Why vaccines matter: understanding the broader health, economic, and child development benefits of routine vaccination

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ABSTRACT

The direct benefits of childhood vaccination in reducing the burden of disease morbidity and mortality in a cost-effective manner are well-established. By preventing episodes of vaccine-preventable diseases, vaccination can also help avert associated out-of-pocket medical expenses, healthcare provider costs, and losses in wages of patients and caregivers. Studies have associated vaccines positively with cognition and school attainment, suggesting benefits of long-term improved economic productivity. New evidence suggests that the measles vaccine may improve immunological memory and prevent co-infections, thereby forming a protective shield against other infections, and consequently improving health, cognition, schooling and productivity outcomes well into the adolescence and adulthood in low-income settings. Systematically documenting these broader health, economic, and child development benefits of vaccines is important from a policy perspective, not only in low and middle-income countries where the burden of vaccine-preventable diseases is high and public resources are constrained, but also in high-income settings where the emergence of vaccine hesitancy poses a threat to benefits gained from reducing vaccine-preventable diseases. In this paper, we provide a brief summary of the recent evidence on the benefits of vaccines, and discuss the policy implications of these findings.

Introduction

Childhood vaccines save an estimated 2–3 million lives worldwide every year, which has contributed substantially to the reduction in global infant mortality rate from 65 per 1,000 live births in 1990 to 29 in 2018.1,2 Vaccines are found to be the most cost-effective approach for reducing childhood disease burden, especially when compared with interventions such as clean water and improved sanitation which can also reduce disease transmission but require expensive and time-consuming infrastructural investment.3 Cross-national policy efforts such as the World Health Organization’s (WHO) Expanded Programme on Immunization (EPI) of 1974, and the multi-agency Global Alliance for Vaccines and Immunization (Gavi), established in 1999, have supported several countries with research, logistical planning, supply chain management, and financing of national vaccination programs. In recent times, routine vaccination has been supplemented with additional efforts to optimize community coverage. An example is the government of India’s Mission Indradhanush campaign initiated in 2015, that resulted in an increase of full vaccination coverage in target districts by 10 percentage points in just six months.4 As a result of these combined in-country and international initiatives, full vaccination rates of children in low-income countries have increased from under 50% to close to 80% during the past two decades.5

With such improvements in vaccination rates and reduction in child mortality, future changes in the global child health policy can be envisaged in three broad areas. First, as vaccine coverage improves, and there is increasing protection of both vaccinated and unvaccinated populations through the phenomenon of community immunity, we are likely to see fewer vaccine-preventable diseases in the general population. For example, polio has been eliminated from almost all countries and is at the verge of complete global eradication. However, the growing recognition of the importance of health equity has shown that clusters of susceptible populations within vaccinated societies can preempt disease outbreaks, such as the reemergence of diphtheria infections in Bangladesh and India.6,7 Second, the decreasing incidence of vaccine-preventable diseases has diminished the public’s memory of the devastation caused by the diseases, leading to a rise in vaccine hesitancy. Therefore, national programs will have to refocus on maintaining the momentum, although in a world with limited government resources, health policy-makers may find it difficult to financially and operationally justify large vaccination programs. Third, the shifting focus from child mortality to morbidity will lead to a greater emphasis on children’s physical, cognitive, and socioemotional development as compared with survival.8,9

Due to changing focus from child survival benefits of vaccines to child development benefits, along with greater reliance on multi-criteria decision-making tools, it is more important than ever before to quantify the broader social and individual benefits of vaccination. In this paper, we discuss evidence from a few key studies, and summarize the benefits
of childhood vaccines beyond the intended reduction in disease burden and child mortality.

**Economic, equity, and global health benefits of vaccines**

Vaccines can have several economic benefits. One of the most discernible benefits is averted medical expenditure. By preventing an episode of the disease through a vaccine, the economic costs of treatment, such as physician fees, drugs and hospitalization expenses, and associated travel costs and wage loss of caregivers could be averted. This is particularly important for low and middle-income countries (LMICs) where a large part of medical expenditure is out-of-pocket. A clear example is the situation in India, where 65% of health expenditure is private, with extreme costs in some cases, which thrusts 51 million people into poverty every year. It is estimated that the measles, rotavirus, and pneumococcal conjugate vaccines could help avert $4.6 billion (2016 US$, adjusted for purchasing power parity) in out-of-pocket medical expenses in 41 Gavi-eligible LMICs during 2016–2030. Vaccines could also reduce the number of people who fall into poverty due to a catastrophic medical expense which is defined as a large proportion (typically, more than 10% to 25%) of household income or expenditure.

