Socioeconomic Inequalities in Childhood Vaccination in India: Pathways and Interventions

by

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Dedication

To amma, my best friend, my confidante, and one of the few people who can understand my silences

To appa and Divya, who held my hand through the worst of the times

To Judit, my sister from a different mother

To Chethan, who supported me in every way he could during the darkest hours of my PhD life

And finally, to India, my motherland, and my fellow Indians, who inspire me everyday

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List of Abbreviations

AHS: Annual Health Survey

ANC: Antenatal Care

ANM: Auxiliary Nurse Midwife

ASHA: Accredited Social Health Activist

AWW: Anganwadi Worker

BCG: Bacillus-Calmette Guerin

CEB: Census Enumeration Block

CHW: Community Health Worker

DALY: Disability Adjusted Life Years

DHS: Demographic Health Survey

DLHS: District Level Household and Facility Survey

DPT: Diphtheria-Pertussis-Tetanus vaccine

DWLS: Diagonally Weighted Least Squares Method

EAG: Empowered Action Group

GAVI: Global Alliance on Vaccine Initiative

GDP: Gross Domestic Product

ICER: Incremental Cost Effectiveness Ratio

IIPS: International Institute of Population Sciences

INR: Indian Rupees

JSY: Janani Suraksha Yojana

MCV: Measles Containing Vaccine

NFHS: National Family Health Survey

NHM: National Health Mission

NRHM: National Rural Health Mission

OM: Otitis Media

OPV: Oral Polio Vaccine

PHC: Primary Health Center

PSA: Probabilistic Sensitivity Analysis

PSU: Primary Sampling Unit

SEM: Structural Equation Modeling

SES: Socioeconomic Status

SIA: Supplementary Immunization Activity

SSU: Secondary Sampling Unit

UIP: Universal Immunization Program

WHO: World Health Organization

Abstract

India has the largest number of children aged under 5 years of any country in the world but also one of the lowest childhood immunization rates globally. Important health initiatives of the Indian government such as the Universal Immunization Program and the Reproductive and Child Health program have increased childhood vaccination rates and decreased socioeconomic inequalities. However, there is a paucity of national level studies that have utilized data collected after 2006 to examine these issues.

In this dissertation, we examined time-trends in socioeconomic inequalities in childhood vaccination over an 11-year period between 2002 and 2013 using cross-sectional data collected during three distinct time-periods: 2002-2004, 2007-2008 and 2012-2013 in 29 Indian states. We assessed the role of availability and acceptability of health services as potential mediators in the association between socioeconomic status and childhood vaccination in 20 Indian states during 2007-2008 and 2012-2013. Finally, we examined the cost-effectiveness of the accredited social health activist (ASHA) program, a community health worker initiative introduced under National Rural Health Mission in 2005, in improving measles vaccination.

We examined the associations between socioeconomic status (SES) and full childhood vaccination for three time-periods, stratifying our analyses by time-period and empowered action group (EAG) state status. Non-EAG states experienced decreased full vaccination rates in 2012-2013 compared to 2007-2008. We found that while SES based-inequalities in vaccination rate decreased in both EAG and non-EAG states, they were present to a greater degree in EAG states for all three time-

periods; however, the gap in SES based-disparities between EAG and non-EAG states decreased during this 11-year time-period.

To examine these inequalities further, we conducted mediation analyses to explore how availability and accessibility of vaccination services could mediate the association between SES and full childhood vaccination during 2007-2008 and 2012-2013. In our analyses, the indirect effect mediated by availability and acceptability of health services was positive and the direct effect of SES on full childhood vaccination was negative for both time-periods. The total direct effect of SES on full childhood was positive in 2007-2008 while negative in 2012-2013.

Finally, we conducted a cost-effectiveness analysis of ASHAs with regards to childhood measles vaccination, obtaining parameter estimates for our cohort simulation model from 2012-2013 data and prior literature. ASHAs were highly cost-effective in our univariate sensitivity analyses and most of the bivariate and probabilistic sensitivity analyses. ASHAs remained cost-effective even when their financial incentive to perform measles vaccination related services was increased by 10 times. They remained cost-effective in long-term scenarios where the cohort size of a village decreased over time as more and more children were vaccinated.

In view of these findings, the Indian government may want to focus its efforts on both EAG and non-EAG states to receive adequate funding and resources to ensure gains in vaccination are not lost. This study also demonstrates the possibility of vaccine hesitancy and lower full vaccination rates among children from richer households due to availing of vaccine services from private healthcare providers who tend to be less accountable than public healthcare providers in ensuring full vaccination of children. Finally, we quantitatively demonstrate the cost-effectiveness of ASHAs even when considering a single outcome among their myriad responsibilities and show that the financial compensation for ASHAs for services they render can be increased without compromising their cost-effectiveness.

Chapter 2 Introduction

The World Health Organization (WHO) defines vaccine preventable diseases as those infectious diseases for which an effective vaccine is widely and often freely available. WHO estimates that around 2.5 million deaths occur globally each year due to vaccine preventable diseases of which 1.8 million deaths occur among children aged below 5 years.[1] Completion of the third dose of diphtheria-pertussis-tetanus vaccine (DPT3) is widely considered to be an indicator of vaccination delivery and receipt, and an approximate measure of immunization systems performance. In 2015, around 22% of the 19.6 million children globally aged less than five years who were not vaccinated with DPT3 were living in India, which is home to around 18% of the world's under-five population.[2] However, the overall coverage of vaccination with BCG (Bacille Calmette-Guerin), DPT, oral polio vaccine (OPV), and measles vaccines have improved between 1992-2006 (Figure 1.1). [2]

India's Universal Immunization Program

The expanded program on immunization (EPI) was introduced in India in 1978 and renamed the universal immunization program (UIP) in 1985.[3] At the time the EPI was launched, , BCG, DPT (diphtheria-whole cell pertussis-tetanus vaccine), and OPV comprised the recommended vaccines in the routine vaccination schedule (Table 1.1). Measles containing vaccine was added in 1985.[3]

In 2017, the UIP schedule has replaced the trivalent DPT vaccine with pentavalent vaccine, which along with the DPT antigens also contains Hepatitis B and *Hemophilus influenzae B* (Hib) antigens; rotavirus vaccine is also being introduced in a phased manner.[4,5] Japanese encephalitis vaccine has been introduced to the routine immunization schedule, but only in endemic areas.[5] All vaccine doses recommended in the UIP are provided free of cost to all children in public healthcare facilities, and are funded by the government of India.

Where are vaccines administered in India?

Childhood vaccines are administered in both private and public health sectors. The contribution of private health sector ranges from 2.3% for DPT to 7.6% for OPV and is limited primarily to states with high per-capita-income, and in urban areas, where residents tend to have higher levels of disposable income. In low-income states, which are home to more than 50% of India's children aged less than 5 years, the contribution of private health sector to childhood vaccination is negligent, and most of the vaccinations are predominantly administered in the public health sector.[6]

Empowered Action Group states

The states of Assam, Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Odisha, Rajasthan, Uttarakhand, and Uttar Pradesh were designated as empowered action group states (EAG) by the Ministry of Health and Family Welfare, Government of India in 2001. These nine states constitute around 45% of the total population in the country and are characterized by relatively high infant, child and maternal mortality rates compared to states such as Kerala, Tamil Nadu, and Goa which have relatively low fertility, infant mortality, maternal mortality and childhood mortality rates compared to rest of India.[7]

The National Rural Health Mission (NRHM) was introduced by the Ministry of Health and Family Welfare of the Indian Government in 2005 and charged with focusing on rural populations. It aims to provide accessible, affordable and quality health care, especially to vulnerable populations in rural areas. One of the specific goals of NRHM is to improve the availability and utilization of maternal and child health care services, including childhood immunization, for the entire population.[8,9] NRHM was also intended to promote equity in availability and utilization of healthcare services for all Indians. NRHM was carried out through key national programs such as the Reproductive and Child Health II project (RCH II), the National Disease Control Programs (NDCP), and the Integrated Disease Surveillance Project (IDSP).[10]

Due to the past poor public health systems performance in EAG states, the NRHM specifically focused on these states, in addition to the seven north eastern states of India.[8] Public health programs were sometimes implemented differently in EAG and non-EAG states under NRHM. For example, Janani Suraksha Yojana (JSY), a program of NRHM focusing on promoting institutional delivery, targeted pregnant women aged 19 years and above with below-poverty line economic status. In non-EAG states, pregnant women were provided financial incentives for undergoing institutional delivery up to two live births, while in EAG states, this limit was extended up to three live births.[11]

Socioeconomic inequality in childhood vaccination: Why does it matter?

Equitability in distribution of health in the population of a country is increasingly recognized as being equally important as the country's average health status in determining the performance of health systems in a country. Good health is a cornerstone to higher educational attainment and labor productivity.[12] In low and middle-income countries like India which lack a universal health financing system such as the National Health System of the UK, ill health can plunge into poverty due to out-of-pocket payments.[13] As a result, primary preventive measures such as childhood vaccinations are particularly important in children, especially those belonging to poor households, whose families may not be able to afford the out-of-pocket payments if that child was to become ill and require extended medical care or hospitalization due to a vaccine preventable disease.[14] Lower vaccination rates due to socioeconomic inequalities affects poorer households more than richer households in low and middle-income countries, as demonstrated by Rheingans et al. with regards to rotavirus vaccine.[15] Hence, socioeconomic inequalities in vaccination reflect accentuated downstream effects on economically disadvantaged sub-populations. It is imperative that vaccination services are utilized to a high degree among socially and financially disadvantaged populations, especially in low- and middle-income countries such as India to prevent magnified downstream effects on health and economy of these countries.

Prior literature on socioeconomic inequalities in childhood vaccination in India

Socioeconomic inequalities in childhood vaccination has been extensively studied in India. One of the earliest papers addressing socioeconomic inequality in vaccination in India was published by Pande and Yazbeck in 2003,[16] utilizing National Family Health Survey 1 (NFHS 1, conducted in a similar pattern to that of Demographic Health Surveys of other countries) conducted during 1992-1993 to assess socioeconomic, gender-based and urban/rural inequalities across states in India. Gender and urban/rural inequalities were assessed using ratio of vaccination indicator between the two groups, while socioeconomic inequalities were assessed using ratio of vaccination rates between the highest and lowest wealth quintile, and concentration index.

One of the authors of the aforementioned paper, Yazbeck published another paper with Gaudin in 2006[17] utilizing NFHS 2 conducted during 1997-1998 examining whether improvements in overall vaccination rates were accompanied with improved inequality measures for socioeconomic status, gender and urbanicity. Wagstaff's inequality adjusted achievement index[18] was used to assess whether improvements in vaccination rates occurred predominantly in wealthier households or these improvements occurred equally among individuals belonging to all socioeconomic classes.

The authors of these two papers concluded that socioeconomic inequalities in vaccination were lowest in states with very poor rates of full vaccination and states with highest rates of vaccination. The degree of inequality varied among states but tended to be lower in the southern states of Andhra Pradesh, Tamil Nadu, Kerala, and Karnataka. Improvement in vaccination rates were accompanied generally by improvement in socioeconomic inequity though the inequity was generally higher in rural areas compared to urban areas. In general, improvement in vaccination rate was not accompanied by worsening of inequity metrics, though the North-South divide persisted in NFHS 2.

Joe, Navaneetham and Mishra utilized NFHS 3 conducted during 2005-2006 to calculate concentration indices for full immunization across India and different states.[19] Six states (Bihar, Assam, Madhya Pradesh, Jharkhand, Rajasthan and Uttar Pradesh) had the highest concentration indices in terms of socioeconomic status indicating highest socioeconomic inequity. Kumar and Mohanty utilized multinomial logistic regression models to assess the socioeconomic differentials in vaccination in Bihar and Gujarat between 1992-2006[20] utilizing the three NFHS datasets after adjusting for factors such as maternal education, maternal occupation, urbanicity, age of mother, birth order of the child, availability of health card, and exposure to mass media.

Arokiasamy et al. in 2012[21] used decomposition analysis to assess the contribution of factors such as sex of the child, birth order, maternal illiteracy, paternal illiteracy, belonging to scheduled castes and scheduled tribes (historically known to be socially and economically disadvantaged castes in India), belonging to Muslim religion, poor household economic status, and mass media exposure status to the concentration index of full immunization status using the NFHS 3 dataset. The analyses were stratified by EAG states (Rajasthan, Uttar Pradesh, Uttaranchal, Bihar, Jharkhand, Chhattisgarh, Madhya Pradesh, Odisha) and southern states of Karnataka, Kerala, Andhra Pradesh, and Tamil Nadu. The southern states, in general, have higher rates of vaccination and lower rates of infant and maternal mortality rates and childhood malnutrition. The authors found that while female literacy contributed the highest when the outcome was concentration index for full immunization in EAG states, in southern states, household economic status was the greatest contributor.

Historic north-south divide vs NRHM focus on high-priority states: Has it changed the landscape of immunization in India?

The EAG states are located mainly in northern India, while the non-EAG states are located predominantly in southern and western India. In the Arokiasamy et al. study published in 2012,[21] full immunization among children aged 12-23 months in EAG states was around 14% lower than the southern states; however, socioeconomic inequality in vaccination was higher among EAG states than non-EAG states. The state reports published under previous National Family Health Surveys (NFHS) conducted during 1992-93, 1998-99, and 2005-06 by the International Institute of Population Sciences have also demonstrated that full immunization among children generally tended to be better among non-EAG states than EAG states.[22] However, the last NFHS for which individual level data is available was during 2005-06 before the full-scale implementation of NRHM. Given the focus of NRHM on EAG states and north-eastern states, it is imperative to measure whether these differences in full immunization rate and socioeconomic inequality between EAG and non-EAG states persisted between 2005-2012 after the introduction of NRHM.

Community health workers: an intervention aimed at reaching the most disadvantaged populations

Community health workers (CHWs) are a "diverse category of health workers, predominantly female, who commonly work in communities outside of fixed health facilities and have some type of formal, but limited training for tasks they are expected to perform".[23] The roles of CHWs can be diverse even within countries, and the focus of their activities tend to differ across high-, middle-, and low-income countries. In countries with well-developed health systems, CHWs have been shown to improve healthcare delivery where large disparities in health outcomes exist between subpopulations.[23] In countries with limited health workforce resources, CHWs play an important role in delivering primary preventive healthcare services. Large scale CHW programs have been initiated in many countries of Asia and Africa such as India, Bangladesh and Ethiopia, where there is an estimated shortage of around 4.25 million health workers.[23] The common theme behind CHW programs in high income, middle income, and low-income countries has been to ensure equitable distribution of healthcare services and health outcomes. There are currently around 225,000 CHWs in India,[24] which is the largest number of CHWs in one country anywhere in the world.[23]

Specific aims of this paper, and research hypotheses associated with each aim

This dissertation initially examined the time trend in socioeconomic inequalities in childhood vaccination in India between 2002 and 2013. This assessment of time trends was followed by an exploration of different dimensions of accessibility such as availability and acceptability as possible mediators of the association between socioeconomic status and childhood vaccination. The time trend assessment and examination of accessibility and availability led to a final investigation of the cost effectiveness of accredited social health activists, who form the newest category of community health workers in India was explored with respect to measles vaccination.

Aim 1

In the first paper, we examined the time trend of socioeconomic inequalities in childhood vaccination in India for three time-periods: 2002-2004, 2007-2008 and 2012-2013. We stratified our analyses by EAG and non-EAG states. We hypothesized that socioeconomic inequalities in vaccination decreased over time in both EAG and non-EAG states. We also hypothesized that the gap in childhood immunization between EAG and non-EAG states decreased over time after the introduction of NRHM in 2005.

Aim 2

In the second paper, we explored availability and acceptability of vaccination services as possible mediators of the association between socioeconomic status and childhood vaccination. We examined the mediation pathways during 2007-2008 and 2012-2013 in non-EAG states. We hypothesized that the total effect-estimate of socioeconomic status on childhood full vaccination decreased over time. We also hypothesized that the proportion of total effect mediated by availability and acceptability of vaccination services decreased over time.

Aim 3

In the third paper, we conducted a cost effectiveness analysis of accredited social health activists (ASHAs), the newest category of CHWs in India, with respect to measles vaccination. We hypothesized that the ASHAs were highly cost effective with regards to measles vaccination under a wide range of values of probabilities and costs of ASHAs, measles, and measles vaccine related events.

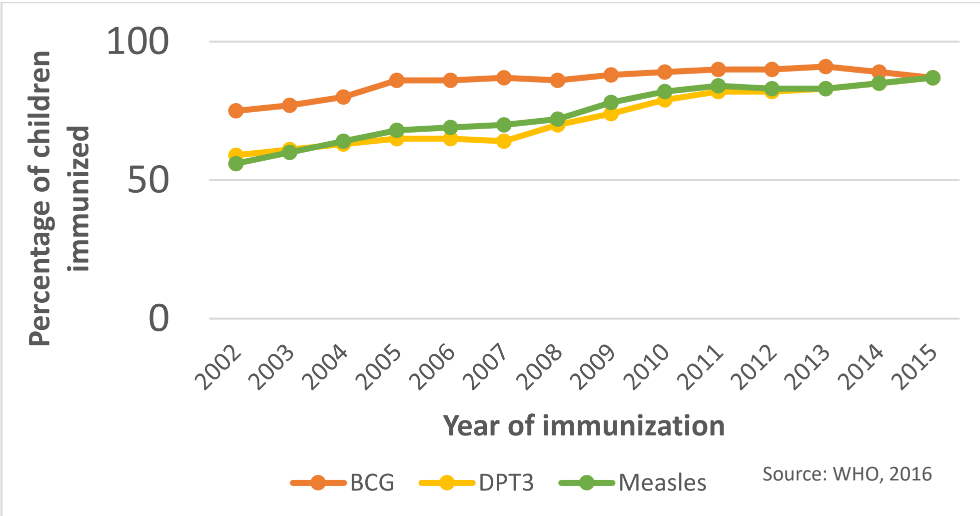
Tables and figures

Table 1.1: Vaccination schedule for BCG, DPT, OPV and measles in India between 2002 and 2013[e]

Vaccine	Birth	6 weeks	10 weeks	14 weeks	9 months	1.5 years	5 years
BCG[a]	✓	--	--	--	--	--	--
DPT[b]	--	✓	✓	✓	--	✓	✓
OPV[c]	✓	✓	✓	✓	--	✓	--
Measles[d]	--	--	--	--	✓	--	--

a. BCG: Bacille Calmette-Guerrin vaccine
b. DPT: Diptheria, whole cell Pertussis and Tetanus toxoid vaccine
c. OPV: Oral Polio Vaccine
d. A booster dose of measles containing vaccine is has been added to the schedule at 1.5 years of age since 2015.
e. In the current schedule (i.e. in 2017), DPT has been replaced by a pentavalent vaccine, which along with the DPT antigens also contains antigens of *Hemophilus influenzae B* and Hepatitis B. Hepatitis B vaccine is also given as a standalone vaccine at birth.

Figure 1.1: Vaccination rates for 1 dose BCG, three doses DPT, three doses OPV, and one dose measles containing vaccine among children aged between 12 and 23 months in India



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Chapter 3 Childhood Vaccination in India: Trends in socioeconomic inequalities, 2002-2013

Introduction

National health system performance is largely based on a country's health status and the equitable distribution of health throughout the population. Good health is, in turn, generally considered key to educational attainment, labor productivity, and income. Health inequalities impede health-related goals and may prevent a country from achieving economic prosperity and the optimal wellbeing of its citizens.

