middle-income countries, 2016–30



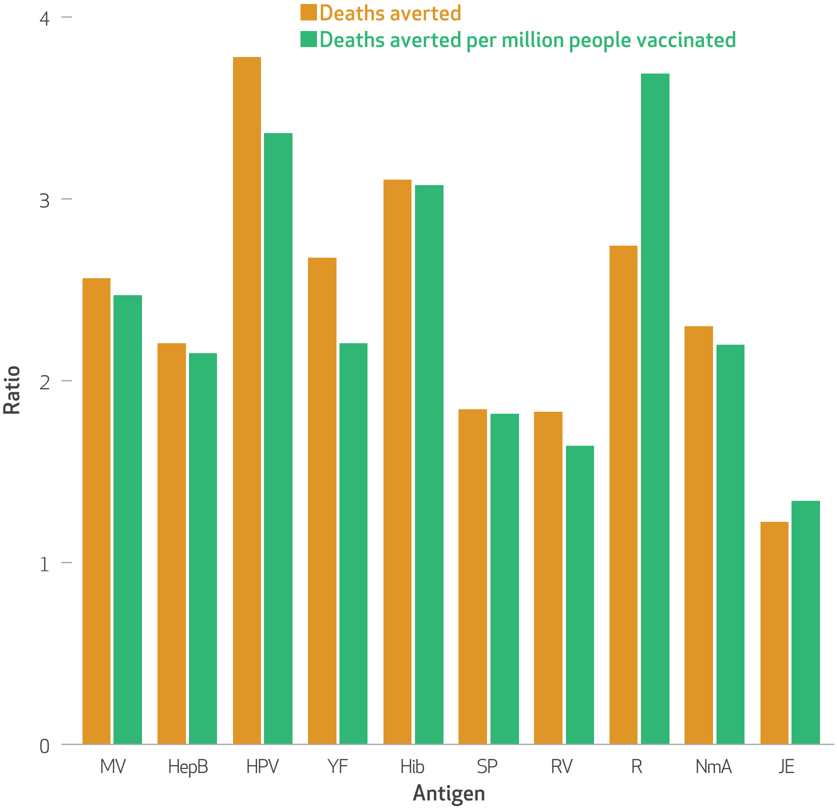
SOURCE Authors' analysis. **NOTES** The antigens are ordered by total disease burden, with measles (MV) having the largest and Japanese encephalitis (JE) the smallest disease burden. HepB is hepatitis B. HPV is human papillomavirus. YF is yellow fever. Hib is *Hemophilus influenzae* type b. SP is *Streptococcus pneumoniae*. RV is rotavirus. R is rubella. NmA is *Neisseria meningitidis* serogroup A.

in the richest two quintiles, respectively. In comparison, the distribution of deaths averted by the Japanese encephalitis vaccine was flatter: 44 percent of averted deaths occurred in the poorest two quintiles, compared to 36 percent in the richest two quintiles. The ratio of averted deaths between the poorest two and the richest two quintiles captures these differences in a comparable metric: The ratio ranged from 3.8 for human papillomavirus to 1.2 for Japanese encephalitis (exhibit 3).

To consider the relative effectiveness of vaccine programs, we estimated the number of deaths averted per million people vaccinated. The results varied widely by vaccine, from fewer than 100 deaths averted per million people vaccinated for Japanese encephalitis and *Neisseria meningitidis* serogroup A to more than 10,000 deaths averted per million people vaccinated for human papillomavirus, measles, and hepatitis B (exhibit 1). For all antigens, the poorest quintile accounted for the greatest number of deaths averted per million vaccinated. In other words, the benefit of vaccination for a person in the poorest quintile was greater than that for a person in a richer quintile. These findings emphasize the stark differences in health risk and prognostic profiles and access to care across income quintiles. When we compared the poorest two to the richest two quintiles, the ratio of deaths averted per million people vaccinated ranged from 3.7, 3.4, and 3.1 for rubella, human papillomavirus, and *Hemophilus influenzae* type b, respectively, to 1.6 and 1.3 for rotavirus and Japanese encephalitis, respectively (exhibit 3).

EXHIBIT 3

Ratios of deaths averted and of deaths averted per million people vaccinated between the poorest two and richest two quintiles by vaccines to be administered in 41 low- and middle-income countries, 2016–30



SOURCE Authors' analysis. **NOTES** The antigens are ordered by total disease burden. The antigens are explained in the notes to exhibit 2.

CASES OF MEDICAL IMPOVERISHMENT AVERTED

All vaccines led to an important reduction in the number of cases of medical impoverishment: Overall, an estimated twenty-four million cases of medical impoverishment were averted by vaccines administered in 2016–30 in the forty-one countries. For context as to the magnitude of the impoverishment cases averted, this reduction in the number of cases of medical impoverishment represents approximately 9 percent of the people in low-income countries whose incomes are below the World Bank poverty line of $1.90 a day in 2013.[38] The largest number of impoverishment cases averted was attributed to hepatitis B (14 million cases), followed by measles (5 million cases) and *Neisseria meningitidis* serogroup A (3 million cases). The large effect of hepatitis B is due to the combination of high treatment costs and a higher number of future cases averted from the cohorts vaccinated in 2016–30 in the analyzed countries when compared to the other illnesses. For measles, the estimated effect is due to the combination of low treatment costs and hospitalization rates with a high number of cases. The vaccine for *Neisseria meningitidis* serogroup A would avert cases that have relatively high treatment costs but that are substantially less frequent than cases of measles and hepatitis B. Finally, the vaccines for Japanese encephalitis and rubella would each avert fewer than 150,000 medical impoverishment cases.