The protection which vaccines provide against the financial risk from a large medical expense can be measured in additional ways. The so-called extended cost-effectiveness (ECEA) studies have estimated large money-metric value of insurance provided by vaccines. The value of insurance is equivalent to risk premium, which is defined as the amount of money one would be willing to pay in order to avoid the financial uncertainty from a vaccine-preventable disease. Paying for vaccines, in this context, is akin to paying for a health insurance premium.

Benefit-cost analysis (BCA) studies of vaccines consider a full range benefits as measured by gains in economic productivity. Several alternative BCA methods exist, including a human capital approach which uses the average annual economic contribution of workers, and a friction cost approach which considers productivity lost during the period when a job position remains unfilled due to sickness. Mortality and morbidity risk reduction benefits of vaccines have also been measured in terms the value of statistical life year (VSLY). VSLY is equivalent to the willingness to pay in order to avoid one disability adjusted life year (DALY) from the disease. It is typically measured as a multiple (approximately 2–4 times) of the per capita national income of a country. Newer studies such as those commissioned by the Copenhagen Consensus Center have considered a fixed value of either $1,000 or $5,000 per DALY across all countries and contexts.

One of the most comprehensive vaccine BCA studies published recently used the VSLY method and examined the economic benefits of 10 vaccines – for *Haemophilus influenzae* type b, hepatitis B, human papillomavirus, Japanese encephalitis, measles, *Neisseria meningitidis* serogroup A, rotavirus, rubella, *Streptococcus pneumoniae*, and yellow fever – in 73 LMICs. The authors considered averted medical expenses, transportation costs, and productivity gains in their analysis, and estimated that during 2001–2020, the vaccines together would provide a social and economic value of $820 billion (2010 US$). During 2011–2020, the rate of return for investment on these vaccines was estimated to be up to 44 times of the initial cost. Routine vaccination has a positive effect on social and health equity among populations. Infectious disease incidence and mortality are often associated with poverty, and exacerbated by lack of access to clean water, sanitation, and basic hygiene among the poor. Routine childhood vaccinations are, thus, estimated to avert the largest burden of diseases, associated medical expenses, and loss in economic productivity in the poorest segments of the society. A recent study in 41 Gavi-eligible LMICs found that universal coverage of the measles, rotavirus, and pneumococcal conjugate vaccines would avert a total of 12.6 million cases of catastrophic health expenditure which might have otherwise propelled patients into poverty. Of those, 75%, 40%, and 22% of cases respectively for the three diseases were from the poorest wealth quintile. New research shows that vaccines can also tackle global health threats such as antimicrobial resistance (AMR). If left unchecked, AMR-related infections are estimated to result in as many as 10 million deaths per year worldwide by 2050, with an associated global economic cost of US$100 trillion. Vaccines could prevent infections – either sensitive or resistant – and also reduce the use of antimicrobials, which in turn could slow the growth of AMR.

**Child development benefits of vaccines**

Persistent or recurrent infections in early life can lead to poor growth and stunting, which in turn can adversely affect adult health, cognitive capacity, and economic productivity. The theoretical basis of the long-term benefits of vaccines is anchored in the widely accepted “fetal origins” hypothesis which links conditions in utero and during early childhood with later life outcomes. Malnutrition, infection, pregnancy and birth complications, and under-stimulation during the first 1000 days of life can have lasting impact on health, cognitive, and economic outcomes well into the old age. In addition to appropriate nutrition and nurturing, health interventions such as routine vaccinations could reduce infectious disease burden in early childhood and thereby help break the intergenerational cycle of poverty, poor health, and low income.