Global policies are increasingly focused on improving health performance while also realizing health equity for all persons in all nations. The onus has clearly been placed on global health partnerships to ensure that the health benefits brought about effectively reach economically and socially disadvantaged populations.[1] Many of the millennium development goals including eradication of extreme poverty and hunger, achieving primary education, and combating HIV/AIDS, malaria, and other diseases, all depend on improving health but also reducing health inequality among the most disadvantaged populations. Moreover, the Sustainable Development Goals, which were adopted by world leaders at the 2015 United Nations Summit, take this a step further and explicitly aim to reduce inequality in access to health, educational services, and other resources.[2]

Childhood vaccination is a key primary prevention measure that saves millions of lives every year. In 2015, WHO estimated that approximately 1.5 million deaths among children aged below 5 globally could be prevented by universal use of safe and effective vaccines.[3,4] Socioeconomic inequality in vaccination matters, in part because the poorest households tend to realize the greatest benefits from vaccination. For example, a study by Rheingans et al. found that the cost effectiveness of rotavirus vaccination was highest in the poorest quintiles in 25 countries eligible for GAVI funding.[5]

India is home to the greatest number of children under 5 years of age in the world, and encouragingly, vaccination rates there have gradually improved over the past few decades. According to India's National Family Health Survey (NFHS), a survey equivalent to the Demographic Health Survey (DHS), the proportion of fully vaccinated children aged between 1-2 years improved from 35% in 1992-1993 to 44% in 2005-2006.[6] However, the extent of that improvement in vaccination rates differed widely between the individual states and territories of India suggesting substantial disparities in access across the entire population.

In 2001, India's ministry of health and family welfare designated eight states as empowered action group (EAG) states: Uttarakhand, Uttar Pradesh, Rajasthan, Bihar, Jharkhand, Chhattisgarh, Madhya Pradesh and Odisha.[7] These states have higher levels of population density and fertility rates while also experiencing higher rates of infant and maternal mortality rates compared to the other states in India. The government placed special emphasis on the implementation of national health programs such as the Reproductive and Child Health-1 program and the UIP in the EAG states compared to other states.[8] Generally childhood vaccination rates have been found to be higher in non-EAG states such as Tamil Nadu, Kerala, Andhra Pradesh, and Karnataka, compared to the EAG states.[9] However, there have been no national level studies that have compared the full vaccination rates of EAG and non-EAG states after 2006.

A lack of more contemporary research is also the case with regard to studies on socioeconomic inequalities in childhood vaccination in India. Most prior literature on socioeconomic inequalities in vaccination at the national level have utilized one or more of the three rounds of NFHS data collected between 1992 and 2006 [6,9–12] with prominent examples including the papers published by Pande and Yazbeck in 2003 (NFHS-1),[10] Gaudin and Yazbeck in 2006 (NFHS-1 and NFHS-2),[11] and Joe et al. in 2010 (NFHS-3).[13] Gaudin and Yazbeck demonstrated that socioeconomic inequalities in vaccination in India's childhood vaccination decreased between 1992 and 1998. Prior literature that utilized data collected between 1998 and 2006 has shown decreasing but persistent socioeconomic inequalities, even in the presence of improved vaccination rates, thereby raising concerns whether the improvement benefits those who need these services the most. However, none of these studies have compared the socioeconomic inequalities in childhood vaccination between EAG and non-EAG states.

The value in comparing EAG and non-EAG states takes on greater significance in the context of the National Health Mission. The National Rural Health Mission (NRHM) was introduced in 2005 by the Ministry of Health and Family Welfare of the Indian government under the 11th five-year plan, and was focused on rural population in India.[14] In 2012, this program was renamed as the National Health Mission (NHM), and in addition to continuing to serve rural areas extended its focus to urban populations as well.[15] The NRHM aimed to provide accessible, affordable, and quality health care, especially to vulnerable populations, with particular emphasis on improving equitable access to maternal and child health care services. The degree of implementation of NRHM varied among the 18 high-priority states and the remaining 17 low-priority states. The 18 high-priority states collectively comprised of the eight EAG states, eight northeastern states of Assam, Nagaland, Manipur, Mizoram, Meghalaya, Arunachal Pradesh, Sikkim and Tripura, Jammu and Kashmir, and Himachal Pradesh.[7,16] For example, Janani Suraksha Yojana, a program under NRHM that provided cash incentives to economically disadvantaged women aged above 19 years was implemented differently in high priority and low priority states with the low priority states providing incentives for undergoing institutional delivery for up to two live births, whereas it was three live births high priority states.[17] Hence, childhood vaccination performance, in terms of both average vaccination rate and equality in childhood vaccination, should be compared between EAG and non-EAG states using data collected after 2005 to evaluate the success of NHM in promoting childhood immunization over the past decade. In our study, the term 'EAG states' refers to the eight EAG states designated by the Indian government and the largest northeastern state of Assam which is one of the NRHM high priority states.

We attempt to address these gaps by utilizing individual level data in India collected between 2002 and 2013 to analyze the time-trends in vaccination rates and socioeconomic inequalities in childhood vaccination in EAG versus non-EAG states. Socioeconomic inequalities are analyzed for three time-periods: 2002-2004, 2007-2008, and 2012-2013. Given that the rates of vaccination coverage have improved over the last decade in India, we hypothesize that socioeconomic inequalities have decreased for full vaccination (receipt of 1 dose of Bacille Calmette-Guerin

(BCG), 3 doses of oral polio vaccine (OPV) and diphtheria-pertussis-tetanus (DPT) each and 1 dose of measles containing vaccine) by 5 years of age in both EAG and non-EAG states. We also examine the influence of rural-urban, gender-based, and maternal education related inequalities in childhood vaccination between 2002-2013 and hypothesize that these inequalities have also decreased during this period of time.

Methods

We utilized four distinct datasets from India for our analyses: the District Level Household and Facilities Survey (DLHS) 2, 3, and 4 which represent three different rounds of the survey administered in 2002-2004, 2007-2008, and 2012-2013, respectively,[18] and the Annual Health Survey (AHS),which was collected during 2012-2013.[19] The DLHS is conducted by India's International Institute of Population Sciences (IIPS, Mumbai, India) while the AHS is conducted by the Office of Registrar General, New Delhi, India on behalf of the Ministry of Health and Family Welfare, India. The DLHS-2 collected data from all states and union territories while the DLHS-3 collected data from all states and union territories except for the state of Nagaland. The DLHS-4 collected data non-EAG states and union territories except Jammu and Kashmir, New Delhi, Daman and Diu, Dadar and Nagar Haveli, Lakshadweep and Gujarat while AHS collected data from the eight EAG states of Uttar Pradesh, Uttarakhand, Rajasthan, Madhya Pradesh, Chhattisgarh, Bihar, Jharkhand, and Odisha, and the ninth state of Assam. For 2012-2013, the data for EAG and non-EAG states were obtained from different surveys. Overall, data was available from 29 states and union territories across the three time-periods and were included in the analyses.

All DLHS surveys are multi-stage stratified surveys.[18] In India, states are divided into administrative divisions known as districts. In DLHS, rural and urban areas of a district were considered natural strata. Urban areas in a district were further stratified, based on their population size, into populations of one million or more class, and less than one million population class cities. The primary sampling units (PSUs) in urban stratum were National Sample Survey Organization urban frame survey blocks, while the secondary sampling units (SSUs) were households. Urban PSUs were selected based on probability proportional to projected population without replacement. In rural stratum, PSUs were selected with probability proportional to size with replacement. The households, being the SSUs, were selected with circular systematic sampling.

The Annual Health Survey utilized a uni-stage, stratified, random sampling design without replacement. In smaller villages with populations of under 2000, with the entire village designated as a sampling unit. In larger villages with population greater than 2000, a two stage sampling technique was employed by dividing them into geographically mutually exclusive enumeration blocks, each not exceeding 2000 in population, and choosing one block randomly from each village for sampling.[19] In urban areas, census enumeration blocks (CEBs) served as the sampling units. In each district, the CEBs within the urban stratum and the villages within each rural stratum were ordered based on the female literacy rate from the census 2001 data. This yielded three disjoint and equal sized substrata within each stratum. The sample CEBs/villages within each substratum were selected by simple random sampling without any replacement, rendering the sample design as self-weighting.

The survey weight of an individual ever-married woman in the DLHS-2, DLHS-3 and DLHS-4 was the inverse of the selection probability of a household. The selection probability of a woman was the product of three probabilities: selection probability of a primary sampling unit (PSU) from a district, a household from a PSU, and a woman from a household. Immunization data was available for up to two most recently born children per woman. In this study, we utilized immunization data for children aged between 12-60 months. The selection probability for a specific child was the ratio of the number of children aged between 12-60 months of a given mother for whom immunization data was available, and the total number of living children aged between 12-60 months the mother had at the time of interview. The survey weight of a child was the inverse of that child's selection probability. We have described the harmonization of survey weights for the DLHS-2, DLHS-3, DLHS-4, and AHS in Appendix A.

Socioeconomic status (SES) of a household was the primary exposure. SES is traditionally measured using income and/or consumption data. However, the DLHS and AHS lacked income and consumption data but included information on household structure, household utilities (e.g. availability of a toilet, type of toilet, whether kitchen is separate from other rooms, type of cooking fuel used, availability of electricity etc.; complete list is available in Appendix B) and household assets (i.e. presence of radio, television, computer, cot with mattress, animals such as cows, buffaloes and goats, and vehicles such as tractors, cars and scooters; complete list is available in Appendix B). We created a composite index to represent SES, where weight for each household structure, utilities, and asset variable was determined using principal composite analysis.[20,21] We multiplied the value of a variable by its factor loading, and standardized the sum of the products to obtain a single ‘asset index’ variable. We performed this procedure for each of the four datasets using Stata (StataCorp, College Station, TX, USA), stratified by rural and urban area of residence.[22] We have listed the variables used for creating asset index in each of the four datasets in Appendix B. Asset index was categorized into quintiles for our bivariate analyses and logistic regression models.

Full vaccination was the primary outcome of interest (i.e., receipt of 1 dose of BCG, 3 doses of DPT, 3 doses of OPV, and 1 dose of MCV) and was treated as an indicator variable. We defined under vaccination as receipt of least one or more doses but not all doses of any of these vaccines, and non- vaccination was the lack of receipt of any doses of any of the aforementioned vaccines. Based on previous literature and prior knowledge,[23] we included the following covariates in the model: state of residence, area of residence (rural/urban), gender of the child, religion of the household, caste of the household, and maternal education. Area of the residence (urban/rural) was a dichotomous variable. Religion of the household was categorized as follows: Hindu, Muslim, Christian, Sikh, Buddhist and others. We categorized the household caste as scheduled caste, scheduled tribe, and others. More detailed information about India’s caste system is available in Appendix C. Maternal education was broken down into the following categories: illiterate, incomplete primary education, completed primary education, incomplete secondary education, completed secondary education, and higher education.

We calculated full vaccination rate for each state for each of the three time-periods, incorporating stratification, clustering, and survey weights. We visually compared full vaccination rates for each state across different time-periods using GIS based choropleth maps of India utilizing maptools,[24] SpatialEpi,[25] and RColorBrewer[26] packages in R[27]. Bivariate analyses were conducted to examine the distribution of covariates and vaccination status among different time periods in EAG and non-EAG states (Table 2.1) using PROC SURVEYFREQ in SAS (SAS Foundation, Cary, NC, USA). We also examined the unadjusted association between asset index and covariates as explanatory variables and full vaccination as the outcome across different time-periods in EAG and non-EAG states using PROC SURVEYFREQ (Table 2.2.1) and PROC SURVEYLOGISTIC in SAS (Table 2.2.2).

We charted concentration curves, plotting cumulative percentage of full vaccination status (y-axis) against the cumulative percentage of the study population, ranked by asset index, extending from the poorest, to the richest in the x-axis (Figure 2.2). These were created for each time-period, stratified by EAG status and area of residence, using the IC2 package[28] in R. The line of equality along the 45^{o} axis indicated equal distribution of vaccination across children belonging to households with different asset indices and served as a reference line to assess the deviation of concentration curves from equality in the distribution of full vaccination rate.

We utilized survey logistic regression models to examine the adjusted association between full vaccination and asset index with the asset index quintiles as the primary exposure, and state, area of residence, gender of the child, maternal education level, religion of the household, and caste of the household as covariates (Table 2.3). We stratified the model by time-period and by EAG status. The model was fit using PROC SURVEYLOGISTIC in SAS (SAS foundation, Cary, NC, USA).

Additionally, we explored the SES-based inequalities in each state in 2012-2013 utilizing a forest plot (Figure 2.3) generated using the ggplot2 package[29] in R. We calculated the odds ratio with

95% confidence intervals of full vaccination among children belonging to poorest quintile households compared to that of children belonging to richest quintile households using PROC SURVEYLOGISTIC in SAS.

Results

Full vaccination rates generally increased in all states of India between 2002 and 2013 (Figure 2.1 and Table 2.1). Among EAG states, full vaccination rates steadily increased from 23.24% in 2002-2004 to 55.65% in 2012-2013. Among non-EAG states, full vaccination rate increased from 58.05% in 2002 to 66.44% in 2007 but dropped to 60.45% in 2012. Despite their non-linear trend between 2002 and 2013, overall, non-EAG states had higher full vaccination rate than non-EAG states across the three time-periods.

In terms of trends of the covariates examined, the proportion of people living rurally decreased by around 4% between 2002 and 2007 and increased by approximately 6% between 2007 and 2012 among EAG states (Table 2.1). Population residing in rural areas steadily decreased from 64.28% in 2002 to 61.6% in 2012 in non-EAG states. The distribution of population by gender remained similar across the three time-periods in both EAG and non-EAG states. Between 2002 and 2013, Hindus decreased by around 3.6% and Muslims increased by around 2.2% in EAG states while in non-EAG states, Hindus decreased by 1% and Muslims increased by 1%. The proportion of population belonging to scheduled caste decreased by around 1.3%, while the proportion of population belonging to scheduled tribes increased by 3.8% in EAG states between 2002 and 2012. In non-EAG states, proportion of population belonging to scheduled castes increased by around 6.8% while the proportion of population belonging to other castes decreased by 8.3%. Maternal education was generally higher in non-EAG states than EAG states across all time-periods. Among EAG states, the proportion of population with illiterate mothers decreased by around 10.5% and the proportion with mothers who had completed primary education increased by around 7.2% between 2002 and 2012. The proportion of population with illiterate mothers decreased by around 10.1% and proportion of population with mothers who had attended higher education increased by around 3.3% between 2002 and 2012 in EAG states.

In our unadjusted analyses, the EAG states generally had lower full vaccination rates than the non-EAG states for all categories of the exposure and the covariates across all time-periods (Table 2.2.1). The rural-urban gap in vaccination decreased with time in both EAG and non-EAG states; in 2012-2013, population living rurally had 10% lower full vaccination rate than people living in urban area. In non-EAG states, however, the rural-urban gap disappeared by 2012-2013, and rural areas had comparable levels of full vaccination with urban areas. The gender inequalities and maternal education-based inequalities in childhood full vaccination decreased across the three time-periods for both EAG and non-EAG states. However, children whose mothers' education level was secondary school and above had better full vaccination rates in EAG states than non-EAG states. Muslim children had similar full vaccination rates as Hindu children in non-EAG states but around 10% lower full vaccination rate in EAG states. Children belonging to scheduled tribes had the highest full vaccination rates among all caste categories in EAG states and the lowest full vaccination rates in non-EAG states. One common trend observed among non-EAG states was the drop in full vaccination rates for almost all categories of exposure and covariates between 2007 and 2012 which was not observed in EAG states.

Both the adjusted logistic regression model (Table 2.3), and the unadjusted, non-parametric concentration curves (Figure 2.2) showed decrease in SES-based inequalities in childhood vaccination between 2002-2013. The adjusted logistic regression model examined SES, area of residence, gender, maternal education, religion, caste-based inequalities in childhood vaccination separately in EAG and non-EAG states. In 2002-2004, the odds of full vaccination among children belonging to poorest quintile households was 66% lower (95% CI: 60%, 63%) compared to the odds of full vaccination among children belonging to richest quintile households in EAG states and 44% lower (95% CI: 28%, 39%) in non-EAG states; EAG states had a higher degree of SES-based inequality in full vaccination compared to non-EAG states. However, in 2012-2013, the children belonging to poorest households had only 11% lower odds of full vaccination compared to children from richest households in both EAG and non-EAG states. The odds ratio of full vaccination was significantly lower for poorest, poor, middle, and rich quintiles compared to richest quintile across all three time-periods in both EAG and non-EAG states; however, the odds ratios increased over time for all four quintiles, indicating decrease in SES-based inequality over time. The degree of SES-based inequality became similar in EAG and non-EAG states by 2012-2013.

Figure 2.2 shows SES-based inequalities in urban and rural areas in EAG and non-EAG states using concentration curves. The degree of SES-based inequality in childhood full vaccination decreased between 2002 and 2014 in both rural and urban areas of India. The SES inequality was slightly higher in rural areas compared to urban areas during the 2002-2004 and the 2007-2008 time-periods in EAG and non-EAG states. The degree of decrease in SES-based inequality was much higher between 2007-2008 and 2012-2013 time-periods compared to the decrease seen between 2002-2004 and 2007-2008. During 2012-2013, the concentration curve almost overlapped the line of equality in rural areas in non-EAG states, whereas it remained distinctly below the line of equality in rural areas of EAG states and urban areas of both EAG and non-EAG states, indicating a reversal of trend with urban areas now experiencing higher SES-based inequality compared to rural areas in non-EAG states.

Figure 2.3 shows the degree of SES-based inequality measured using the adjusted odds of full vaccination among children belonging to poorest households compared to children belonging to richest households in each Indian state during 2012-2013 for which data was available. Among the EAG states, SES-based inequality was not significant in Uttarakhand and Odisha. The other eight states had statistically significant SES-based disparity in childhood full vaccination. Among non-EAG states, SES based-disparity was reversed in Sikkim, where children belonging to poorest households had statistically significantly higher odds of full vaccination than children belonging to richest households. Other northeastern states such as Tripura and Meghalaya also showed reversal of SES-based disparity, though not statistically significant. Among the southern states, Karnataka and Tamil Nadu exhibited significant SES-based disparity. The degree of SES-based inequality was not always correlated with the rate of full vaccination. For example, Punjab, Karnataka and Maharashtra, which had some of the highest full vaccination rates in India had significant SES-based disparity. Conversely, the eastern states of Sikkim and West Bengal had both the highest rates of full vaccination, and either non-significant or reversed SES-based disparity. Most of the EAG states had improved full vaccination rates over time but showed persistent, significant SES-based inequality in childhood full vaccination.

Male children had consistently significantly higher odds than female children of full vaccination across all time-periods in both EAG and non-EAG states (Table 2.3). This gender-based inequality in full vaccination, however, decreased across the three time-periods and remained statistically significant in 2012-2013 only in non-EAG states. Similarly, rural-urban disparities in full vaccination decreased across time in both EAG and non-EAG states; in 2012-2013, population living rurally had 19% lower odds of full vaccination compared to urban population (95% CI: 16%, 22%) in EAG states and 7% higher odds in non-EAG states (95% CI: 1%, 13%) after adjusting for other covariates. The maternal education-based disparities in full vaccination showed a linear trend in all three time-periods in EAG states and in 2007-2008 and 2012-2013 time-periods in non-EAG states. Maternal education-based disparities were generally lower for non-EAG states compared to EAG states. From 2002-2012, maternal education-based disparities decreased in EAG states. In non-EAG states, during 2002-2004, only children of illiterate mothers had statistically significant lower full vaccination rates than children of mothers with higher education. However, between 2007-2012, maternal education-based disparities decreased for children of illiterate mothers in non-EAG states, while it remained stagnant or increased for other categories of maternal education.