The number of medical impoverishment cases decreased greatly with increasing wealth (exhibit 2). As expected, the vast majority of averted impoverishment cases occurred in the poorest quintiles, and fewer than 20,000 cases were averted in the richest quintile. For many vaccines (for example, those for measles, hepatitis B, human papillomavirus, rotavirus, *Neisseria meningitidis* serogroup A, and Japanese encephalitis), more than 40 percent of the averted cases occurred in the poorest quintile. Overall, the results suggest that vaccination would lead to an important reduction in medical impoverishment cases in the poorer quintiles.

Removing the adjustment for total fertility rates would lead to lower ratios of averted deaths between the two poorest and two richest quintiles (appendix exhibits A10 and A11).[17] In other words, there would be fewer benefits in the poorest two quintiles than in the base-case results. The poorest quintiles have higher fertility rates (and thus more people susceptible to disease), and removing this adjustment would narrow such differences between the poor and the rich.

Discussion

This study estimated the future distributional impact of vaccination on mortality and medical impoverishment for ten antigens in forty-one low- and middle-income countries for cohorts vaccinated in the period 2016–30. We found that these vaccine benefits would primarily accrue in the poorest income quintiles. In other words, the projected coverage of vaccine programs would likely relieve more mortality and household economic burden for the poor than for the rich.

It is important to note that the poorest quintiles would gain the most from vaccine programs because they have the most to gain, in both health and economic terms. Differences in health risk and prognostic profiles and care access would likely result in a largely unequal distribution of deaths in the absence of vaccine programs. These estimated differences are so stark that vaccine programs would disproportionately benefit the poor even though that population would have the lowest vaccine coverage. At face value, this suggests that even pro-rich vaccine coverage, in which the richest quintiles enjoy higher coverage rates, would result in the poorest quintiles' gaining greater health outcomes, and that vaccine programs could become even more pro-poor if coverage were equal across income quintiles. Alternatively, we also observe that vaccine programs risk exacerbating existing health inequities if current pro-rich vaccine coverage rates remain.

We acknowledge that in addition to income, there are many other critical equity dimensions worth examining, such as gender and geography—for example, we may see differences in the distribution of benefits between males and females or between rural and urban areas. The distributional analysis presented here could be further applied in the future to examine the distributional impact across these equity-relevant dimensions.

Policy Implications

Our projection of the distributional impact of vaccines has important policy implications. First, policy makers should be informed about the potentially large health and economic distributional impact that vaccines may have and should view vaccination policies as important channels for improving health equity and reducing poverty. Strong efforts should be made to improve vaccine coverage rates among the poor—for example, by prioritizing the introduction of vaccines in a country's poorer geographic regions, which are likely to be the regions most at risk; and introducing demand-creation activities, such as vaccination campaigns in poorer communities and communication strategies targeting the poor. Further analyses should be conducted to describe local inequities so that context-specific policies could be designed to address those inequities.

Policy makers should view vaccination policies as important channels for improving health equity and reducing poverty.

Second, distributional impact should be taken into account in decision making about introducing or expanding vaccination programs. Vaccines projected to have greater benefits accruing to the poor (or other marginalized subgroups) could be prioritized over other vaccines or interventions with less equity impact.

Third, when faced with issues of affordability or sustainability of vaccine programs (for example, in countries that will soon "graduate" from receiving aid support), policy makers could consider phased introductions to prioritize the populations most at risk and with the highest projected disease burden.

Fourth, merely ensuring equal access to vaccines will not reduce the health and economic outcome gaps that exist across income quintiles. The poor face higher baseline risks, which are tied to social determinants of health, and they have lower access to treatment. Additional steps may be needed to address those factors.

Finally, and most importantly, empirical data on the distribution of the health (both mortality and morbidity) and financial burden of vaccine-preventable diseases by key subpopulations (such as by income quintile and geographical setting) are critically needed to enable monitoring of how health policies affect health equity. Our modeling exercise is a step toward addressing this data gap, but we urge governments and donors to set up data collection systems to gather this key information.

Conclusion

Vaccines are known to have substantial health impact and to be cost-effective.[20,39] In addition to highlighting these benefits, this study aimed to show not only that vaccines could have significant health and economic benefits, but also that these benefits could largely accrue among the poor. With reducing poverty and improving equity on the global development agenda, sustained investments in vaccines could make a large contribution toward achieving the Sustainable Development Goals and universal health coverage. ■

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NOTES

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17 To access the appendix, click on the Details tab of the article online.

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