There is a small but growing literature on the potential child development benefits of routine vaccines. The measles vaccine is especially important in this context as episodes of measles could damage protective immune memory for a period of 2–3 years, increasing susceptibility to future measles and non-measles infections. Using sophisticated techniques, scientists have showed that measles infection in children wipes out preexisting antibodies to different pathogens in the months after the infectious episode, leaving them vulnerable to multiple other infections and possible death. A recent longitudinal study of approximately 2,000...
children each in Ethiopia, India, and Vietnam has linked measles vaccination at ages 6–18 months of life with 0.1–0.2 higher anthropometric z-scores, 1.7–4.5 percentage points higher scores on standardized cognition tests, and 0.2–0.3 additional schooling grades at ages 7–8 and 11–12 years.\textsuperscript{71} The vaccine has also been associated with 0.2 more schooling grade attainment among South African children and 7.4\% higher school enrollment rate among children in Bangladesh.\textsuperscript{72,73}

Similar growth, cognition, and schooling benefits have been observed among \textit{Haemophilus influenzae} type B (Hib) vaccinated children in India,\textsuperscript{4,75} and fully vaccinated children in the Philippines.\textsuperscript{76} Another study found that exposure to tetanus vaccination in utero increased schooling attainment by 0.3 years for some children in Bangladesh.\textsuperscript{77} At the aggregate level, India’s national vaccination program has been associated with 0.3–0.5 higher height-for-age and weight-for-age z-scores at ages 0–4 years,\textsuperscript{78} and 0.2 additional schooling grades among adults.\textsuperscript{79}

**Concluding remarks**

Childhood vaccines have numerous positive effects beyond disease prevention. The concept of broader benefits of vaccines which would include cognition, schooling, economic productivity, fertility, and related outcomes was first proposed by a key 2005 article.\textsuperscript{80} During the present decade, researchers have utilized and expanded this framework across several dimensions and country contexts.\textsuperscript{76,77,78-85}

A new online database called the Value of Immunization Compendium Evidence (VoICE), created and maintained by the International Vaccine Access Center at the Johns Hopkins University, Bloomberg School of Public Health, now tracks research on the broader benefits of vaccines on health, educational, economic, and equity outcomes worldwide.\textsuperscript{86} The Immunization Economics community of research and practice compiles similar and related information.\textsuperscript{87} Finally, the World Health Organization is developing an approach for systematically measuring the broader benefits, known as the Full Public Health Value Propositions (FPHVP), in the context of LMICs.\textsuperscript{88,89} Regardless of income level, countries around the world are facing a crises in the acceptance of the societal benefits of routine vaccines. Going forward, we hope that these new frameworks will be widely used for child health policy globally.

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**References**

1. World Health Organization. World Health Organization: 10 facts on immunization; 2018 [accessed 2019 Apr 9]. https://www.who.int/features/factfiles/immunization/en/.

2. World DataBank: World Development Indicators. The World Bank; 2017. http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators.

3. Ozawa S, Mirelman A, Stack ML, Walker DG, Levine OS. Cost-effectiveness and economic benefits of vaccines in low- and middle-income countries: a systematic review. Vaccine. 2012;31:96–108. doi:10.1016/j.vaccine.2012.10.103.

4. Pramanik S, Agrahari K, Srivastava A, Varanasi V, Setia M, Laxminarayan R. Integrated child health and immunization survey-rounds 1 & 2. New Delhi (India): Immunization Technical Support Unit, Ministry of Health and Family Welfare, Government of India; 2016.

5. World Health Organization. Progress towards global immunization goals - 2016. Geneva (Switzerland); 2016. http://who.int/entity/immunization/monitoring_surveillance/SlidesGlobalImmunization.pptx?ua=1.

6. Murhekar M. Epidemiology of diphtheria in India, 1996–2016: implications for prevention and control. Am J Trop Med Hyg. 2017;97:313–18. doi:10.4269/ajtmh.17-0047.

7. Jaliloh MF, Bennett SD, Alam D, Koutu P, Lourenço D, Alamgir M, Feldstein LR, Ehlman DC, Abad N, Kapil N. Rapid behavioral assessment of barriers and opportunities to improve vaccination coverage among displaced Rohingyas in Bangladesh, January 2018. Vaccine. 2019;37:833–38. doi:10.1016/j.vaccine.2018.12.042.