Children belonging to Muslim households had significantly lower odds of full vaccination compared to children belonging to Hindu households across all three time-periods in EAG and non-EAG states after adjusting for other covariates. However, the odds ratio of full vaccination among these children increased across time. The odds ratio of full vaccination among Christian children compared to Hindu children was generally not statistically significant in all three time-periods except for 2012-2013 where Christian children had significantly higher odds of full vaccination compared to Hindu children in EAG states. Sikh children had significantly higher odds of full vaccination across all three time-periods than Hindu children in EAG states; in non-EAG states, the odds ratio of full vaccination was not statistically significant except during 2007-2008. Children belonging to scheduled caste and scheduled tribe households had consistently lower odds of full vaccination compared to children belonging to households of other, more socially advantaged, castes in both EAG and non-EAG states. However, these odds ratios improved over time in EAG states, while they remained stagnant in non-EAG states. Children belonging to scheduled tribes had consistently lower odds of full vaccination compared to children belonging to scheduled castes in all three time-periods; this disparity was much higher in non-EAG states compared to EAG states.

Discussion

The rate of full vaccination of children 12-60 months in India generally increased and was accompanied by a decrease in SES-based vaccination disparities over the 11-year span of time (2002-2013) examined in this study. However, we found the decrease in SES-based inequalities in vaccination did not represent a steady decline, but rather fell to a much greater degree between 2007-2013 compared to 2002-2007. This may make sense from a policy standpoint since children included in the latter time-period were born prior to the launch of the NRHM whereas those included in the DLHS 4 and AHS datasets (2012-2013) were born well after NRHM was introduced. The decrease is especially apparent in more rural areas where NRHM was focused initially. The core objective of NRHM was to enhance public health delivery systems by improving the infrastructure and coverage of rural areas by professional and non-professional health care providers.[7] Given that more than 90% of childhood vaccinations are administered in public health facilities,[30] these findings signify the impact of policies and programs such as the NRHM in achieving the millennium development goal of reducing childhood mortality.

The trends in childhood vaccination observed in EAG states and non-EAG states are important from a policy point of view. Under NRHM, 18 states were considered as high-priority states: the eight EAG states, the eight northeastern states, and the states of Jammu and Kashmir, and Himachal Pradesh. The EAG states and most of the northeastern states showed a positive trend in improvement in full vaccination rates across the three time-periods; however, some states historically known for higher vaccination coverage such as the southern states of Tamil Nadu and Andhra Pradesh declined in full vaccination coverage between 2007-2013. These findings may be indicative of the true underlying effect or may be based on spurious results due to potential defective data collection in 2012-2013. It should be noted that DLHS was used for our analyses in non-EAG states in all three time-periods; hence, it is unlikely that any change in survey methodology or data collection techniques may have affected the parameter estimates. It should also be noted that the decline in vaccination rates between 2007 and 2013 was not observed in all non-EAG states and some non-EAG states like Karnataka, Kerala and West Bengal sustained their average full vaccination rates of more than 70% coverage during the 2007-2013 period. Due to the non-uniformity in the trend of full vaccination rates observed in non-EAG states, it is less likely that these findings were spurious.

The decrease in childhood vaccination rates seen between 2007 and 2013 in DLHS data obtained from Tamil Nadu was also found in the NFHS: in 2005-2006 (NFHS-3), full vaccination coverage among children aged 12-23 months in Tamil Nadu during was 80.9%, while in 2015-2016 (NFHS-4), it was 69.7%.[31] To verify the findings from DLHS-4, Murhekar et al. independently conducted cluster surveys across 15 strata in Tamil Nadu during 2015, and reported full vaccination coverage of 79.9% among children aged 12-23 months.[32] They opined that the low vaccination coverage among children in DLHS 4 who were born between 2007 and 2011, could be due to change in vaccination strategy of the government of Tamil Nadu following death of four infants following measles vaccination in April 2008. The Tamil Nadu government terminated outreach vaccination activities and required all children to be vaccinated in health facilities, a policy was that was finally reversed in 2011 but could account for the increase in vaccination observed in the NFHS-4 and Murhekar et al. study compared to DLHS-4. Decline in full vaccination rate in states such as Andhra Pradesh and Himachal Pradesh has to be investigated further to whether these decreases were due to national level or state specific policies, and whether this trend reversed after 2013.

After controlling for SES, we observed the decreases in gender, rural/ urban, and caste-based inequalities over time in both EAG and non-EAG states, which is reassuring. In keeping with previous research,[33,34] maternal education remains a strong predictor of full vaccination, even after adjusting for other sociodemographic factors. In EAG states, a linear trend was observed between maternal education level and full vaccination rate. However, in non-EAG states, children of mothers with higher education experienced improvements in full vaccination as did children of mothers who are illiterate or lack primary education. Interestingly, in non-EAG states, this improvement did not extend to children of mothers with primary and secondary education which is both surprising and unexpected. This may indicate that vaccination rates are stagnating among children of mothers with better education in non-EAG states, perhaps as a side product of the central and state governments' overwhelming focus on more rural and poor populations.

India is a Hindu majority country with much smaller populations in descending order of size of Muslims, Christians and Sikhs. In our analyses, full vaccination among Christian and Sikh children was equivalent to or better than Hindu children which may be due to their higher educational attainment and SES status and population concentrations in states like Kerala, Goa and Punjab which are generally known to have well developed public health systems. However, Muslim children, who have historically had lower vaccination rates compared to children of other religions,[35] appear to be closing the disparity gap in both EAG and non-EAG states, which is a welcome sign, though it is important for the Indian government to continue to ensure access so that these improvements are sustained and built upon.

The reversal of rural-urban disparities in vaccination in non-EAG states may be an indicator of the rapid urbanization followed by development of urban slums with populations known to have poor health outcomes.[36] The government of India extended the coverage of NRHM to urban areas, and renamed NRHM to the as NHM to reflect that change in focus. Efforts are also underway to introduce community health workers, such as accredited social health activists who have long been active in rural areas, in urban areas to improve the access of urban poor to public healthcare facilities. Caste-based inequalities decreased over time in both EAG and non-EAG states; however, they decreased to a greater extent in EAG states than non-EAG states. This stresses the need for non-EAG state governments to focus on reaching out to the socially disadvantaged scheduled castes and scheduled tribes, especially to the remotely located scheduled tribe population, to ensure equitable distribution of vaccination services.

Our study shows that the gap in childhood vaccination between EAG and non-EAG states of India has been closing. However, the decrease is accentuated by the relatively flat vaccination rates in the southern states that have remained either unchanged or decreased compared to the increases in the EAG states. It may be time for the government of India, which has focused heavily on the EAG states as part of the NHM, to revisit their strategy in the southern states to ensure that the past progress in childhood vaccination is not lost or even reversed.

It is important to note that improved vaccination rates did not always translate into a concomitant lowering of SES-based inequality. Indian states such as Rajasthan, Punjab, Kerala, and Tamil Nadu, all of which have full vaccination rates exceeding 60%, are also characterized by high inequality. Conversely, the states of Meghalaya and Tripura, both with less than 40% full vaccination, had very low levels of SES-based inequality. And finally, states such as West Bengal and Sikkim achieved both high levels of full vaccination rate and low levels of SES-based inequality. Clearly, one does not necessarily follow from the other but instead highlights the need for the state governments to concentrate on improving vaccination while also ensuring that these services are equitably distributed and equally accessible for everyone in the population, especially those from those most disadvantaged groups.

This study has a few limitations. The cross-sectional nature of this study prevents us from examining causal relationships between sociodemographic factors and vaccination outcomes. Data was not available from states of Gujarat, Jammu and Kashmir and Nagaland, and the union territories such as New Delhi and Lakshadweep in the DLHS-4 and AHS. Nevertheless, the states included in the analysis encompass more than 90% population of India in our analyses. Survey weights were calculated differently in the DLHS and the AHS datasets. Regardless, the survey weights were, harmonized methodically in three steps as described in Appendix A. The proportion of population living rurally increased between 2007 and 2013 in EAG states. We downscaled the AHS weights using the method described in Appendix A, and recreated table 1. The downscaling of weights did not change the distribution of population living in rural and urban areas. This limitation, however, has been mitigated by stratification by area of residence when creating the asset index variable, and adjusting for rural area of residence in our logistic regression models, which ensured that increased representation of rural population in 2012-2013 did not bias our estimates.

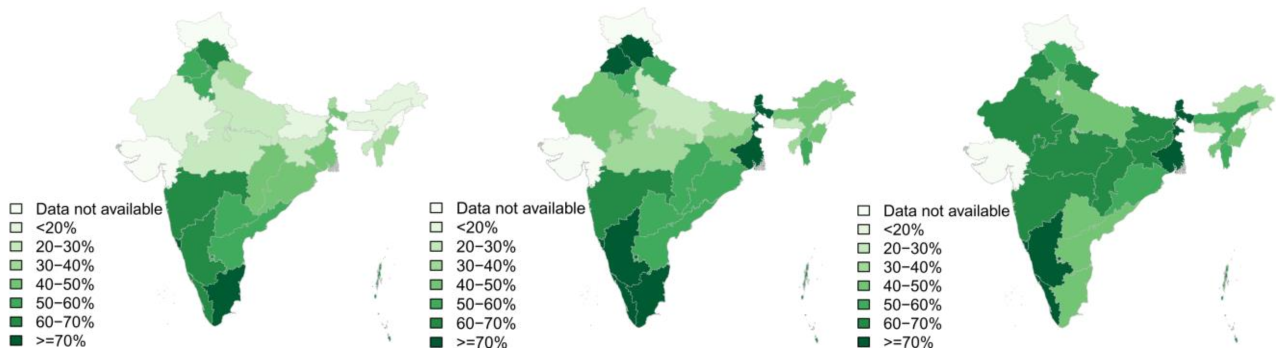
The study also has a number of strengths including the use of national data used from three different time-periods. Most previous studies conducted at a national level utilized DLHS-3 (2007-2008) and/or the NFHS-3 (2005-2006) both of which contain data that is now a decade old. We have provided a more contemporary characterization of childhood immunization in India using the DLHS-4 and AHS representing data collected in the last 5 years. That said, the Indian government should consider measures to release these datasets as soon as possible after completion of data collection; the NFHS-4, which was administered in 2015-2016 and contains information on childhood immunization but was not released to researchers until January 2018. We have also studied the trends in vaccination disparities over a longer period compared to previous studies. A final strength of this study is the analysis of data not only at the national level, but also at individual state level permitting cross-state and cross-territorial comparisons.

Our findings demonstrate the improvement in vaccination coverage and reductions in SES based disparities, especially in EAG states, concurrent with the introduction of initiatives such as NHM. However, given that a substantial proportion of children remain partially vaccinated or not vaccinated at all, the central and state governments should focus on improving access to health care, and on retention of children within the health system to obtain preventive health services such as vaccination. The reduction and plateauing of full vaccination rates in southern states, which have traditionally had high vaccination coverage, is a concern. The government should also focus on urban areas, especially the poorest households such as those in urban slums, to ensure that these population segments can equitably access important preventive health services such as vaccination.

Potential future directions of this research include examination of mediators and effectiveness of interventions aimed at improving vaccination in an equitable manner. Examination of mechanisms helps to inform policy of possible directions to focus their efforts on. Given a wide range of interventions aimed at improving health care service, these interventions have to be systematically examined in a quantitative manner to assess the most effective interventions with least economic burden.

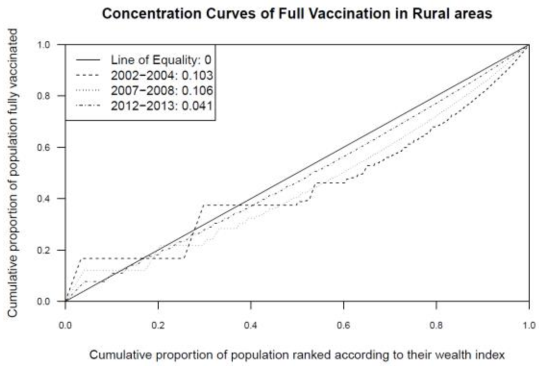
Tables and Figures

Figure 2.1: Proportion of children aged between 1-5 years fully vaccinated in in India during 2002-2004, 2007-2008, and 2012-2013

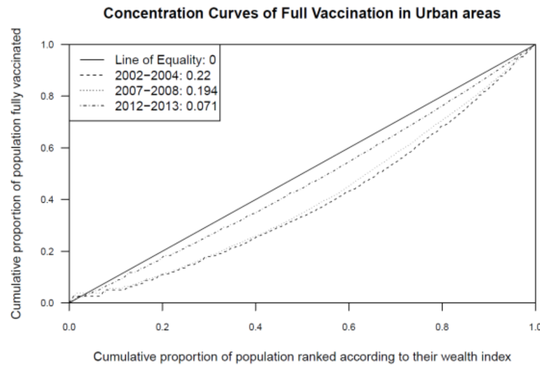


2002-2004 2007-2008 2012-2013

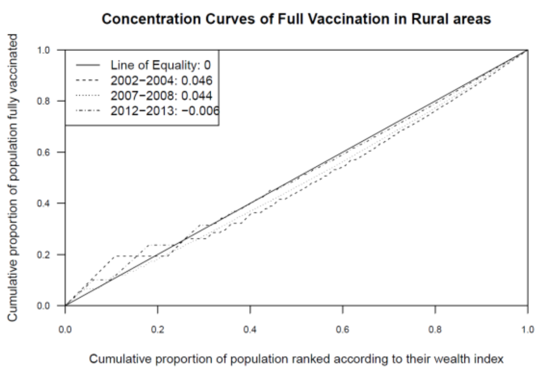
Figure 2.2: Concentration curves of childhood full vaccination in India during 2002-2004, 2007-2008, and 2012-2013 in rural and urban areas



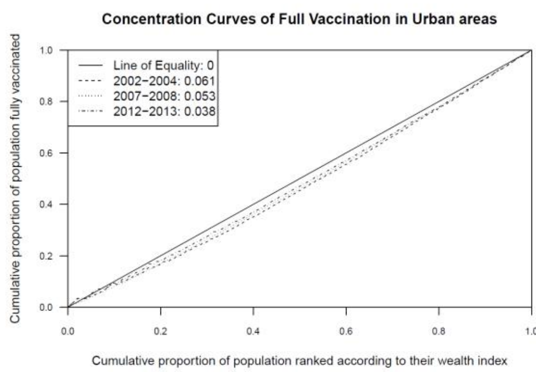
India: Rural (EAG states)



India: Urban (EAG states)



India: Rural (Non-EAG states)



India: Urban (Non-EAG states)

Note: Concentration indices have been provided next to time-periods

Figure 2.3: Forest plot showing odds ratio with 95% confidence interval of full vaccination in children aged 1-5 years belonging to poorest households compared to richest households in Indian states during 2012-2013

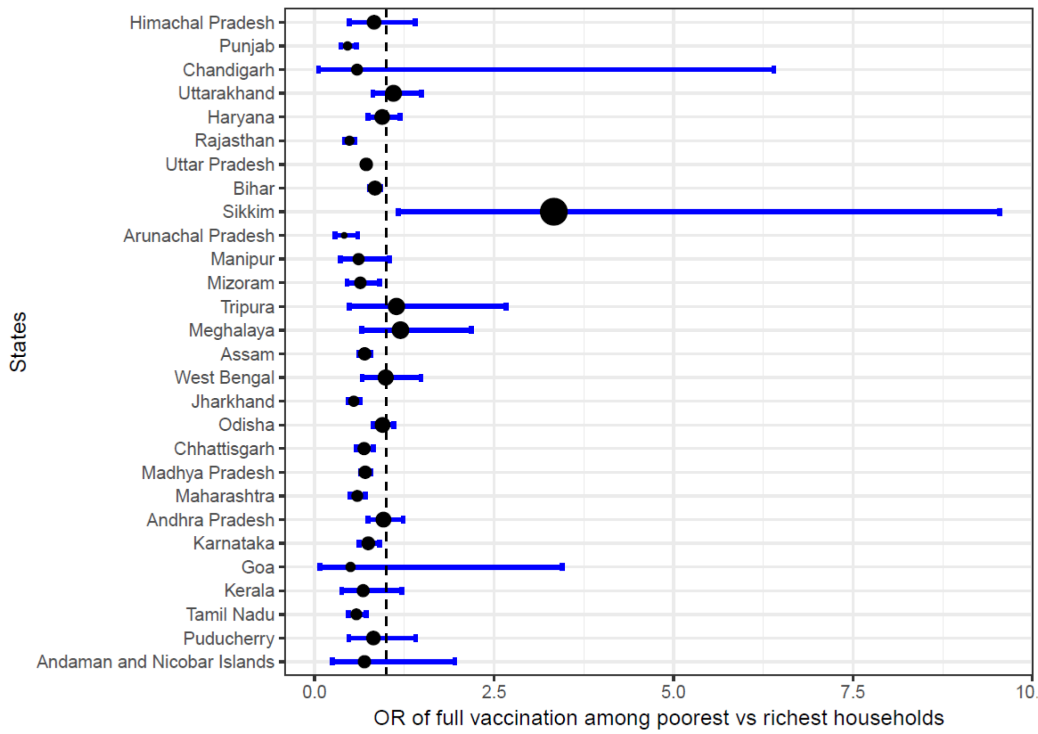


Table 2.1: Distribution of explanatory variables and vaccination status during 2002-2004, 2007-2008, and 2012-2013

	EAG states			Non-EAG states		
	2002-2004[a]	**2007-2008[b]**	**2012-2013[c]**	**2002-2004[a]**	**2007-2008[b]**	**2012-2013[d]**
	N[e]/ Nweight[f] (%)	**N/ Nweight (%)**	**N/ Nweight (%)**	**N/ Nweight (%)**	**N/ Nweight (%)**	**N/ Nweight (%)**
Area of residence						
Rural	95,317/ 43003085 (81.78)	100534/ 54836168 (77.63)	1384643/ 75248804 (83.77)	58323/ 22845058 (64.28)	50643/ 24790577 (65.48)	48982/ 17983879 (61.6)
Urban	32415/ 9579792 (18.22)	15458/ 15797285 (22.37)	240751/ 14578927 (16.23)	25037/ 12696844 (35.72)	16802/ 13069208 (34.52)	29616/ 11210456 (38.4)
Gender						
Male	66679/ 27566908 (52.43)	60319/ 36732576 (52)	860736/ 47642568 (53.08)	43521/ 18541604 (52.17)	35434/ 19742124 (52.15)	41521/ 15328813 (52.52)
Female	61053/ 25015969 (47.57)	55673/ 33900877 (48)	763941/ 42121312 (46.92)	39835/ 16998842 (47.83)	32008/ 18116721 (47.85)	37065/ 13859189 (47.48)
Maternal education						
Illiterate	79280/ 35229891 (67)	67968/ 41428740 (58.65)	683606/ 49798062 (55.44)	27953/ 12489214 (35.14)	17492/ 10023462 (26.48)	16137/ 5848088 (20.03)
Incomplete Primary Education	15904/ 6052616 (11.51)	18341/ 10775535 (15.26)	199914/ 10570075 (11.77)	14732/ 5938662 (16.71)	14487/ 7438218 (19.65)	3594/ 1309850 (4.49)
Completed Primary Education	3500/ 1283257 (2.44)	3528/ 1989683 (2.82)	198641/ 8704744 (9.69)	5783/ 2703966 (7.61)	4965/ 3035315 (8.02)	10052/ 3689064 (12.64)
Incomplete Secondary Education	19893/ 7006743 (13.33)	19156/ 11482364 (16.26)	374171/ 13921008 (15.5)	24482/ 9865286 (27.76)	21011/ 11609962 (30.67)	30444/ 11662551 (39.95)
Completed Secondary Education	4172/ 1363282 (2.59)	3493/ 2286126 (3.24)	87552/ 3238615 (3.61)	4859/ 1894434 (5.33)	4623/ 2613947 (6.9)	9645/ 3531773 (12.1)
Higher Education	4983/ 1647088 (3.13)	3506/ 2671004 (3.78)	81510/ 3595228 (4)	5551/ 2650339 (7.46)	4867/ 3138881 (8.29)	8726/ 3153009 (10.8)
Religion						
Hindu	107790/ 43969958 (83.62)	95630/ 57862885 (81.92)	1328424/ 71849241 (80.05)	52770/ 26332031 (74.09)	42970/ 28327067 (74.83)	52702/ 21930443 (75.14)

Muslim	18009/ 8012671 (15.24)	16883/ 11269428 (15.96)	250355/ 15680603 (17.47)	9287/ 5770867 (16.24)	7278/ 5792343 (15.3)	8818/ 4472172 (15.32)
Christian	1025/ 303546 (0.58)	1316/ 555394 (0.79)	22211/ 1231030 (1.37)	11949/ 1516540 (4.27)	9723/ 1616345 (4.27)	8519/ 1175722 (4.03)
Sikh	312/ 117381 (0.22)	279/ 177458 (0.25)	3736 /184385 (0.21)	3811/ 1110701 (3.13)	3743/ 1201967 (3.18)	4831/ 932719 (3.2)
Buddhist	58/ 17247 (0.03)	24/ 12437 (0.02)	710/ 34945 (0.04)	2862/ 566614 (1.59)	2091/ 704900 (1.86)	2198/ 530745 (1.82)
Others	538/ 162074 (0.31)	1859/ 755182 (1.07)	18967/ 777058 (0.87)	2681/ 245149 (0.69)	1636/ 214374 (0.57)	1506/ 144011 (0.49)
Caste						
Scheduled Caste	24569/ 11028738 (21.21)	22044/ 13488582 (19.29)	312039/ 17870248 (19.91)	15320/ 7439265 (21.21)	13350/ 8295066 (22.63)	18819/ 7659709 (27.93)
Scheduled Tribes	14863/ 5236069 (10.07)	16381/ 8023588 (11.48)	203148/ 12387736 (13.8)	18809/ 3308167 (9.43)	15641/ 4133114 (11.28)	14921/ 3023452 (11.02)
Others	86964/ 35723111 (68.71)	75735/ 48402216 (69.23)	1109216/ 59499279 (66.29)	48277/ 24325549 (69.36)	36760/ 24224061 (66.09)	40727/ 16743309 (61.04)
Vaccination status						
Fully vaccinated	31494/ 12272534 (23.34)	42318/ 25250417 (35.75)	987025/ 49986309 (55.65)	41694/ 20633785 (58.05)	41684/ 25153431 (66.44)	44926/ 17648796 (60.45)
Partially vaccinated	51034/ 20063920 (38.15)	64688/ 40408078 (57.21)	539451/ 33070104 (36.82)	32792/ 12443624 (35.01)	22313/ 11774595 (31.1)	27574/ 10064013 (34.47)
Not vaccinated	45204/ 20246423 (38.5)	8986/ 4974958 (7.04)	98918/ 6771318 (7.54)	8874/ 2464492 (6.93)	3448/ 931760 (2.46)	6098/ 1481526 (5.07)

a. DLHS-2
b. DLHS-3
c. AHS
d. DLHS-4
e. Number of observations
f. Weighted frequency

Table 2.2.1: Unadjusted associations between socioeconomic position indicators and full vaccination

	EAG states			Non-EAG states		
	2002-2004[a]	2007-2008[b]	2012-2013[c]	2002-2004[a]	2007-2008[b]	2012-2013[d]
	N[e](%[f])	N (%)	N (%)	N (%)	N(%)	N (%)
Area of residence						
Rural	95317 (20.4)	100534 (33.68)	1384643 (54.27)	58323 (55.68)	50643 (65.93)	48982 (60.54)
Urban	32415 (36.52)	15458 (42.92)	240751 (62.77)	25037 (62.33)	16802 (67.41)	29616 (60.31)
Gender						
Male	66679 (24.73)	60319 (37)	860736 (55.89)	43521 (58.7)	35434 (66.79)	41521 (60.92)
Female	61053 (21.81)	55673 (34.39)	763941 (55.32)	39835 (57.35)	32008 (66.06)	37065 (59.94)
Maternal education						
Illiterate	79280 (15.27)	67968 (26.76)	683606 (49.7)	27953 (47.67)	17492 (54.14)	16137 (50.42)
Incomplete Primary Education	15904 (29.79)	18341 (39.46)	199914 (58.22)	14732 (58.08)	14487 (65.67)	3594 (59.56)
Completed Primary Education	3500 (36.02)	3528 (48.85)	198641 (60.25)	5783 (61.49)	4965 (68.15)	10052 (62.95)
Incomplete Secondary Education	19893 (41.01)	19156 (50.79)	374171 (64.63)	24482 (65.37)	21011 (72.53)	30444 (62.73)
Completed Secondary Education	4172 (54.27)	3493 (59.46)	87552 (68.75)	4859 (68.38)	4623 (74.68)	8726 (63.37)
Higher Education	4983 (61.62)	3506 (65.49)	81510 (72.71)	5551 (68.83)	4867 (76.46)	8726 (64.82)
Religion						
Hindu	107790 (24.7)	95630 (37.36)	1328424 (57.13)	52770 (60.34)	42970 (68.04)	31134 (60.85)
Muslim	18009 (14.68)	16883 (26.07)	250355 (47.32)	9287 (48.02)	7278 (58.81)	8818 (60.57)
Christian	1025 (28.92)	1316 (44.8)	22211 (63.77)	11949 (53.75)	9723 (58.26)	8519 (51.58)
Sikh	312 (53.97)	279 (49.75)	3736 (71.65)	3811 (60.68)	3743 (77.3)	4831 (61.52)
Buddhist	58 (56.57)	24 (67.13)	710 (63.17)	2862 (63.12)	2091 (68.22)	2198 (61.48)
Others	538 (45.34)	1859 (45.85)	18967 (69.62)	2681 (51.98)	1636 (56.5)	1506 (58.35)

Caste						
Scheduled Caste	4664 (18.31)	22044 (31.93)	312039 (52.72)	15320 (57.02)	13350 (68.49)	18819 (58.32)
Scheduled Tribes	14863 (20.69)	16381 (37.3)	203148 (58.17)	18809 (45.33)	15641 (50.79)	14921 (54.09)
Others	86964 (25.38)	75735 (36.56)	1109216 (56)	48277 (60.41)	36760 (68.96)	40727 (62.31)
Wealth index quintile						
Poorest	36613 (15.07)	33477 (25.43)	305399 (49.8)	20148 (49.64)	6948 (58.7)	16460 (57.9)
Poor	24395 (18.34)	27926 (31.88)	301819 (51.31)	5547 (50.29)	8883 (60.35)	14394 (59.15)
Middle	25562 (20.23)	22464 (37.47)	300234 (54.36)	17047 (54.8)	13554 (64.11)	15998 (59.47)
Rich	21891 (30.15)	17417 (45.33)	302476 (59.44)	19138 (62.12)	18013 (68.83)	15818 (62.21)
Richest	19271 (42.93)	14600 (54.55)	302480 (64.74)	21433 (67.14)	20021 (74.11)	15898 (64.83)

a. DLHS-2
b. DLHS-3
c. AHS
d. DLHS-4
e. Number of observations
f. Percentage of children fully vaccinated

Table 2.2.2: Unadjusted associations between socioeconomic status and covariates and full vaccination measured using survey logistic regression

	EAG states			Non-EAG states		
	2002-2004[a]	**2007-2008[b]**	**2012-2013[c]**	**2002-2004[a]**	**2007-2008[b]**	**2012-2013[d]**
	OR (95% CI)	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**
Socioeconomic status (SES)						
Poorest	0.24 (0.22, 0.25)	0.28 (0.27, 0.3)	0.54 (0.52, 0.56)	0.49 (0.45, 0.53)	0.51 (0.47, 0.55)	0.75 (0.7, 0.8)
Poor	0.3 (0.28, 0.32)	0.39 (0.37, 0.41)	0.57 (0.56, 0.59)	0.51 (0.46, 0.56)	0.55 (0.51, 0.59)	0.77 (0.72, 0.83)
Middle	0.34 (0.31, 0.36)	0.5 (0.48, 0.53)	0.65 (0.63, 0.67)	0.6 (0.56, 0.65)	0.63 (0.59, 0.68)	0.79 (0.74, 0.84)
Rich	0.57 (0.54, 0.62)	0.69 (0.66, 0.73)	0.8 (0.78, 0.82)	0.81 (0.76, 0.86)	0.78 (0.73, 0.83)	0.89 (0.83, 0.94)
Richest	Ref	Ref	Ref	Ref	Ref	Ref
Area of residence						
Rural	0.45 (0.42, 0.48)	0.68 (0.64, 0.72)	0.71 (0.68, 0.73)	0.76 (0.71, 0.82)	0.94 (0.88, 1.003)	1.01 (0.95, 1.06)
Urban	Ref	Ref	Ref	Ref	Ref	Ref
Gender						
Male	1.18 (1.13, 1.22)	1.12 (1.09, 1.15)	1.03 (1.01, 1.04)	1.06 (1.01, 1.1)	1.03 (0.99, 1.08)	1.05 (1.01, 1.09)
Female	Ref	Ref	Ref	Ref	Ref	Ref
Maternal education						
Illiterate	0.11 (0.1, 0.12)	0.19 (0.18, 0.21)	0.37 (0.36, 0.39)	0.42 (0.37, 0.47)	0.37 (0.33, 0.41)	0.55 (0.5, 0.59)
Incomplete Primary Education	0.26 (0.24, 0.29)	0.35 (0.32, 0.38)	0.52 (0.5, 0.55)	0.64 (0.56, 0.74)	0.61 (0.55, 0.68)	0.79 (0.7, 0.89)
Completed Primary Education	0.35 (0.31, 0.4)	0.51 (0.45, 0.57)	0.57 (0.55, 0.6)	0.73 (0.64, 0.85)	0.67 (0.59, 0.76)	0.91 (0.84, 0.995)
Incomplete Secondary Education	0.43 (0.39, 0.47)	0.54 (0.5, 0.6)	0.69 (0.66, 0.71)	0.86 (0.76, 0.97)	0.82 (0.74, 0.91)	0.9 (0.84, 0.96)
Completed Secondary Education	0.73 (0.64, 0.83)	0.77 (0.69, 0.87)	0.83 (0.8, 0.87)		0.91 (0.8, 1.04)	0.92 (0.85, 1)
Higher Education	Ref	Ref	Ref	Ref	Ref	Ref
Religion						
Hindu	Ref	Ref	Ref	Ref	Ref	Ref
Muslim	0.52 (0.48, 0.57)	0.58 (0.55, 0.62)	0.67 (0.65, 0.7)	0.61 (0.56, 0.67)	0.7 (0.64, 0.76)	1.004 (0.92, 1.09)
Christian	1.25 (0.98, 1.59)	1.37 (1.17, 1.17)	1.32 (1.21, 1.44)	0.76 (0.68, 0.85)	0.66 (0.59, 0.72)	0.67 (0.61, 0.74)
Sikh	3.64 (2.67, 4.96)	1.66 (1.19, 2.33)	1.91 (1.51, 2.42)	1.004 (0.89, 1.13)	1.61 (1.46, 1.77)	1.05 (0.96, 1.15)

Buddhist	3.93 (1.92, 8.05)	3.42 (1.33, 8.82)	1.27 (0.75, 2.13)	1.11 (0.9, 1.36)	1.01 (0.86, 1.19)	1.04 (0.89, 1.23)
Others	2.6 (1.95, 3.45)	1.42 (1.22, 1.65)	1.71 (1.5, 1.94)	0.69 (0.48. 0.995)	0.6 (0.46, 0.78)	0.78 (0.6, 1.01)
Caste						
Scheduled Caste	0.66 (0.62, 0.7)	0.81 (0.78, 0.85)	0.88 (0.85, 0.9)	0.87 (0.81, 0.93)	0.98 (0.92, 1.04)	0.85 (0.8, 0.89)
Scheduled Tribes	0.77 (0.71, 0.83)	1.03 (0.98, 1.09)	1.09 (1.05, 1.13)	0.54 (0.49, 0.61)	0.47 (0.43, 0.51)	0.71 (0.66, 0.77)
Others	Ref	Ref	Ref	Ref	Ref	Ref

Table 2.3: Logistic regression model with full vaccination (1 dose of BCG, 3 doses of OPV and DPT each, and 1 dose of measles vaccine) as the outcome, and SES as the primary explanatory variable

	EAG states			Non-EAG states		
	2002-2004	**2007-2008**	**2012-2013**	**2002-2004**	**2007-2008**	**2012-2013**
Number of districts	**284**	**292**	**284**	**249**	**257**	**263**
Number of PSUs	**11504**	**14239**	**21116**	**10075**	**12389**	**13140**
	OR (95% CI)	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**
Socioeconomic status (SES)						
Poorest	0.44 (0.4, 0.47)	0.53 (0.5, 0.57)	0.7 (0.67, 0.72)	0.66 (0.61, 0.72)	0.63 (0.57, 0.7)	0.7 (0.64, 0.76)
Poor	0.54 (0.5, 0.59)	0.67 (0.63, 0.71)	0.76 (0.73, 0.78)	0.71 (0.63, 0.79)	0.74 (0.68, 0.81)	0.76 (0.7, 0.82)
Middle	0.6 (0.55, 0.65)	0.77 (0.73, 0.82)	0.81 (0.78, 0.83)	0.79 (0.72, 0.84)	0.81 (0.75, 0.88)	0.85 (0.79, 0.91)
Rich	0.76 (0.71, 0.82)	0.88 (0.83, 0.93)	0.89 (0.87, 0.92)	0.89 (0.83, 0.96)	0.9 (0.83, 0.96)	0.89 (0.84, 0.96)
Richest	Ref	Ref	Ref	Ref	Ref	Ref
Area of residence						
Rural	0.63 (0.59, 0.67)	0.78 (0.74, 0.83)	0.81 (0.78, 0.84)	0.92 (0.86, 0.99)	1.04 (0.97, 1.12)	1.07 (1.01, 1.13)
Urban	Ref	Ref	Ref	Ref	Ref	Ref
Gender						
Male	1.18 (1.13, 1.23)	1.12 (1.09, 1.15)	1.01 (1, 1.03)	1.05 (1, 1.1)	1.02 (0.98, 1.07)	1.05 (1.01, 1.09)
Female	Ref	Ref	Ref	Ref	Ref	Ref
Maternal education						
Illiterate	0.25 (0.23, 0.28)	0.32 (0.29, 0.35)	0.47 (0.45, 0.49)	0.7 (0.61, 0.8)	0.49 (0.44, 0.56)	0.58 (0.53, 0.64)
Incomplete Primary Education	0.46 (0.41, 0.51)	0.48 (0.43, 0.53)	0.61 (0.58, 0.63)	1 (0.86, 1.16)	0.73 (0.64, 0.82)	0.7 (0.62, 0.8)
Completed Primary Education	0.55 (0.48, 0.63)	0.6 (0.53, 0.67)	0.68 (0.65, 0.71)	1 (0.86, 1.17)	0.84 (0.73, 0.96)	0.83 (0.76, 0.91)
Incomplete Secondary Education	0.64 (0.58, 0.71)	0.66 (0.6, 0.72)	0.78 (0.75, 0.81)	1.03 (0.9, 1.18)	0.91 (0.82, 1.02)	0.92 (0.85, 0.99)
Completed Secondary Education	0.92 (0.81, 1.05)	0.85 (0.75, 0.96)	0.91 (0.87, 0.95)	1.08 (0.91, 1.27)	0.97 (0.85, 1.11)	0.93 (0.86, 1.02)
Higher Education	Ref	Ref	Ref	Ref	Ref	Ref
Religion						

Hindu	Ref	Ref	Ref	Ref	Ref	Ref
Muslim	0.6 (0.55, 0.65)	0.71 (0.66, 0.75)	0.74 (0.72, 0.77)	0.65 (0.6, 0.71)	0.6 (0.54, 0.66)	0.76 (0.7, 0.83)
Christian	0.96 (0.74, 1.26)	0.91 (0.77, 1.07)	1.13 (1.03, 1.23)	1 (0.88, 1.14)	0.94 (0.81, 1.08)	0.92 (0.81, 1.05)
Sikh	1.79 (1.2, 2.65)	1.18 (0.86, 1.61)	1.33 (1.08, 1.63)	1.1 (0.94, 1.3)	1.48 (1.29, 1.7)	1.07 (0.95, 1.21)
Buddhist	2.8 (1.37, 5.73)	2.05 (0.77, 5.43)	0.98 (0.6, 1.62)	1.16 (0.93, 1.45)	1.11 (0.93, 1.32)	0.97 (0.82, 1.15)
Others	1.07 (0.81, 1.41)	1.17 (1, 1.37)	1.35 (1.2, 1.53)	1.11 (0.66, 1.87)	0.82 (0.61, 1.11)	0.77 (0.57, 1.02)
Caste						
Scheduled Caste	0.84 (0.79, 0.89)	0.95 (0.91, 0.99)	0.97 (0.94, 0.99)	0.93 (0.87, 1)	0.98 (0.91, 1.05)	0.92 (0.87, 0.98)
Scheduled Tribes	0.8 (0.74, 0.87)	0.92 (0.86, 0.97)	0.95 (0.91, 0.99)	0.79 (0.7, 0.89)	0.65 (0.59, 0.71)	0.8 (0.74, 0.88)
Others	Ref	Ref	Ref	Ref	Ref	Ref

Table 2.4: Distribution of socioeconomic indicators in AHS, 2012-2013 with new scaling[a]

Variable	N[b]	N-weighted[c]	Proportion (%)[d]
Rural area of residence	1384643	49197358	83.9
Female	763941	27489464	46.91
Maternal Education			
Illiterate	683606	32848465	56.02
Incomplete Primary Education	199914	6819457	11.63
Completed Primary Education	198641	5605334	9.56
Incomplete Secondary Education	374171	8944552	15.25
Completed Secondary Education	87552	2104888	3.59
Higher Education	81510	2314811	3.95
Religion			
Hindu	1328424	46810471	79.89
Muslim	250355	10378252	17.71
Christian	22211	784540	1.34
Sikh	3736	117949	0.2
Buddhist	710	22033	0.04
Others	18967	478244	0.82
Caste			
Scheduled Caste	312039	11819774	20.17
Scheduled Tribe	203148	7653905	13.06
Other castes	1109216	39117810	66.76
Vaccination status			
Full vaccination	987025	32450445	55.34
Partial vaccination	539451	21723428	37.05
No vaccination	98918	4463634	7.61

a. Refer to Appendix A
b. Unweighted frequency
c. Weighted frequency
d. Percentage of weighted study population in a given category

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Chapter 4 Childhood vaccination in India and socioeconomic status - the role of accessibility as mediator: 2007-2013

Introduction

Childhood vaccination is a critical primary preventive measure that has saved and improved the lives of millions of children globally.[1] Recently, the performance of national immunization systems is being measured not only by population level vaccination coverage, but also by the degree of immunization equality across sociodemographic and economic groups in a given country.[2] According to the 2016 WHO report "State of Inequity: Childhood Immunization", full childhood vaccination rates increased at a median rate of 11% over the last decade in low and middle-income countries. However, in almost a third of the 68 low and middle-income countries studied in the report, full vaccination coverage among children aged less than 1 year was at least 20% higher in the richest than the poorest quintiles.[2]

In India, full vaccination rates in children have been increasing while socioeconomic inequalities in immunization have been decreasing in India over the past two decades,[3–7] with full vaccination rates in children aged 1-5 years improving from 37% in 2002 to 57% in 2013.[8] However, recent analyses conducted using the nationally representative District Level Household Survey 4 (DLHS-4) and Annual Health Survey (AHS) make obvious that these inequalities persist with full vaccination coverage among children aged 1-5 years belonging to poorest quintile approximately 19% lower than that of children belonging to richest quintile.[8]

It has been repeatedly demonstrated that even among Indian states with similar rates of vaccination, the extent to which children from poorer households are vaccinated relative to children from richer households may vary. Other studies have also shown that some relatively well-performing states have been experiencing widening wealth-based inequalities in childhood vaccination over the past decade.[4,9] However, to our knowledge, none of these studies have explored the mechanisms underlying these inequalities, which need to be better understood in order to develop more effective and targeted interventions to reduce inequalities in childhood vaccination.[3]

Accessibility to health services is defined as the opportunity for and freedom to use health services. Access "reflects an understanding that there is a set of circumstances that allows for the use of appropriate health services"[10] and it is important that health services, including vaccination services, be easily accessible to individuals and households to maximize their utilization. Thiede, Akweongo and McIntyre, in their book '*The Economics of Health Equity*' consider accessibility to have three distinct dimensions: availability, affordability and acceptability of health services. Availability refers to the service obtainability or having appropriate health services at one's disposal at the right place and time. Affordability denotes whether the cost of health services fits with users' ability to pay for these services and acceptability refers to the perception of adequacy or satisfactoriness of health services by individuals and communities.[10]

Recognition of the dimensions that predominantly mediate the association between socioeconomic status and childhood vaccination rates can inform policy makers about the current state of affairs and interventions that are most likely to succeed. We aim to bridge the knowledge gap regarding the pathways that mediate the association between socioeconomic status and childhood full vaccination in India by utilizing the accessibility framework. Specifically, we explore the mediation of this association by different dimensions of accessibility during the 2007-2008 and 2012-2013 time periods.