8. Chan M. Linking child survival and child development for health, equity, and sustainable development. Lancet. 2013;381:1514–15. doi:10.1016/S0140-6736(13)60944-7.

9. Shonkoff JP, Richter L, van der Gaag J, Bhutta ZA. An integrated scientific framework for child survival and early childhood development. PEDIATRICS. 2012;129:e460–72. doi:10.1542/peds.2011-0366.

10. Ozawa S, Clark S, Portnoy A, Grewal S, Stack ML, Sinha A, Mirelman A, Franklin H, Friberg IK, Tam Y. Estimated economic impact of vaccinations in 73 low- and middle-income countries, 2001–2020. Bull World Health Organ. 2017;95:629–38. doi:10.2471/BLT.16.178475.

11. Hooda SK. Out-of-pocket payments for healthcare in India. J Health Manag. 2017;19:1–15. doi:10.11607/ijhpm.97206341682535.

12. Wagstaff A, Flores G, Smitz M-F, Hsu J, Chepynoga K, Ezenou P. Progress on impoverishing health spending in 122 countries: a retrospective observational study. Lancet Global Health. 2018;6:e180–92. doi:10.1016/S2214-109X(17)30486-2.

13. Riumallo-Herl C, Chang AY, Clark S, Constenla D, Clark A, Brenzel L, Verguet S. Poverty reduction and equity benefits of introducing or scaling up measles, rotavirus and pneumococcal vaccines in low-income and middle-income countries: a modelling study. BMJ Global Health. 2018;3:e000613.

14. Megiddo I, AR C, Nandi A, Chatterjee S, Prinja S, Khera A, Laxminarayan R. Analysis of the universal immunization programme and introduction of a rotavirus vaccine in India with IndiaSim. Vaccine. 2014;32(Supplement 1):A151–61.

15. Megiddo I, Klein E, Laxminarayan R. Potential impact of introducing the pneumococcal conjugate vaccine into national immunisation programmes: an economic-epidemiological analysis using data from India. BMJ Global Health. 2018;3:e000636. doi:10.1136/bmjgh-2017-000636.

16. Verguet S, Murphy S, Anderson B, Johansson KA, Glass R, Rheingans R. Public finance of rotavirus vaccination in India and Ethiopia: an extended cost-effectiveness analysis. Vaccine. 2013;31:4902–10. doi:10.1016/j.vaccine.2013.07.014.

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17. Johansson KA, Memirie ST, Pencenka C, Jamison DT, Verguet S. Health gains and financial protection from pneumococcal vaccination and pneumonia treatment in Ethiopia: results from an extended cost-effectiveness analysis. PLoS One. 2015;10:e0142691.
18. Verguet S, Olson ZD, Babigumira JB, Desaegher D, Johansson KA, Kirke ME, Levin CE, Nugent RA, Pencenka C, Shrieve MG. Health gains and financial risk protection afforded by public financing of selected interventions in Ethiopia: an extended cost-effectiveness analysis. Lancet Global Health. 2015;3:e288–96. doi:10.1016/S2214-1094(14)00346-8.
19. Chang AY, Riumallo-Herl C, Peralta NA, Clark S, Clark A, Constena D, Garske T, Jackson ML, Jean K, Jit M. The equity impact vaccines may have on averting deaths and medical impoverishment in developing countries. Health Aff. 2018;37:316–24. doi:10.1377/hlthaff.2017.0861.
20. Wagstaff A, Flores G, Hsu J, Smitz MF, Chepynoga K, van Wilgenburg K. Progress on catastrophic health spending in 133 countries: a retrospective observational study. Lancet Global Health. 2018;6:e169–79.
21. Verguet S, Laxminarayan R, Jamison DT. Universal public finance for tuberculosis treatment in India: an extended cost-effectiveness analysis. Health Econ. 2014;24:318–32. doi:10.1002/hec.3019.
22. Park M, Jit M, Wu JT. Cost-benefit analysis of vaccination: a comparative analysis of eight approaches for valuing changes to mortality and morbidity risks. BMC Med. 2018;16:139. doi:10.1186/s12916-018-1130-7.
23. Zhou F, Shefer A, Wenger J, Messonnier M, Wang LY, Lopez A, Moore M, Murphy TV, Cortese M, Rodewald L. Economic evaluation of the routine childhood immunization program in the United States, 2009. Pediatrics. 2014;133:577–85. doi:10.1542/peds.2013-0698.
24. Robinson LA, Hammitt JK, Jamison DT, Walker DG. Conducting benefit-cost analysis in low- and middle-income countries: introduction to the special issue. J Ben Cost Anal. 2019;10:1–14. doi:10.1017/bca.2019.4.
25. Robinson LA, Hammitt JK, O’Keeffe L. Valuing mortality risk reductions in global benefit-cost analysis. J Ben Cost Anal. 2019;10:15–50. doi:10.1017/bca.2018.26.
26. Laxminarayan R, Jamison DT, Kruhipnic AJ, Norheim OF. Valuing vaccines using value of statistical life measures. Vaccine. 2014;32:5065–70. doi:10.1016/j.vaccine.2014.07.003.
27. Laxminarayan R, Klein EY, Darley SR, Adeyi O. Global investments in TB control: economic benefits. Health Aff. 2009;28:w730–42. doi:10.1377/hlthaff.28.4.w730.
28. Viscusi WKK, Aldy JEJ. The value of a statistical life: a critical review of market estimates throughout the world. J Risk Uncertain. 2003;25:7–76. doi:10.1023/A:1025598106257.
29. Jamison DT, Jha P, Bloom D. The challenge of diseases. Copenhagen consensus 2008 challenge paper: diseases. Copenhagen: Copenhagen Consensus Center; 2008.
30. Jamison DT, Jha P, Laxminarayan R, Ord T. Infectious disease, injury, and reproductive health. Copenhagen: Copenhagen Consensus Center; 2012.
31. Jha P, Hum R, Gauvreau CL, Jordan K. Benefits and costs of the health targets for the post-2015 development agenda. In: Lomborg B, editor. Prioritizing development. 1st ed. Cambridge: Cambridge University Press;2018. p.219–30.
32. Ozawa S, Clark S, Portnoy A, Grewal S, Brenzel L, Walker DG. Return on investment from childhood immunization in low- and middle-income countries, 2011–20. Health Aff. 2016;35:199–207. doi:10.1377/hlthaff.2015.1086.
33. Levin CE, Sharma M, Olson Z, Verguet S, Shi JF, Wang SM, Qiao YL, Jamison DT, Kim JJ. An extended cost-effectiveness analysis of publicly funded HPV vaccination to prevent cervical cancer in China. Vaccine. 2015;33:2830–41.
34. Driessen J, Olson ZD, Jamison DT, Verguet S. Comparing the health and social protection effects of measles vaccination strategies in Ethiopia: an extended cost-effectiveness analysis. Soc Sci Med. 2015;139:115–22. doi:10.1016/j.socscimed.2015.06.018.