Methods

We utilized two rounds of India's district level household and facility survey (DLHS) datasets for our analyses. DLHS is a national level, multilevel stratified survey conducted by the International Institute of Population Sciences in India every 5 years.[11] We used DLHS-3 (n=67441) and DLHS-4 (n=78621), conducted during 2007-2008 and 2012-2013 respectively. These two datasets had data from 20 states and union territories of India in common (Figure 1).[12] The DLHS-4 did not include Empowered action group (EAG) states in India are which are states with greater population density, elevated maternal mortality, and high infant mortality rates, and are given increased priority for implementation of national level schemes such as Janani Suraksha Yojana, a cash-based incentive scheme to promote institutional delivery.[13,14] The states covered under both DLHS-3 and DLHS-4 were non-EAG states.

DLHS employs a multi-stage stratified and clustered survey design. In India, states are divided into administrative divisions known as districts. In DLHS, rural and urban areas of a district were considered natural strata. Urban areas in a district were further stratified, based on their population size, into populations of one million or more class, and less than one million population class cities. The primary sampling units (PSUs) in urban stratum were National Sample Survey Organization urban frame survey blocks, while the secondary sampling units (SSUs) were households. Urban PSUs were selected based on probability proportional to projected population without replacement. In rural stratum, PSUs were selected with probability proportional to size with replacement. The households, being the SSUs, were selected with circular systematic sampling. We included children aged 1-5 years in our analyses. We conducted separate analyses for DLHS-3 and DLHS-4 to be able to compare the results from the two time-periods and restricted our analyses to rural area of residence.

Primary outcome

Our primary outcome of interest was full vaccination. During 2007-2008 and 2012-2013, the following vaccines were covered in the first year of life under India's universal immunization program (UIP) schedule and constitute full vaccination: Bacillus Calmette-Guerin (BCG) given at birth, oral polio vaccine (OPV) given at 6, 10, and 14 weeks of age, diphtheria-tetanus-whole cell pertussis (DPT) vaccine given at 6, 10, and 14 weeks of age, and measles containing vaccine (MCV) given at 9 months of age.[15–17] Vaccines covered under the UIP schedule are provided free-of-cost to all children at government run public health centers. Vaccine coverage of a child was determined by vaccination card wherever available, and maternal recall if vaccination card was not available.

Primary exposure

Our primary exposure of interest was socioeconomic status of households. Since income data was not available in the DLHS, we used asset ownership data to construct a single asset index variable.[18,19] A complete list of the variables used in the construction of the asset index variable in DLHS 3 and DLHS 4 have been provided in Appendix B. Principal component analysis (PCA) was utilized to obtain the appropriate weights for each asset variable, similar to the method recommended by World Bank, and used in the Demographic Health Surveys (DHS) globally.[20,21] The PCA technique has been further explained in Appendix A. These weights were then used in regression analysis, and the results standardized, to obtain a single wealth index variable that was an indicator of the socioeconomic status of the households. Wealth index was calculated separately for DLHS-3 and DLHS-4. The variables used in the calculation of the wealth index have been listed in appendix B.

Covariates

We considered the following covariates as potential confounders of the association between socioeconomic status and full vaccination: religion, caste, and maternal education. Religion was classified into four categories: Hindu, Muslim, Christian, and other religions. Caste was classified into two categories: scheduled castes and scheduled tribes, and other castes. Maternal education, an ordinal categorical variable, had six categories: illiterate, incomplete primary education, completed primary education, incomplete secondary education, completed secondary education, and attended higher education.

Mediators

We considered availability, affordability, and acceptability from the accessibility framework as the mediating variables in our analyses.[10] Since all vaccines considered in our analyses are available free of cost under the UIP in public health facilities, where more than 90% of childhood vaccinations are administered,[17] we did not include affordability as a mediator in our final models. Availability and acceptability were considered to be latent variables constructed by summarizing information from underlying variables using confirmatory factor analysis conducted using the lavaan package in R.[22] We constructed the correlation plots for observed variables used in constructing availability and acceptability variables using the psych package in R (Figure 3.3).[23]

Availability

We constructed availability as a latent variable based on two observed variables: availability of a health center in the village and availability of a vaccine administrator. Availability of a health center was defined as presence of a subcenter or a primary health center or a community health center or a rural hospital in a village. Auxiliary nurse midwife (ANM) is the primary vaccine administrator in sub center and primary health centers.[24] Hence, availability of a healthcare worker was defined as the presence of an ANM in the village. Information about health care centers and health care workers was available in the village dataset in DLHS-3 and DLHS-4, while information about the covariates and the outcome variable was available in the ever-married women dataset in DLHS-3 and immunization dataset in DLHS-4. We therefore merged the village dataset with the ever-married women and immunization dataset in DLHS-3 and DLHS-4 respectively, using SAS 9.4 (SAS Inc, Cary, NC) for our analyses. We verified that availability of health center and availability of ANM variables were not highly correlated using Pearson and polychoric correlation matrices to avoid collinearity (Figure 3.3).

Acceptability

Acceptability was measured based on the mothers' utilization of healthcare services. We explored the feasibility of utilizing the following variables for creating the latent variable acceptability using exploratory factor analysis and correlation plots: at least 1 antenatal care visit (ANC) in the last pregnancy, at least 1 dose of tetanus toxoid vaccine in last pregnancy, institutional delivery in last pregnancy, and utilization of any family planning services. Based on the results of prior knowledge, missingness of data and correlation plots (Figure 3.3), we used utilization of at least 1 ANC in last pregnancy and institutional delivery in last pregnancy to create the acceptability variable.

The directed acyclic graph of the observed and latent variables used in our final analyses has been provided in Figure 3.1.

Mediation analyses

The distribution of exposure, mediators, covariates, and the outcome variable was explored using SAS 9.4 (Table 3.1). We used structural equation modeling (SEM) for our mediation analyses because the mediators were latent variables.[25] We utilized the lavaan[22] and the lavaan.survey packages[26] in R for SEM.

In our analyses using the lavaan package, since our outcome was a binary variable, we specified the diagonally weighted least squares method (DWLS) to calculate the parameter estimates. Since the DWLS method does not yield standard error for the parameter estimates, we used bootstrapping with 1000 samples to calculate standard errors. In addition, theta parameterization was also specified because of the categorical nature of observed variables used in the construction of latent variables and the outcome variable. The parameter estimates obtained were standardized.[27]

We specified the outcome as a continuous variable in our analyses using the lavaan.survey package since lavaan.survey package cannot handle non-continuous dependent variables. In these analyses, the complex survey nature of the data was considered. Maximum likelihood method was used to calculate the parameter estimates, and standard errors derived using the maximum likelihood method were adjusted for the complex sampling design using the Gamma matrix.[26] The parameter estimates obtained were standardized.

The total effect of the exposure on the outcome was the sum of the beta coefficients of the direct and indirect i.e., effects mediated by availability and acceptability of vaccination services of SES on full vaccination. Proportion mediated by indirect effects was calculated using the percentage of the sum of the absolute values of direct and indirect effects attributable to indirect effect. A graphical representation of direct and indirect effects has been provided in Figure 3.4 along with the beta-coefficients of the effect estimates obtained via the lavaan-survey SEM analyses.[28]

Results

Table 3.1 shows the distribution of exposure, covariates, observed variables constituting the mediators, and the outcome in DLHS-3 and DLHS-4. Hindus constituted the majority religion around 65% in both DLHS-3 and DLHS-4. The percentage of study population that was Hindu was 3.34% higher in DLHS-4 compared to DLHS-3, while the percentage of Christians was around 3.6% lower. Other castes including other backward castes constituted nearly 80% of the population in both DLHS-3 and DLHS-4. Individuals belonging to scheduled castes and scheduled tribes formed around 20% of the study population in DLHS-3, and around 24% of the study population in DLHS-4. In general, maternal education levels were higher in DLHS-4 compared to DLHS3. Health center availability was higher while availability of ANM was lower in DLHS-4 population compared to DLHS-3. Proportion of children whose mothers had used antenatal care remained similar between DLHS-3 and DLHS-4, while proportion of children whose mothers had underwent institutional delivery increased in DLHS-4 compared to DLHS-3. Full vaccination rate in the DLHS-4 population was 4.6% lower than that of DLHS-3.

Table 3.2 shows the probit regression coefficients for the association between wealth index and full vaccination, after adjusting for religion, caste and maternal education without accounting for mediation by accessibility dimensions. In both DLHS-3 and DLHS-4, wealth index was statistically significantly, and positively, associated with full vaccination.

Table 3.3 and Figure 3.4 show the probit and linear regression coefficients denoting parameter estimates for our mediation analyses obtained via SEM. In both sets of models, availability of health services and acceptability of health services were statistically significantly and positively associated with socioeconomic status. Full vaccination was positively associated with availability and acceptability with statistical significance.

In our analyses conducted using lavaan.survey package, after accounting for mediation by accessibility, in DLHS-3, the direct effect estimate of wealth index with full vaccination was negative. However, the total effect was positive and statistically significant, owing to the greater degree of positive indirect effect, compared to the negative direct effect. In DLHS-4, the direct effect estimate and the total effect estimate of wealth index on full vaccination were negative and statistically significant. The proportion of total effect estimate mediated by indirect effect estimate decreased from 65% in DLHS-3 to around 42% in DLHS-4.

Higher levels of maternal education were associated with increased full vaccination rates in DLHS-3 and DLHS-4. Scheduled castes and scheduled tribes had lower probability of full vaccination compared to other, less disadvantaged castes. Children from Hindu households had better vaccination rates than children from households practicing other religions; children from Muslim households had lower full vaccination rates than children from households of other religions in DLHS-3 and higher vaccination rates in DLHS-4. Children from Christian households had lower full vaccination rates than children from households of other religions in DLHS-3 and DLHS-4.

Discussion

Using two nationally administered surveys in India from 2007-2008 and 2012-2013, the association between wealth index and vaccination status decreased in magnitude between 2007-2008 and 2012-2013. In our study populations in the DLHS-3 and DLHS-4, we demonstrated that the association between socioeconomic status and childhood vaccination is significantly mediated by acceptability of healthcare services. The total effect of wealth index on full vaccination became negative in DLHS-4 which indicates reduction in economic inequalities in full vaccination between these two time-periods.

The positive total effect estimate in DLHS-3 and the decrease in magnitude of association between wealth index and full childhood vaccination between DLHS-3 and DLHS-4 supports findings from prior literature that has shown better full vaccination rates among children from richer households than among children from poorer households, but a decrease in the degree of economic inequality in childhood vaccination. Within a 5-year period, a reversal in direction of total effect of wealth index on full vaccination was observed, which shows that once availability and acceptability of health services are accounted for, wealth index, which is a proxy for economic status, was negatively associated with full vaccination; the positive indirect effect mediated by availability and acceptability was negated by negative direct effect of wealth index during 2012-2013.

The negative direct effect estimate observed for DLHS-3 and DLHS-4 may reflect true direct negative effect of wealth index on full childhood vaccination after accounting for mediation via availability and acceptability of health services. However, due to a lack of previous studies that have explored pathways of socioeconomic inequalities in childhood vaccination, we are unable to compare our results to those of previous studies. The true underlying effect, if any, may reflect changing attitudes towards vaccination among richer households i.e. vaccine hesitancy or some health system related factor that may be impeding full vaccination of children from richer households, but not poorer households.

In some countries, like the US, higher socioeconomic status is associated with greater degree of vaccine hesitancy.[29] In our other work, improvement in full vaccination rates among children of mothers with high education and richer households was found to have stagnated or even decreased between DLHS-3 and DLHS-4. Hence, our effect estimate, if reflecting the true underlying effect, may be an indicator of vaccine hesitancy among richer households and needs to be explored further. Currently, there are no studies available that have explored the extent of vaccine hesitancy and its sociodemographic indicators in India.

In a study by Sharma et al. in 2016[17] about the role of private health sector in immunization, private sector's role was found to be limited primarily to high income states such as those covered by the DLHS. Richer households generally rely more on private health sector than public sector for health care.[30] However, in a study by Howard and Roy (2004),[31] measles vaccination was significantly lower among households which used private health sector for vaccination compared to households which used public health sector for vaccination. In another study by Hagan et al. (2017),[32] only 22% of the private practitioners interviewed used a vaccination register to record vaccine doses, and around 60% of practitioners did not administer more than two doses of any vaccines on a single visit. These findings may suggest a lack of accountability among private health practitioners compared to public practitioners with respect to insuring full vaccination of children as a government mandate which private providers ostensibly would not be held to. When combined with increased use of the private health sector in India over the past decade, the lower likelihood of vaccination in the private (vs. public) sector may be contributing to decreasing completion of vaccination among richer children in recent years and accounting for the negative direct effect of wealth index on full vaccination observed in DLHS-4.

Our findings may not reflect underlying true effect under some conditions. We used indirect measures such as availability of health care center and availability of ANM to measure availability of vaccination services, and utilization of antenatal care services and institutional delivery for acceptability of vaccination services due to lack of available data in DLHS-3 and DLHS-4. If these observed variables do not validly measure availability and acceptability of vaccination services, measurement error of latent mediators may produce biased indirect and direct effect estimates which make the results of our study unreliable. Hence, the effect estimates from our study need to be interpreted within the context of these caveats.

Policy implications

The findings from this study may reflect the impact of nationwide initiatives such as the National Rural Health Mission, which was introduced during 11th five-year plan in India between 2005 and 2012.[13,14] NRHM focused on improving the public health delivery system by improving the infrastructure and providing primary health care providers such as ANM in rural areas; it also focused on improved utilization of available healthcare services by introducing a new category of community health workers known as accredited social health workers. Decreased proportion of total effect mediated by availability and acceptability in DLHS-4 compared to DLHS-3 may reflect improved healthcare infrastructure and acceptance of vaccination services among rural households, in which NRHM probably plays an important part. These effect estimates, if they reflect true indirect and direct effect, indicate the success of NRHM in improving accessibility of health services and reducing wealth-based inequality in utilization of childhood vaccines. However, this study also demonstrates the need to encourage private health practitioners to maintain vaccine records and ensure full vaccination coverage; increased accountability of private health sector generally is required in the context of childhood vaccination to sustain the improvements in vaccination rates.

Strengths and limitations

The study has some limitations. We used cross-sectional data which precludes us causal assumptions of the observed associations. A higher risk of reverse causation bias and selection bias are the drawbacks associated with cross-sectional studies, and therefore, epidemiologists less commonly conduct mediation analyses on cross-sectional data. In mediation analyses, a causal relationship is assumed between exposure and mediators, and mediators and outcome, which requires that exposures, mediators, and outcomes temporally succeed each other respectively; this temporal succession cannot be assured in cross-sectional studies. The datasets did not contain data from the EAG states which traditionally have had lower rates of childhood immunization than non-EAG states. Consequently, the findings obtained may not be generalizable to all states of India.

This study also has several strengths. The study covered a multi-state population with large sample sizes which enabled us to conduct structural equation modeling. Though the estimates were relatively small in some of the mediating pathways, the standard errors were also small, which ensured stability of our estimates. We utilized both traditional maximum likelihood and bootstrapping to calculate standard errors which ensured more accurate estimates. Since our sample size of around 50,000 per dataset was relatively large, we were able to fit converged structural equation models with two mediators and multiple confounders.

In our study, socioeconomic status is measured using wealth index which in turn was created using asset data which is subject to relatively lower changes over time compared to income. Hence, theoretically, reverse causation bias is minimized because it is unlikely that wealth index changed after the occurrence of outcome. Availability of health services also tends to change relatively less over time, and therefore, availability of vaccination services likely temporally preceded childhood vaccination. Acceptability was measured using availing of antenatal care during the most recent pregnancy and undergoing institutional delivery during last pregnancy which preceded childhood immunization; consequently, acceptability of vaccination services preceded full vaccination of the most recent child.

Future directions

Our findings from cross-sectional data show decreased SES based-inequalities in childhood vaccination over time and decrease in proportion of effect estimate of wealth index on full childhood vaccination mediated by availability and acceptability. However, cohort studies are essential to explore causal relationships between socioeconomic status, availability of vaccination services, acceptability of vaccination services, and childhood vaccination. To measure availability of vaccination services, information regarding availability of vaccines on vaccine administration days is the most valid measure and can be measured in future cohort studies. Availability of statistical techniques to incorporate complex survey design in SEM will allow generalization of the results to underlying Indian population from whom the individuals and households were sampled, and data was obtained. The role of vaccine hesitancy and perceptions of vaccine necessity need to be explored further by both qualitative and quantitative studies to fully examine the profiles and attitudes of mothers and sociodemographic profile of households that refuse vaccines and underlying reasons in different states of India, not only among children who were not vaccinated, but also among children who were partially vaccinated. Recognition of pathways using direct measures and valid estimates can inform health policy of central and state governments for targeted interventions.

Table 3.1: Distribution of mediators, confounders, exposure and outcome in DLHS-3 and DLHS-4

	DLHS-3 (2007-2008) N (%)	**DLHS-4 (2012-2013) N (%)**
Wealth index: Mean (SD)	0.49 (1.17)	0.12 (1.09)
Religion		
Hindu	42970 (63.71)	52735 (67.05)
Muslims	7278 (10.79)	8824 (11.22)
Christians	9723 (14.42)	8523 (10.84)
Others	7470 (11.08)	8539 (10.86)
Caste		
Scheduled Castes and Scheduled Tribes	13350 (19.79)	18824 (23.94)
Maternal education		
Illiterate	17492 (25.94)	16148 (20.53)
Incomplete Primary Education	14487 (21.48)	3599 (4.58)
Completed Primary Education	4965 (7.36)	10057 (12.79)
Incomplete Secondary Education	21011 (31.15)	30456 (38.73)
Completed Secondary Education	4623 (6.85)	9652 (12.27)
Higher Education	4867 (7.22)	8733 (11.1)
Availability		
Health center	24187 (35.86)	29841 (37.94)
Auxiliary nurse midwife	30584 (45.35)	31964 (40.64)
Acceptability		
At least one antenatal care visit	57147 (84.73)	66956 (85.14)
Underwent institutional delivery during last pregnancy	38402 (56.94)	49067 (62.39)
Full vaccination	41684 (61.8)	44961 (57.17)

Table 3.2: Probit coefficients and 95% confidence intervals of total effect of wealth index in DLHS-3 and DLHS-4, without accounting for mediation by accessibility dimensions

	DLHS-3 (2007-2008) Estimate[a] (95% CI)	**DLHS-4 (2012-2013) OR (95% CI)**
Wealth index	0.03 (0.027, 0.037)	0.007 (0.002, 0.011)
Hindu vs other religions	0.053 (0.02, 0.09)	0.035 (-0.0003, 0.07)
Muslim vs other religions	-0.36 (-0.42, -0.3)	0.05 (-0.01, 0.1)
Christian vs other religions	-0.56 (-0.61, -0.52)	-0.35 (-0.39, -0.3)
Scheduled castes and scheduled tribes vs other castes	-0.15 (-0.18, -0.12)	-0.12 (-0.15, -0.1)
Maternal education	0.12 (0.11, 0.13)	0.11 (0.097, 0.11)
a. Beta coefficient of probit regression with DWLS estimator		

Table 3.3: Effect estimates and 95% confidence intervals of total effect, indirect effects, and direct effect of wealth index in DLHS-3 and DLHS-4

	Lavaan SEM model		**Lavaan.survey SEM model**	
	DLHS-3 (2007-2008) Estimate[a] (95% CI)	**DLHS-4 (2012-2013) Estimate (95% CI)**	**DLHS-3 (2007-2008) Estimate[b] (95% CI)**	**DLHS-4 (2012-2013) Estimate (95% CI)**
Availability ~ Wealth index	0.011 (0.006, 0.016)	0.009 (0.006, 0.012)	0.055 (0.046, 0.063)	0.003 (-0.002, 0.008)
Acceptability ~ Wealth index	0.029 (0.027, 0.032)	0.007 (0.003, 0.011)	0.043 (0.04, 0.047)	0.028 (0.024, 0.033)
Full vaccination ~ Availability	0.78 (0.62, 0.94)	1.13 (1.002, 1.27)	-0.009 (-0.056, 0.039)	0.36 (0.22, 0.49)
Full vaccination ~ Acceptability	2.56 (2.36, 2.76)	1.27 (1.13, 1.42)	1.027 (0.936, 1.118)	0.66 (0.55, 0.77)
Indirect effect-estimate of wealth index with availability as mediator	0.009 (0.005, 0.013)	0.01 (0.006, 0.014)	-0.0005 (-0.003, 0.002)	0.001 (-0.0008, 0.003)
Indirect effect-estimate of wealth index with acceptability as mediator	0.075 (0.066, 0.084)	0.009 (0.004, 0.016)	0.045 (0.039, 0.05)	0.019 (0.016, 0.023)
Direct effect-estimate of wealth index after accounting for mediation by availability and acceptability	-0.01 (-0.03, 0.008)	-0.02 (-0.04, -0.006)	-0.025 (-0.034, -0.016)	-0.028 (-0.036, -0.019)
Total effect-estimate	0.07 (0.06, 0.09)	-0.002 (-0.017, 0.013)	0.019 (0.013, 0.025)	-0.008 (-0.016, -0.0002)
Proportion mediated by indirect effect	89.47%	47.99%	64.54%	41.67%
Proportion of indirect effect mediated by acceptability	89.4%	51.67%	-0.038 (-0.06, -0.015)	0.002 (-0.02, 0.03)
Hindu vs other religions	0.08 (0.03, 0.12)	0.08 (0.04, 0.12)	-0.13 (-0.16, -0.1)	0.04 (0.002, 0.08)
Muslim vs other religions	-0.4 (-0.46, -0.34)	0.07 (0.004, 0.14)	-0.17 (-0.21, -0.14)	-0.11 (-0.15, -0.075)
Christian vs other religions	-0.63 (-0.68, -0.58)	-0.35 (-0.41, -0.3)	-0.02 (-0.04, -0.008)	-0.02 (-0.04, -0.004)
Scheduled castes and scheduled tribes vs other castes	-0.16 (-0.19, -0.13)	-0.13 (-0.16, -0.1)	0.03 (0.027, 0.036)	0.02 (0.017, 0.028)
Maternal education	0.14 (0.13, 0.15)	0.12 (0.11, 0.13)		

a. Beta coefficient of probit regression model with DWLS estimator
b. Beta coefficient of multiple linear regression model with MLM estimator

Figure 3.1: Path diagram of the mediation analysis model

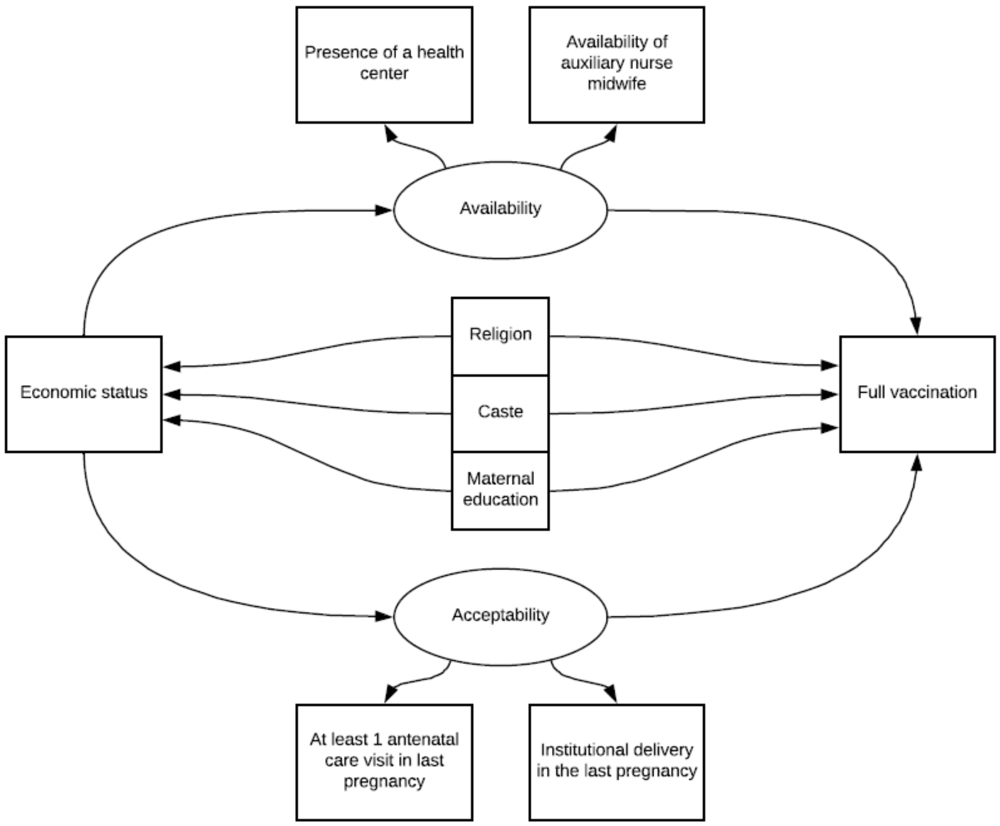


Figure 3.2: States covered under DLHS-3 and DLHS-4

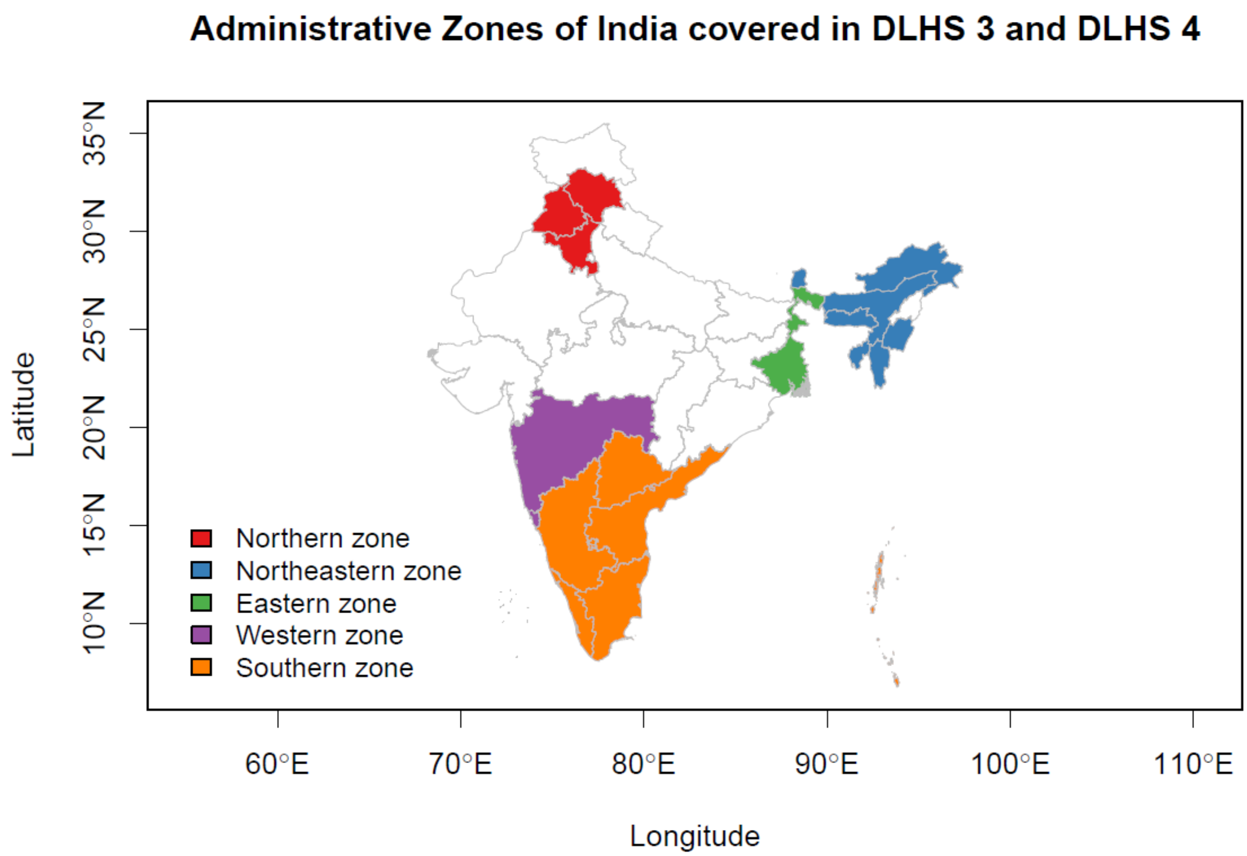
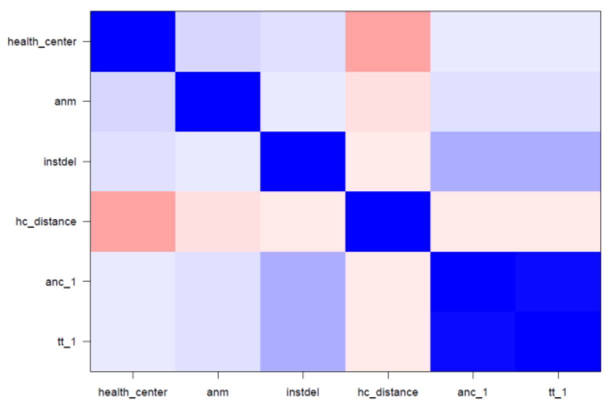
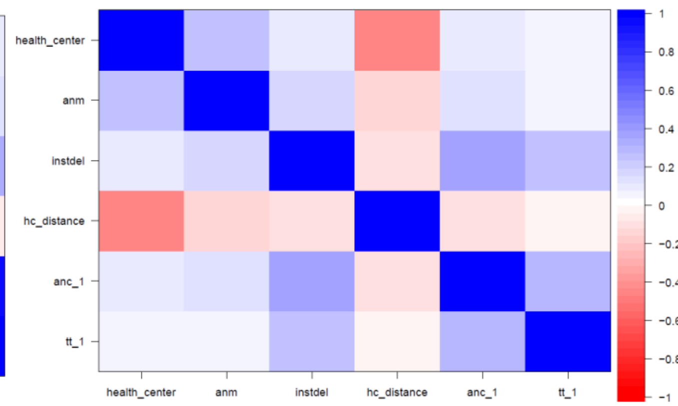


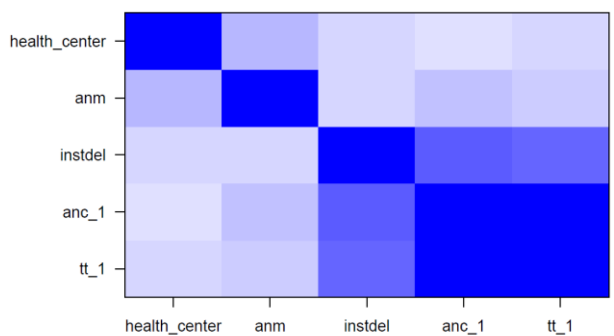
Figure 3.3: Correlation plot of different components of availability, affordability, and acceptability dimensions of accessibility to childhood vaccination service



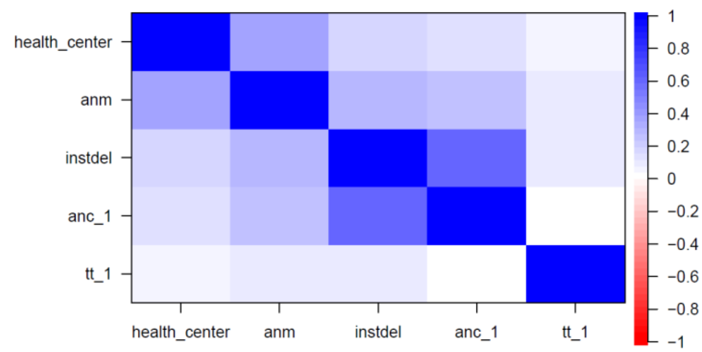
DLHS-3 (a)



DLHS-4 (b)



DLHS-3 (b)

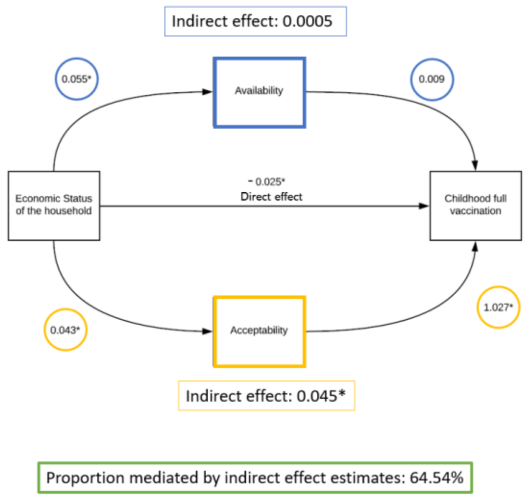


DLHS-4 (b)

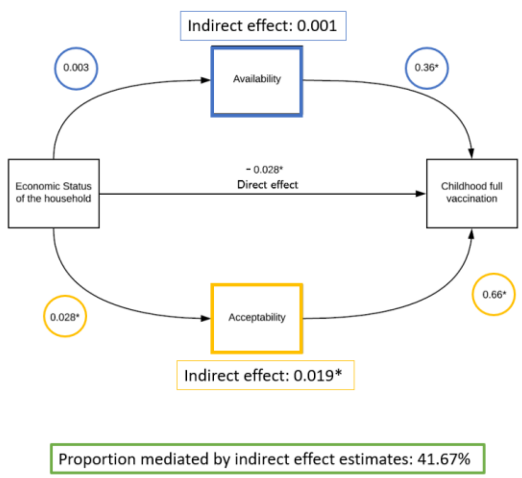
Health_center: Availability of a health center in the village
ANM: Auxiliary Nurse Midwife
Instdel: Institutional delivery in last pregnancy
Hc_distance: Distance to the nearest health care center
Anc_1: Had at least 1 antenatal care visit in the last pregnancy
Tt_1: Received at least 1 dose of tetanus toxoid injection in last pregnancy
DLHS-3(a) and DLHS-4(a) were generated using Pearson correlation matrix; DLHS-3(b) and DLHS-4(b) were generated using polychoric correlation matrix

Figure 3.4: Beta coefficients of the association between the exposure, mediators and the outcome in the lavaan.survey analyses

DLHS-3 (2007-2008)



DLHS-4 (2012-2013)



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Chapter 5 The Impact of India's Accredited Social Health Activists on Childhood Measles Vaccination, 2012-2013: A Cost-Effectiveness Analysis

Introduction

Community health workers in low and middle-income countries

Community health workers (CHWs) comprise a diverse category of healthcare workers who commonly work in communities outside of healthcare facilities. These workers typically receive some degree of formal training related to their roles and responsibilities, but they do not possess a professional or paraprofessional training, and are not required to hold a tertiary education degree.[1,2] The role of CHWs tend to differ based on the degree of economic development in a given country and vary across high-income, middle-income and low-income countries.[2] In the latter, CHWs largely focus on maternal and child health outcomes, such as promotion of antenatal care, institutional delivery, postnatal care, childhood nutrition, and childhood immunization in addition to family planning advice and services, and aiding the control of infectious diseases such as HIV, tuberculosis, and malaria.[1,3] In 2014, there were an estimated 5 million CHWs around the world, with the largest number, 2.3 million, working in India.[2]

Health workers in India

Community health workers in India

Community health workers in India, who are typically female, principally are comprised of three distinct group of workers: auxiliary nurse midwives (ANMs), anganwadi workers (AWWs), and accredited social health activists (ASHAs).[4,5] ASHAs are the newest category of CHWs in India and were formally introduced throughout the country as a part of the National Rural Health Mission (NRHM) of India's ministry of health and family welfare in 2005,[6,7] although some community health workers with similar roles to that of ASHAs were in place prior to 2005 (e.g. Mitanins in Chhattisgarh).[8]

The role of ASHAs is three-pronged: they function as community health link workers, health service providers, and as health activists.[7,9] As community health link workers, ASHAs directly connect mothers and children to health services which may include accompanying pregnant women to antenatal care services and to healthcare facilities for their delivery, taking infants and children in for immunizations, and referring children with life-threatening conditions such as severe diarrhea and pneumonia for hospitalization. As healthcare providers, they are trained to provide basic antenatal and postnatal advice, counsel mothers on child nutrition, give family planning advice and via drug kits, provide oral contraceptive pills and act as a source for basic medications for infectious diseases such as childhood diarrhea, malaria and tuberculosis. As health activists, they are expected to promote equity in access to healthcare and improve utilization of healthcare services in the rural communities they serve. In most states, ASHAs do not have a regular monthly salary but rather are incentivized for performing specific functions such as accompanying pregnant women for institutional delivery and taking children in for their routine immunization. For example, ASHAs receive an incentive of INR 150 per immunization session for mobilizing children to receive vaccine doses in these sessions in a village.[10] However, the repertoire of responsibilities of ASHAs consist of both financially-incentivized tasks such as accompanying pregnant women for institutional delivery and non-incentivized tasks such as counseling of pregnant women. Theoretically, one ASHA is deployed for every 1000 individuals; practically, some studies reported that ASHAs cover a much larger population.[11]

ANMs are a category of health care workers whose functions include provision of maternal health care such as antenatal care, institutional delivery and postnatal care, immunization covered under Expanded Program of Immunization (EPI), and provision of family planning services such as contraceptive pills. They are stationed primarily in subcenters and primary health centers.[12] AWWs are the unit health care workers under Integrated Child Development Scheme (ICDS) in India. Their functions broadly include promotion of health and nutrition of children below 6 years, and of pregnant and lactating women aged between 15 and 44 years. One of their functions also includes promotion of immunization among children aged less than 6 years in conjunction with the ANMs and ASHAs.[13] AWWs are stationed in anganwadi centers.