35. Interagency Coordination Group on Antimicrobial Resistance. No time to wait: securing the future from drug-resistant infections; 2019 https://www.who.int/antimicrobial-resistance/interagency-coordination-group/IACG_final_report_EN.pdf#ua-1.
36. Goossens H. Antibiotic consumption and link to resistance. Clin Microbiol Infect. 2009;15(Suppl 3):12–15. doi:10.1111/j.1469-9331.2009.02725.x.
37. van de Sande-bruijsma N, Grundmann H, Verloo D, Tiemersma E, Monen J, Goossens H, Ferech M. Antimicrobial drug use and resistance in Europe. Emerging Infect Dis. 2008;14:1722–30. doi:10.3201/eid1411.070467.
38. World Health Organization. Antimicrobial resistance: global report on surveillance 2014. Geneva: World Health Organization; 2014.
39. CDDEP. State of the world’s antibiotics. Washington (DC): Center for Disease Dynamics, Economics & Policy; 2015.
40. Utt E, Wells C. The global response to the threat of antimicrobial resistance and the important role of vaccines. Pharm Policy and Law. 2016;18:179–97. doi:10.3233/PPL-160442.
41. The Review on Antimicrobial Resistance chaired by Jim O’Neill. Tackling drug-resistant infections globally: final report and recommendations. London: HM Government, Wellcome Trust; 2016.
42. Bloom DE, Brenzel L, Cadarette D, Sullivan J. Moving beyond traditional valuation of vaccination: needs and opportunities. Vaccine. 2017;35:A29–35. doi:10.1016/j.vaccine.2016.12.001.
43. Global Antibiotic Resistance Partnership. Rationalizing antibiotic use to limit antibiotic resistance in India(+) . Indian J Med Res 2011;134:281–94.
44. Laxminarayan R. Antimicrobial effectiveness: balancing conservation against innovation. Science. 2014;345:1299–301. doi:10.1126/science.1254163.
45. Sevilla JP, Bloom DE, Cadarette D, Jit M, Lipsitch M. Toward economic evaluation of the value of vaccines and other health technologies in addressing AMR. PNAS. 2018;115:12911–19. doi:10.1073/pnas.1717161115.
46. Bloom DE, Black S, Salisbury D, Rappuoli R. Antimicrobial resistance and the role of vaccines. Proc Natl Acad Sci USA. 2018;115:12868–71. doi:10.1073/pnas.1717157115.
47. Dewey KG, Begum K. Long-term consequences of stunting in early life. Mat Child Nutr. 2011;7(Suppl 3):5–18. doi:10.1111/j.1476-0328.2011.0033-s.
48. Almond D, Currie J. Killing me softly: the fetal origins hypothesis. J Econ Perspect. 2011;25:153–72. doi:10.1257/jep.25.3.153.
49. Currie J, Vogl T. Early-life health and adult circumstance in developing countries. Annu Rev Econ. 2013;5:1–36. doi:10.1146/annurev-economics-081412-103704.
50. Barker DJ. The fetal and infant origins of adult disease. BMJ. 1990;301:1111–1111. doi:10.1136/bmj.301.6761.1111.
51. Barker DJ. Fetal origins of coronary heart disease. BMJ. 1995;311:171–74. doi:10.1136/bmj.311.6988.171.
52. Adair LS, Fall CH, Osmond C, Stein AD, Martorell R, Ramirez-Zea M, Sachdev HS, Dahly DL, Bas I, Norris SA. Associations of linear growth and relative weight gain during early life with adult health and human capital in countries of low and middle income: findings from five birth cohort studies. Lancet. 2013;382:525–34. doi:10.1016/S0140-6736(13)60103-8.
53. Alderman H, Hoddinott J, Kinsey B. Long term consequences of early childhood malnutrition. Oxf Econ Pap. 2006;58:450–74. doi:10.1093/oepp/ppl008.
54. Behrman JR, Calderon MC, Preston SH, Hoddinott J, Martorell R, Stein AD. Nutritional supplementation in girls influences the growth of their children: prospective study in Guatemala. Am J Clin Nutr. 2009;90:1372–79. doi:10.3945/ajcn.2009.27524.
55. Dercon S, Porter C. Live aid revisited: long-term impacts of the 1984 Ethiopian famine on children. J Eur Econ Assoc. 2014;12:927–48. doi:10.1111/jeea.12088.
56. Hoddinott J, Alderman H, Behrman JR, Hoddad L, Horton S. The economic rationale for investing in stunting reduction.
Matern Child Nutr. 2013;9(Suppl 2):69–82. doi:10.1111/mcn.2013.9.issue-s2.