Evaluation of community health workers

Compared to ANMs and AWWs, ASHAs have been more extensively evaluated following their introduction via NRHM. Almost all these studies have been qualitative in nature and have included studies conducted at national and local levels. In a 2011 national evaluation of ASHAs,[14] India's ministry of health and family welfare summarized the difficulties in the assessment of ASHAs including wide variation in the implementation of ASHA's work which differs across states and districts within the same state. These inter- and intra-state differences make it more challenging to estimate the impact of ASHAs on different health outcomes. The report also noted that ASHAs work as a part of the overall health system in a village, which adds to the challenge of isolating their effectiveness from other CHWs and physicians.

Studies conducted by researchers at both state and district levels have predominantly focused on assessments of knowledge, attitude, and skills of these workers. The findings from these studies showed that ASHAs function as a link to health care to a much greater degree than as health care providers or health activists.[4] Studies have also revealed that ASHAs tended to perform better with incentivized versus non-incentivized tasks[15] as well as functioning more effectively when there was a sustained support from the public health system.[9]

Many studies have also highlighted the discontent ASHAs express with respect to compensation and recommended that the ASHAs should receive more generous incentives, especially when serving a larger population.[4,15–17] For example, in the Saprii et al. study of 2015,[4] twenty-one ASHAs were interviewed who resided in very remote villages, less remote villages, and the district headquarters of Senapati district in Manipur state. All ASHAs in all settings expressed their dissatisfaction with the limited, inconsistent and often irregular incentive payments. In another study conducted in Bageshwar and Haldwani blocks of Uttarakhand,[17] twenty ASHAs were interviewed and most of them reported monetary compensation to be the most important motivating factor for doing the work but also indicated they were not satisfied with the amount of compensation they received.

Globally, few studies have attempted to quantitatively assess the performance of CHWs. One of the first was based in Kenya and published in 1984 in which the author utilized a cost-benefit analysis.[1,18] This study showed a large cost-benefit ratio of about 9.5 in the overall study, and quantitatively demonstrated the effectiveness of the CHW program in Kenya. In another study by Buttorf et al. in 2012 conducted in Goa, India, utilization of lay health workers to supplement the treatment of common mental disorders by primary care physicians was both cost-effective and cost-saving.[19]

We aim to fill this paucity of quantitative research on effectiveness of CHWs by using data on health care facilities and health care workers at a village level, in addition to data about childhood immunization at an individual level. We will utilize a cost-effectiveness model to better capture the impact of the ASHA program. To the authors' knowledge, this is one of the first studies that attempts to quantify the benefits of the ASHA program.

Why do we need to quantitatively evaluate community health workers?

India is the second most populated country in the world with 1.2 billion residents and has the largest annual birth cohort of 26 million newborns. Yet, India invests only 4.7% of its GDP in healthcare,[20] which is one of the lowest rates in the world. Approximately seventy percent of India's population lives in rural areas where there is less availability of professionally trained healthcare workers,[21] and CHWs such as ASHAs are needed to fill this gap. Given limited resources and the high need, policy makers need quantitative evidence to invest more in the ASHA program. This study will provide quantitative evidence for cost-effectiveness of ASHAs and justify provision of higher incentives and encourage greater support for ASHAs from the rest of the healthcare community.

Goals of this study

This study aims to conduct a cost-effectiveness analysis of ASHAs in India by examining their impact on the measles vaccination among children aged 0-5 years. This analysis will utilize the data from DLHS-4 conducted in the state of Maharashtra as a representative example to calculate measles vaccination rates in villages with and without ASHA availability.

Why was measles vaccination selected?

Measles is a highly contagious viral disease which infected 95%-98% of children aged less than 18 years prior to the introduction of measles vaccine.[22] Measles infection may involve multiple organ systems, resulting in a number of clinical complications including diarrhea, otitis media, pneumonia, croup and encephalitis, among others. Pneumonia and encephalitis are the most common causes of death due to measles. Measles can also cause blindness, particularly in children in developing countries, due to complications such as untreated keratomalacia. The probability of more serious measles sequelae increases if a child has pre-existing malnutrition or vitamin A deficiency, both of which are highly prevalent in India.[23,24] Hence, vaccination against measles is an important public health and preventive measure to reduce childhood morbidity and mortality in India.

Approximately ninety percent of measles containing vaccine (MCV) doses are administered in public health care facilities in India.[25] MCV is a live attenuated vaccine, and is one of the vaccines covered under the universal immunization program (UIP) of India.[26] Until 2015, only one dose of

MCV was provided to children and recommended for administration in the ninth month after birth making MCV the last recommended vaccine provided in the first year of a child's life. Consequently, provision of MCV typically signifies completion of routine immunization during infancy. Therefore, measles vaccination was chosen as the outcome for this cost-effectiveness analysis.

Why did we utilize data from a single state?

Health is a state matter in India. This means that although major health programs and policies are introduced at the national level by the central government, state governments can and often do modify and implement these programs according to their particular needs and resources. As a result, the effectiveness of ASHAs may differ among states because of potentially substantial differences in health infrastructure, resource allocation and training modalities for CHWs. Consequently, we chose to conduct this analysis utilizing data from a single state.

We selected a state where the ASHA program was implemented but ASHAs were available in less than 80% of villages in 2012-2013. This enabled us to calculate the proportion of study population with the measles vaccination in villages both with and without ASHA while avoiding large standard errors. The state of Maharashtra, which fulfilled all these requirements, was chosen for our analysis.

Methods

Overview of model and analysis

We conducted cost-effectiveness analysis of having an ASHA in a village. To do this, we simulated two hypothetical villages: one with an ASHA in the village, and one without an ASHA in the village. The two villages were similar in all other respects. We have provided a simplified flow chart of our model in Figure 4.1. In the model, we assumed that every child from the age of 9 months up to 60 months is eligible for a dose of MCV. We used a cohort Markov model to assess the impact of the presence of ASHA in the village on MCV vaccination in children. The primary outcomes of interest were costs and disability-adjusted life years (DALY). Using 2011 census data, we estimated that this village will have approximately 84 children aged below 60 months in an ASHA population catchment of 1000. We built the model using R[27] with a cohort of 84 Indian children. We generated graphical outputs of our models via ggplot2[28] and scatterplot3d[29] packages in R.[27]

We considered measles vaccine induced encephalitis and a number of potential complications of measles infection when constructing this model including pneumonia, otitis media (OM), keratomalacia, malnutrition, and encephalitis. These complications could lead to more serious clinical sequelae: pneumonia could result in death, OM in permanent hearing loss, keratomalacia in corneal scarring and permanent blindness, malnutrition in death, and encephalitis in permanent neurological damage and death. We considered the costs and benefits of each scenario from a societal perspective.

We incorporated measles infection and its complications over the first five years of life, and the lifetime effects of these complications. We constructed our model for 68 years because the current average life expectancy of an Indian is 68.3 years.[30] Our model had a single cycle for the first five years of life and iterated through 5-68 years of life with a cycle length of one year. We estimated the burden of measles infection and its complications over the first five years, with the mutually exclusive end health states being healthy state, permanent blindness, permanent hearing loss, permanent neurological damage, and death. Subsequently, we estimated the lifetime effects of these health states beyond age 5 and until 68 years.

Model inputs

The parameters used in our model have been listed in Table 4.1.

Probability of measles vaccination in villages with and without the availability of ASHA

We calculated the probability of measles vaccination among children aged between 0-5 years with and without an ASHA available in the village using the district level households and facilities survey 4 (DLHS-4) dataset collected during 2012-2013 in the state of Maharashtra.[31] This data was collected via surveys conducted by International Institute of Population Sciences (Mumbai, India) from 21 states and union territories. DLHS-4 utilized a multi-stage, stratified survey design, and collected data from healthcare facilities, villages and households. We merged the village and household level datasets to combine individual level childhood vaccination and village level healthcare facilities and professionals' availability information using SAS (SAS Institute Inc., Cary, NC).

We initially calculated the baseline prevalence of childhood measles vaccination in villages without an ASHA available using the PROC SURVEYFREQ in SAS. Then, we calculated the odds ratio of MCV vaccination if an ASHA is available in a village, after adjusting for the availability of a health care center, availability of an auxiliary nurse midwife, and the availability of an anganwadi worker in the village. The following logistic regression model was used, after accounting for the survey design:

$$
\begin{aligned}
&logit(MCV\ vaccination) \\
&\quad = \beta_0 + \beta_1 . availability\ of\ ASHA + \beta_2 . availability\ of\ a\ healthcare\ center \\
&\quad + \beta_3 . availability\ of\ an\ anganwadi\ worker \\
&\quad + \beta_4 . availability\ of\ an\ auxiliary\ nurse\ midwife
\end{aligned}
$$

Here, exponentiated β_1 provides the odds ratio. We converted the odds ratio to prevalence ratio using the following formula:[32]

$$PR = \frac{OR}{\left(1 - P_{ref}\right) + \left(P_{ref} * OR\right)}$$

where PR was the prevalence ratio, OR was the odds ratio, and P_{ref} was the prevalence of the outcome in the reference group i.e. prevalence of MCV vaccination in villages without ASHA. We multiplied the baseline prevalence by the calculated prevalence ratio to obtain the prevalence of MCV vaccination in villages with ASHA.

Cost data

The cost of a dose of MCV dose was obtained from Dabral et al.[33] and was estimated to be INR 30. This cost includes the cost of a vial of measles vaccine, dose wastage, transport cost, handling charges, use of syringes, vaccine provider time cost, travel cost, surveillance cost, campaign cost, and cold chain maintenance cost.

The costs associated with ASHAs were split into fixed costs and variable costs. The fixed costs included costs associated with selection and training of ASHAs, and costs associated with social mobilization and their drug kits. This cost was considered to be INR 10000, in accordance with Ministry of Health and Family Welfare guidelines.[34] The incentive-based cost of providing a dose of MCV to a child was obtained via the study published by Prinja et al. The average incentive-based cost per ASHA per measles dose was INR 112.[35]

The costs of hospitalization and outpatient management for the treatment of MCV-induced encephalitis and complications of measles infection were obtained from the key indicators of social consumption in India Health report published by the National Sample Survey Office of government of India in 2014.[36] The cost of hospitalization included both medical expenses (direct expenses) and indirect expenses. Medical expenses consisted of cost of medicines, bed charges, charges for diagnostic tests, and fees for physicians/surgeons. The indirect expenses consisted of expenses incurred by the household during the treatment of the disease such as all transport charges paid by the household members during the treatment of the disease and food and lodging charges of the escort(s) during this period. Cost of outpatient treatment mainly included medical expenditures. Cost of hospitalization for measles complications were obtained per disease group; cost of outpatient treatment was the same for all measles complications.

Disability-adjusted Life Years (DALYs)

Utility weights for measles complications were obtained via the 2004 WHO Global Burden of Disease report.[37] We applied a standard discount rate of 3% per year to the health outcomes in the future.

Calculation of the incremental cost-effectiveness ratio (ICER)

ICER was calculated in our main and sensitivity analyses using the formula:

$$ICER = \frac{Cost\ with\ ASHA\ in\ a\ village - Cost\ without\ ASHA\ is\ in\ a\ village}{DALYs\ with\ an\ ASHA\ is\ not\ available\ in\ a\ village - DALYs\ without\ an\ ASHA\ in\ a\ village}$$

In accordance with WHO guidelines, an intervention was considered to be cost-effective when the cost per DALY averted was less than three times the GDP per capita of India[38] (USD 1,550.1 or INR 76,990 in 2013); an intervention was highly cost-effective when the cost per DALY averted was less than the GDP per capita.

Sensitivity analyses

We conducted univariate, bivariate and multivariate, probabilistic analyses of the parameter assumptions to measure the uncertainty of our analysis. We determined the range of values for each parameter of our model based on the available literature. For those parameters for which ranges were not available, we considered +/-25% as a conservative estimate of the range while ensuring that the ranges did not exceed plausible values. The value of the parameters used in our analyses, their ranges, their distributions, and their sources have been provided in Table 4.1.

Results

External validation of baseline analysis

In 2009, Dabral conducted a cost-effectiveness analysis of supplementary immunization activity (SIA) for measles vaccination in India.[33] We have provided the comparisons between this paper and our study in Table 4.3. In the study by Dabral, SIA involved administration of either a single dose or two doses of measles vaccine. According to the model used in this paper, 0.46 measles cases were averted per measles vaccine dose, 0.41 DALYs were averted per dose of measles vaccine, and 0.9 DALYs were averted per case of measles averted. In our paper, 0.26 cases were averted per measles vaccine dose, 0.18 DALYs were averted per dose of measles vaccine, and 0.71 DALYs were averted per measles case avoided. Since our analyses considered administration of single dose of measles vaccine, the effectiveness of measles vaccine was naturally lower than the SIA paper, which involved administration of both first and second doses of the measles vaccine. The SIA paper assumed lower life expectancy for individuals who had neurological damage and blindness due to measles; hence, the DALYs averted per measles case was slightly higher than in our paper where we assumed similar life expectancy for every individual irrespective of their health status. Overall, we obtained conservative estimates compared to that of Dabral, 2009.

Costs and DALYs associated with ASHAs

The costs and DALYs associated with availability and non-availability of an ASHA in a village are shown in Table 4.2. The total costs in a village without ASHA were INR 4868 and the lifetime measles related DALYs were 7.56 years. In a village with ASHA, the total costs associated was

INR 21919. Of the costs associated with the availability of ASHA in a village, fixed cost was INR 10000, incentive-based cost was INR 7461, and the medical cost associated with measles complications and sequelae was INR 4458. Availability of ASHAs was associated with a lifetime measles related DALY of 5.94 years. The cost per measles related DALY averted when an ASHA was available in a village was INR 10523, which was well below the per-capita GDP of INR 76990 in India in 2013. Hence, having an ASHA available in a village was highly cost-effective for measles vaccination based on our model.

Univariate sensitivity analyses

We conducted univariate sensitivity analyses on probabilities and costs and the results are in Figure 4.2. Overall, the parameters affecting the ICER the most were the probability of death following pneumonia infection (range: 1.95% - 16.7%), susceptibility to measles infection after receiving one dose of MCV (range: 0%-54%), and probability of pneumonia after measles infection (range: 10%-30%). The highest cost per DALY averted was INR 27892 when the probability of death following pneumonia infection was 1.95%. The intervention remained highly cost-effective under all these scenarios where one parameter was varied at a time.

We calculated the ICER for every percent increase in measles vaccination induced by having an ASHA in the village from the baseline rate of 68.78% up to 20% increase in Figure 4.3. The cost associated per DALY averted with 1% increase in vaccination rate was INR 107289, and the ICER decreased to INR 5705 when the vaccination rate increased by 20% from the baseline. The intervention remained cost-effective when the percent increase was just 1% and was highly cost-effective when the increase in measles vaccination rate was 2% or higher.

In our base case, we start with a large cohort of unvaccinated children in a village. But, we assumed that the cohort size available for measles vaccination decreases over time as more children were vaccinated. Therefore, to estimate the long-term cost-effectiveness of the ASHA intervention, we reduced the cohort size of children aged less than 5 years in villages with and without ASHAs (Figure 4.4). We varied the cohort size of children in villages between five and eighty-four children. The cost associated per DALY averted increased as the cohort size decreased. With a cohort size of five children, the cost per DALY averted was INR 108028, which was less than the three times the value of per capita GDP, and hence, still cost-effective. At a cohort size of 8 children or more, the incremental cost-effectiveness ratio was less than the per capita GDP, and therefore, the intervention was highly cost-effective.

Bivariate sensitivity analyses

Based on the results of univariate sensitivity analyses, we conducted bivariate sensitivity analyses with two pairs of parameters that were impactful: probability of pneumonia among measles cases – probability of death among pneumonia cases (Figure 4.5), and incentivization costs associated with an ASHA – probability of death among pneumonia cases (Figure 4.6). In general, increased probability of pneumonia among measles cases and increased probability of death among pneumonia cases were associated with reduced cost per DALY averted (Figure 4.5). The highest cost per DALY averted, INR 34178, was obtained when the probability of pneumonia among measles cases was 10%, and the probability of death among pneumonia cases was 1.95%. The intervention was highly cost-effective for all combinations of values of probability of pneumonia and probability of death among pneumonia cases.

In our second bivariate sensitivity analysis, we varied the incentive costs per MCV dose associated with an ASHA between INR 89 and INR 1,000. In general, the cost per DALY averted increased as we increased the incentive costs associated with ASHA per MCV dose and decreased the probability of death due to pneumonia. The highest cost per DALY averted, INR 121924, was obtained when the incentive costs associated with ASHA was highest at INR 1,000 and the probability of death among children with pneumonia was lowest at 1.95%. In our model, ASHAs tended to be more cost-effective when the incentive was lower and the probability of death due to pneumonia was higher. Overall, in our bivariate analyses, the cost per DALY averted was highly cost-effective in 95.22% of combinations of the values of incentive costs of ASHAs and probability of death among pneumonia cases and cost-effective in remaining combinations.

Probabilistic sensitivity analysis (PSA)

We conducted probabilistic sensitivity analysis varying all parameters in 100000 Monte Carlo simulation iterations (Figure 4.7). We varied the willingness to pay per DALY averted and examined how frequently having an ASHA in a village was cost-effective in the simulation iterations. At a willingness to pay per DALY averted of INR 20000, which is about 25% of the per capita GDP of India, the intervention was cost-effective in 90% of iterations and the intervention was cost-effective in 100% of iterations at a willingness-to-pay of INR 100000 per DALY averted. Hence, ASHAs were highly cost-effective for measles vaccination even at relatively lower levels of willingness to pay per DALY averted.