57. Maccini S, Yang D. Under the weather: health, schooling, and economic consequences of early-life rainfall. Am Econ Rev. 2009;99:1006–26. doi:10.1257/aer.99.3.1006.

58. Maluccio J, Hoddinott J, Behrman J, Quisumbing A, Martorell R, Stein AD. The impact of nutrition during early childhood on education among guatemalan adults. Econ J. 2009;119:734–63. doi:10.1111/j.1468-0297.2009.02220.x.

59. Martorell R, Horta BL, Adair LS, Stein AD, Richter L, Fall CHD, Bhargava SK, Biswas SKD, Perez L, Barros FC. Weight gain in the first two years of life is an important predictor of schooling outcomes in pooled analyses from five birth cohorts from low- and middle-income countries. J Nutr. 2010;140:348–54. doi:10.3945/jn.110.112300.

60. Nandi A, Ashok A, Kinra S, JR B, Laxminarayan R. Early childhood nutrition is positively associated with adolescent educational outcomes: evidence from the Andhra Pradesh child and parents study (APCAPS). J Nutr. 2016;146:1–8.

61. Nandi A, Behrman JR, Bhalotra S, Deolalikar AB, Laxminarayan R. Human capital and productivity benefits of early childhood nutritional interventions. In: Bundy DAP, et al., editors. Disease control priorities third edition, volume 8: child & adolescent development. Washington (DC): World Bank Publications; 2017. p. 385–402.

62. Stein AD, Barros FC, Bhargava SK, Hao W, Horta BL, Lee N, Kuzawa CW, Martorell R, Ramji S, Stein A. Birth status, child growth, and adult outcomes in low- and middle-income countries. J Pediatr. 2013;163:1740–1746.e4. doi:10.1016/j.jpeds.2013.08.012.

63. Stein AD, Wang M, Martorell R, Norris SA, Adair LS, Bas I, Sachdev HS, Bhargava SK, Fall CHD, Gigante DP. Growth patterns in early childhood and final attained stature: data from five birth cohorts from low- and middle-income countries. Am J Hum Biol. 2010;22:353–59. doi:10.1002/ajhb.20998.

64. Victora CG, Adair L, Fall C, Hallal PC, Martorell R, Richter L, Sachdev HS. Maternal and child undernutrition: consequences for adult health and human capital. Lancet. 2008;371:340–57.

65. Nandi A, Behrman JR, Kinra S, Laxminarayan R. Early-life nutrition is associated positively with schooling and labor market outcomes and negatively with marriage rates at age 20–25 years: evidence from the Andhra Pradesh children and parents study (APCAPS) in India. J Nutr. 2018;148:140–46. doi:10.1093/jn/nnx012.

66. Nandi A, Behrman J, Laxminarayan R. The impact of a national early childhood development program on future schooling attainment: evidence from ICDS in India. Econ Dev Cult Change. 2019. In Press. doi:10.1086/703078.

67. Serup S, Benn CS, Poulsen A, Krause TG, Aaby P, Ravn H. Live vaccine against measles, mumps, and rubella and the risk of hospital admissions for nontargeted infections. JAMA. 2014;311:826–35. doi:10.1001/jama.2014.470.

68. Mina MJ. Measles, immune suppression and vaccination: direct and indirect nonspecific vaccine benefits. J Infect. 2017;74(Suppl 1):S10–7. doi:10.1016/j.jinf.2016.03.009.

69. Mina MJ, Metcalf CJE, de Swart RL, Osterhaus ADME, Grenfell BT. Long-term measles-induced immunomodulation increases overall childhood infectious disease mortality. Science. 2015;348:694–99. doi:10.1126/science.aan3662.

70. Mina MJ, Kula T, Leng Y, Li M, de Vries RD, Knip M, Siljander H, Rewers M, Choy DF, Wilson MS. Measles virus infection diminishes preexisting antibodies that offer protection from other pathogens. Science. 2019;366:599–606. doi:10.1126/science.aay6485.

71. Nandi A, Shet A, Behrman JR, Black MM, Bloom DE, Laxminarayan R Anthropometric, cognitive, and educational benefits of measles vaccination: longitudinal cohort analysis in Ethiopia, India, and Vietnam; 2018. CDDEP Working paper.

72. Driessen J, Razaque A, Walker D, Canning D. The effect of childhood measles vaccination on school enrolment in Matlab, Bangladesh. Appl Econ. 2015;47:6019–40. doi:10.1080/00036846.2015.1061647.

73. Aneke TD, Newell M-L, Tanser F, Pillay D, Bärnighausen T. The causal effect of childhood measles vaccination on educational attainment: A mother fixed-effects study in rural South Africa. Vaccine. 2015;33:5020–26. doi:10.1016/j.vaccine.2015.04.072.

74. Nandi A, Deolalikar AB, Bloom DE, Laxminarayan R. Haemophilus influenzae type b vaccination and anthropometric, cognitive, and schooling outcomes among Indian children. Ann N Y Acad Sci. 2019;1449:70–82. doi:10.1111/nyas.14127.

75. Upadhyay AK, Srivastava S. Association between Haemophilus influenzae type B (Hib) vaccination and child anthropometric outcomes in Andhra Pradesh (India): evidence from the young lives study. J Public Health. 2017;25:581–89. doi:10.1086/703897-018-0241-7.

76. Bloom DE, Canning D, Shenoy ES. The effect of vaccination on children’s physical and cognitive development in the Philippines. Appl Econ. 2012;44:2777–83. doi:10.1080/00036846.2011.566203.

77. Canning D, Razaque A, Driessen J, Walker DG, Streetfield PK, Yunus M. The effect of maternal tetanus immunization on children’s schooling attainment in Matlab, Bangladesh: follow-up of a randomized trial. Soc Sci Med. 2011;72:1429–36. doi:10.1016/j.socscimed.2011.02.043.

78. Aneke TD, Kumar S. The effect of a vaccination program on child anthropometry: evidence from India’s Universal Immunization Program. J Public Health (Oxf). 2012;34:489–97. doi:10.1093/pubmed/fds032.

79. Nandi A, Kumar S, Shet A, Bloom DE, Laxminarayan R. Childhood vaccinations and adult schooling attainment: long-term evidence from India’s universal immunisation programme. Rochester (NY): Social Science Research Network; 2019 [accessed 2019 Oct 29]. https://papers.ssrn.com/abstract=3379828.

80. Bloom DE, Canning D, Weston M. The value of vaccination. World Econ. 2005;6:15.

81. Deogaonkar R, Hutubessy R, van der Putten I, Evers S, Jit M. Systematic review of studies evaluating the broader economic impact of vaccination in low and middle income countries. BMC Public Health. 2012;12:878–878. doi:10.1186/1471-2458-12-878.

82. Bloom DE, Fan VY, Sevilla JP. The broad socioeconomic benefits of vaccination. Sci Transl Med. 2018;10:eaaaj2345. doi:10.1126/scitranslmed.aaaj2345.

83. Constenla D, Garcia C, Lefcourt N. Assessing the economics of dengue: results from a systematic review of the literature and expert survey. Pharmacoeconomics. 2015;33:1107–35. doi:10.1007/s40273-015-0294-7.

84. Bärnighausen T, Berkley S, Bhutta ZA, Bishai DM, Black MM, Bloom DE, Constenla D, Driessen J, Edmunds J, Evans D, Reassessing the value of vaccines. Lancet Global Health. 2014;2:e251–2. doi:10.1016/S2214-109X(13)70170-0.

85. Nandi A, Shet A, Behrman JR, Black MM, Bloom DE, Laxminarayan R Anthropometric, cognitive, and schooling benefits of measles vaccination: longitudinal cohort analysis in Ethiopia, India, and Vietnam. Vaccine. 2019;37:4336–43. doi:10.1016/j.vaccine.2019.06.025.

86. International Vaccine Access Center. The value of immunization compendium of evidence. VoICE; 2019 [accessed 2019 Oct 30]. https://immunizationevidence.org/.

87. Harvard TH Chan School of Public Health. Bill & Melinda Gates Foundation. ImmunizationEconomics.org. ImmunizationEconomics.org; 2019 [accessed 2019 Nov 7]. http://immunizationeconomics.org.

88. Saadatian-Elahi M, Horstick O, Breiman RF, Gessner BD, Gubler DJ, Louis J, Parashar UD, Tapia R, Picot V, Zinsou J-A. Beyond efficacy: the full public health impact of vaccines. Vaccine. 2016;34:1139–47. doi:10.1016/j.vaccine.2016.01.021.

89. Jit M, Hutubessy R, ME P, Sundaram N, Audimulam J, Salim S, Yoong J. The broader economic impact of vaccination: reviewing and appraising the strength of evidence. BMC Med. 2015;13. doi:10.1186/s12916-015-0446-9.