Discussion

Our analyses showed that the ASHAs remained highly cost-effective with respect to measles vaccination in most of our sensitivity analyses. Our bivariate analyses show that ASHAs were particularly cost-effective in situations where probability of pneumonia as a sequela of measles and probability of death among pneumonia cases were high. The probabilistic sensitivity analysis shows these results are highly robust to parameter assumptions and there is a very high probability that having ASHAs in villages are highly cost-effective. ASHAs were highly cost-effective at the current levels of fixed and incentive-based costs and remained cost-effective even when their incentives were increased by 10 times in our model. On a long-term basis, when the cohort of children that were yet to be vaccinated decreased in size, the incremental cost-effective ratio remained highly cost-effective at cohort size of 8 children in the village and above. Overall, our analyses showed that ASHAs remained cost-effective with respect to measles vaccination under a wide range of values for multiple parameters used in our models.

Vaccinations are among the most cost-effective public health interventions known, and consequently most programs that promote childhood vaccination are also likely to be highly cost-effective. This analysis shows that ASHAs remain cost-effective with higher levels of financial incentives even under conservative assumptions such as those used in our model. This finding is important in the context of the widespread dissatisfaction of ASHAs with their financial compensation. In many states, ASHAs have reported working many times higher than the average 2-3 hours/week stipulated by central and state governments,[39] which combined with low monetary compensation may lead to the perception of overburdening. Although literature regarding ASHA retention is not available due to the relatively recent implementation of the ASHA program in India, a Kenyan study published in 2018 reported that higher monetary incentives were associated with significantly lower attrition rate among CHWs.[40] Higher attrition rates can result in higher costs of the ASHA program due to increased training costs for new ASHA recruits. Hence, given the cost-effectiveness of the ASHA program, the central and state governments should consider increasing the financial incentives to improve retention of ASHAs reduce the costs associated with recruiting and training new ASHAs, and improve the population health in a cost-effective manner.

This study has some limitations. We did not consider the multiple responsibilities of ASHAs, including functions such as promoting institutional delivery and family planning, ensuring timely and frequent antenatal and postnatal care to pregnant women, and social mobilization to improve sanitation and health awareness in the communities that ASHAs serve. Presumably, however, this analysis is a lower bound on the benefits of ASHAs since it only includes the benefits of measles vaccination and does not capture the benefits of these additional activities of ASHAs. We also did not consider herd immunity to measles infection. We utilized the baseline vaccination rate and vaccination rate with the availability of ASHAs obtained using data from one state of India, which may not be fully generalizable to other Indian states.

The introduction of National Rural Health Mission in India has resulted in improved vaccination rates and reduced socioeconomic inequality in childhood vaccination across all states of India. However, full childhood vaccination rates remain unacceptably low, below 70%, with a stagnation in the reduction in the percentage of unvaccinated children over the last decade. Although socioeconomic inequalities in childhood vaccination have been reduced, they nonetheless still persist.[41] The nationwide ASHA coverage in 2014 was reported to be 70%;[42] this underlines the need for better coverage and better retention of ASHAs, who can reach out to communities with unvaccinated and partially vaccinated children and increase immunizations, thereby improving full vaccination rates and ultimately reducing socioeconomic inequalities. In states like Rajasthan, there were difficulties in recruitment of ASHAs who fulfilled the required qualifications such as having completed 8th grade of school.[10] Therefore, better incentivization may also help in attracting more suitable candidates for the position of ASHAs who constitute a vital part of the community health workforce in India.

Future directions

Cost-effectiveness analyses of other ASHA responsibilities, such as promotion of institutional delivery among pregnant women and promotion of sanitation in a village, could inform health policy by guiding program prioritization for the responsibilities of ASHAs. This could also provide evidence about the specific service areas in which ASHAs require more training, and responsibilities for which ASHAs can be better incentivized.

Other types of analyses such as cost benefit analyses can help encompass all the responsibilities of ASHAs into a single analysis. Budget impact analysis is another method that can be used along with cost-effectiveness analyses to assess the financial consequences of introducing ASHAs in new geographical areas, and the expansion of responsibilities allocated to ASHAs. This analysis can be suitably modeled to consider the different combinations of changes in healthcare landscape and demographical changes currently underway in India.

Overall, this study fills a major research gap in quantification of the value of ASHAs. Quantification of benefits provides a sound rationale for more investment in the community health worker programs, and for better incentivization of community health workers. Over the last three decades, there has been a global movement to increase CHW numbers and integrate them into existing health systems, with more than half of the CHWs in the world have been introduced in India.[43] The implementation of the CHW programs is often associated with significant costs and resource allocations from local governments and ministries.[43] As such, both qualitative and quantitative evidence are required to justify higher investments in the ASHA program by the Indian government, including potentially higher incentives to ASHAs. This study provides evidence that a significant increase in financial remuneration of ASHAs is cost-effective, even when a single health outcome such as measles vaccination is considered.

Table 4.1: Probabilities, costs and utilities utilized in the analyses

PROBABILITIES				
Variable	**Median/ Mean**	**Range (IQR[a]/ 95% CI[b])**	**Distribution for PSA[c]**	**Source(s)**
Measles vaccination given the presence of ASHA[d] in the village	79.3%	72.08% - 85.01%	Normal	DLHS[e] 4 (rural Maharashtra), after adjustment for availability of a health center, ANM and AWW in the village
Measles vaccination without an ASHA in the village	68.78%	60.24% - 77.33%	Normal	DLHS-4 (rural Maharashtra)
Encephalitis after measles vaccination	1/1000000	1/2000000- 1/500000	Normal	Dabral, 2009[33]
Susceptibility to measles after measles vaccination	15%	0 - 54%	Beta	Dabral, 2009[33] Uzicanin & Zimmerman, 2011[44] Puri et al., 2001[45]
Susceptibility to measles without measles vaccination	100%			
Measles infection among susceptible individuals per year	7%	6% - 8%	Normal	Sharma et al., 2004[46] Thakur et al., 2002[47]
Pneumonia among children with measles infection	20%	10% - 30%	Normal	Dabral, 2009[33]
Otitis media among children with measles infection	5%	5% - 15%	Normal	Dabral, 2009[33]

Encephalitis among children with measles infection	0.1%	0.1% - 0.3%	Beta	Dabral, 2009[33] Fisher et al., 2014[48]
Keratomalacia among children with measles infection	0.1%	0.05% - 0.2%	Normal	Dabral, 2009[33]
Malnutrition among children with measles infection	3.5%	3% - 4%	Normal	Dabral, 2009[33]
Probability of death among children with pneumonia	10%	1.95% - 16.7%	Normal	Farooqui et al., 2015[49]
Probability of death among children with encephalitis	50%	10% - 75%	Normal	Fisher et al., 2014[48]
Probability of death after malnutrition	15%	10% - 23%	Normal	Rice et al., 2000[50]
Probability of hearing loss among children with otitis media	1%	0.5% - 2%	Normal	
Probability of permanent neurological damage after measles encephalitis	25%	20% - 30%	Normal	Fisher et al., 2014[48]
Probability of blindness among children with keratomalacia	5%	2.5% - 10%	Normal	Sommer, 1989[51]
Probability of death among children with no complications, keratomalacia and otitis media	0.4%	0.2% - 0.8%	Normal	Dabral, 2009[33]
Probability of obtaining treatment after encephalitis	20% (Hospital) 30% (OPD[f])	5% - 40% 20% - 40%	Beta Normal	
Probability of obtaining treatment after pneumonia	5% (Hospital) 30% (OPD)	2 - 20% 20% - 40%	Beta Normal	
Probability of obtaining treatment after otitis media	5% (Hospital) 30% (OPD)	2 - 20% 20% - 40%	Beta Normal	
Probability of obtaining treatment after keratomalacia	20% (Hospital) 30% (OPD)	5% - 40% 20% - 40%	Beta Normal	

Probability of obtaining treatment after malnutrition	5% (Hospital) 10% (OPD)	2 - 20% 5 - 20%	Beta Beta	
UTILITIES (DALYs[g])				
Variable	**Disability weight (Range/ Distribution in PSA)**	**Duration**	**Source of disability weights**	**Source of duration**
Measles Episodes	0.152 (0.076 – 0.304/ Normal)	7 days	WHO GBD[h] 2004 disability weights[37]	Dabral, 2009[33]
Encephalitis after measles vaccination	0.45 (0.225 – 0.9/ Normal)	1 month	WHO GBD 2004 disability weights[37]	
Encephalitis after measles infection	0.45 (0.225 – 0.9/ Normal)	1 month	WHO GBD 2004 disability weights[37]	Dabral, 2009[33]
Otitis media after measles infection	0.00	2 years	WHO GBD 2004 disability weights[37]	Dabral, 2009[33]
Keratomalacia after measles infection	Corneal scar: 0.277 (0.14 – 0.554/ Normal)	Until death	WHO GBD 2004 disability weights[37]	
Malnutrition after measles infection	Wasting: 0.053 (0.027 – 0.106/ Normal)	1 month	WHO GBD 2004 disability weights[37]	Dabral, 2009[33]
Neurological damage after encephalitis	0.379 (0.1895 – 0.758/ Normal)	Until death	WHO GBD 2004 disability weights[37]	
Hearing loss after otitis media	0.229 (0.115 – 0.458/ Normal)	Until death	WHO GBD 2004 disability weights[37]	
Blindness after keratomalacia	0.5 (0.25 – 0.75/ Normal)	Until death	WHO GBD 2004 disability weights[37]	
COSTS (in INR[i])				
Variable	**Median/ Mean**	**IQR/ 95% CI**	**Distribution in PSA**	**Source**
Accredited Social Health Activists (Fixed costs)	10000	7500 – 12500	Normal	Evaluation of ASHA programme, 2010-2011[34]
Accredited Social Health Activists (Incentive per MCV dose per child)	112	89-138	Normal	Prinja et al., 2014[35]
MCV[j] dose	30			Dabral, 2009[33]
Encephalitis after measles vaccination inpatient treatment	23984	7482 - 34561	Normal	Key Indicators of Social Consumption in India, 2014[36]
Encephalitis after measles infection inpatient treatment	23984	7482 - 34561	Normal	Key Indicators of Social Consumption in India, 2014[36]

Pneumonia after measles infection inpatient treatment	12820	4811 - 18705	Normal	Key Indicators of Social Consumption in India, 2014[36]
Keratomalacia after measles infection inpatient treatment	9307	1778 - 13374	Normal	Key Indicators of Social Consumption in India, 2014[36]
Otitis media after measles infection inpatient treatment	15285	6626 - 19158	Normal	Key Indicators of Social Consumption in India, 2014[36]
Malnutrition after measles infection inpatient treatment	14117	4625 - 19206	Normal	Key Indicators of Social Consumption in India, 2014[36]
Outpatient treatment per ailing person suffering from an ailment	629	386 - 785	Normal	Key Indicators of Social Consumption in India, 2014[36]

a. IQR: Inter-quartile range
b. CI: Confidence Interval
c. PSA: Probabilistic Sensitivity Analysis
d. ASHA: Accredited Social Health Activist
e. DLHS-4: District Level Household and Facility Survey 4. 2012-2013
f. OPD: Outpatient department
g. DALY: Disability adjusted life-year
h. GBD: Global Burden of Disease report
i. INR: Indian Rupees
j. MCV: Measles containing vaccine

Table 4.2: Projected costs and DALYs[a] associated with availability of ASHAs[b] in a cohort of eighty-four children aged below 5 years

	No ASHA available	**ASHA available**
Cohort size	84	84
Total costs (INR[c])	4867.66	21918.65
Fixed costs of ASHAs (INR)	-	10000
Incentive based costs of ASHAs (INR)	-	7460.54
Number of MCV doses administered	57.78	66.61
MCV[d] cost per dose administered (INR)	30	30
Medical costs (INR)	4867.66	4458.1
Number of cases of measles	10.62	8.33
Number of cases of pneumonia	2.12	1.67
Number of cases of otitis media	1.06	0.83
Number of cases of keratomalacia	0.01	0.0083
Number of cases of malnutrition	0.37	0.29
Number of deaths due to complications of measles	0.27	0.21
DALYs	7.56	5.94
Incremental DALYs	0	1.62
Cost in INR per DALY averted	0	10522.51

a. DALY: Disability adjusted life year
b. ASHA: Accredited Social Health Activist
c. INR: Indian Rupees
d. MCV: Measles containing vaccine

Table 4.3: Comparison between our results and Dabral, 2009[33]

Dabral (SIA)	Routine[a]	SIA[b]	Our paper	No ASHA[c]	ASHA[d]
Cohort size	839473	839473	**Cohort size**	84	84
Number of MCV doses	486894.3	629604.8	**Number of MCV doses**	57.78	66.61
DALYs	125349	66712	**DALYs**	7.56	5.94
Number of measles cases	139982	74504	**Number of measles cases**	10.62	8.33
Measles cases averted/ measles vaccine dose		0.46	**Measles cases averted/ measles vaccine dose**		0.26
DALYs averted/ measles vaccine dose		0.41	**DALYs averted/ measles vaccine dose**		0.18
DALYs averted/ measles case avoided		0.9	**DALYs averted/ measles case avoided**		0.71

a. Routine measles vaccination under universal immunization program
b. Supplemental immunization activity for measles
c. No availability of accredited social health activist in a village
d. Accredited social health activist available in a village

Figure 4.1: Proximal branches of simplified flow chart used in the analyses

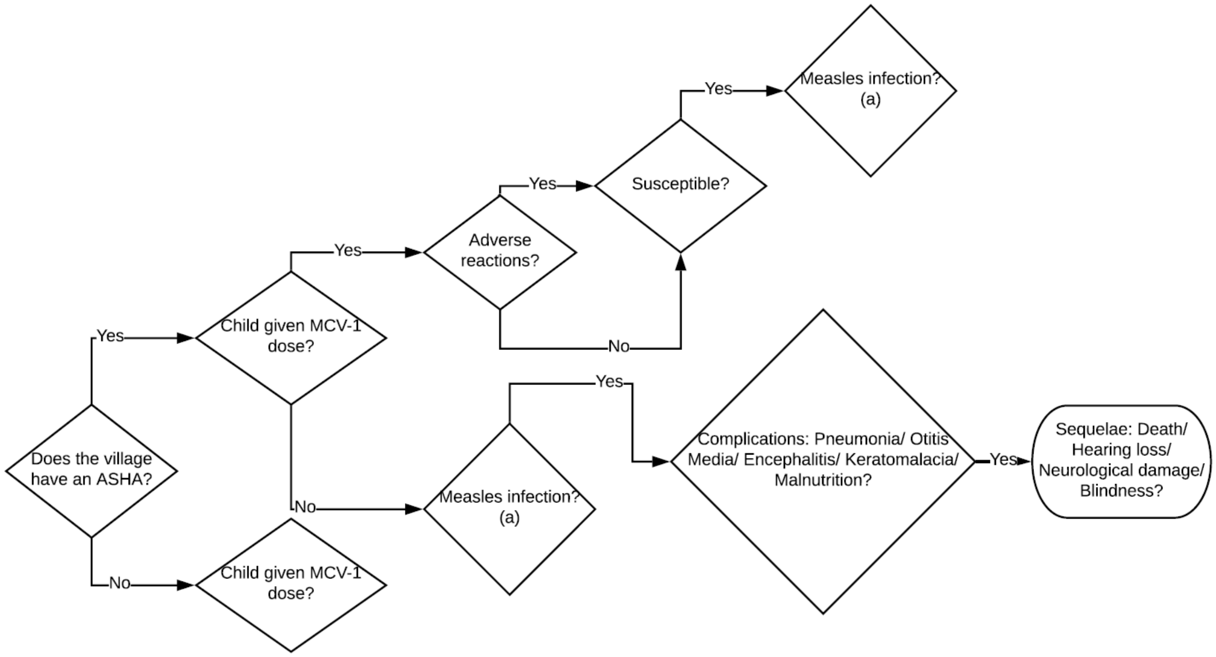


Figure 4.2: Tornado diagram generated using univariate sensitivity analyses

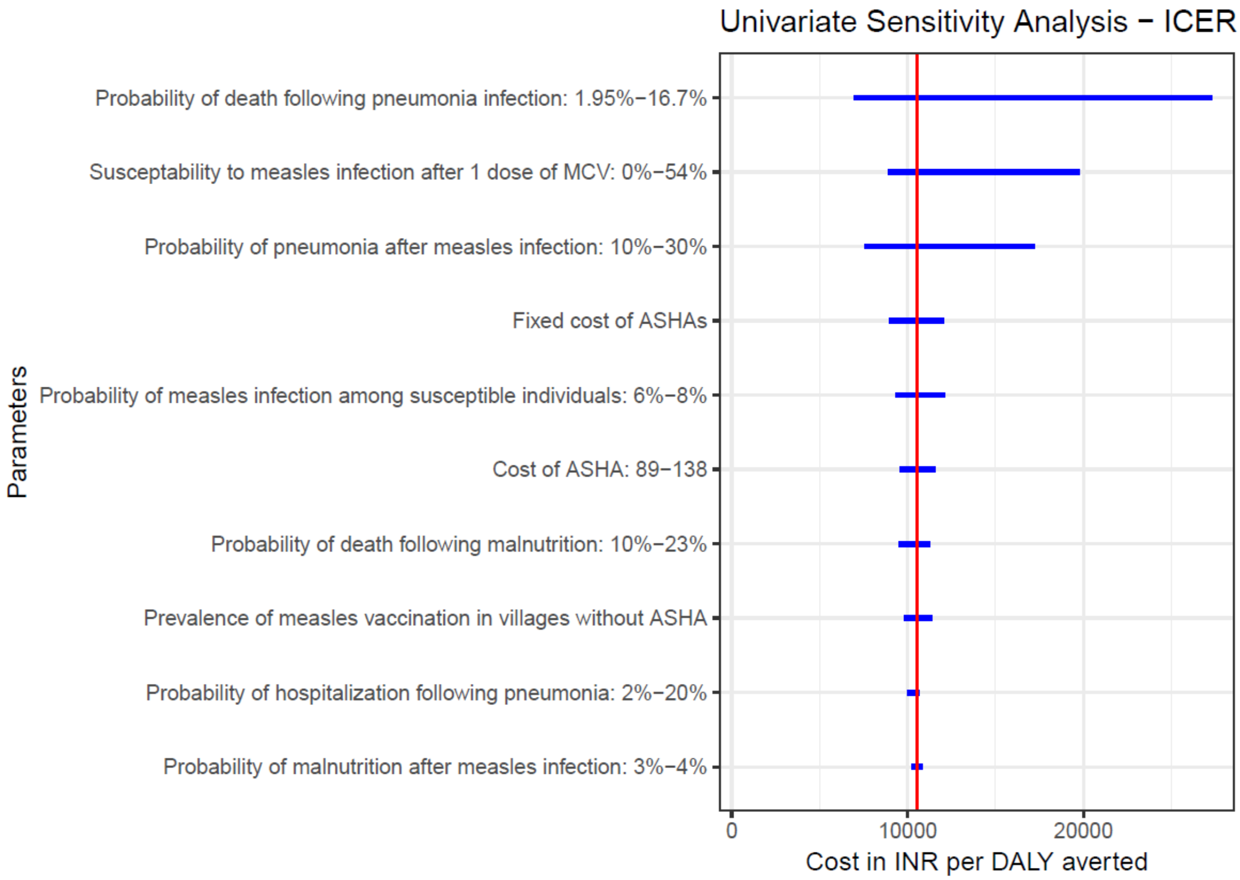


Figure 4.2 note: All parameters were varied, but only top 10 are shown

Figure 4.3: Changes in ICER for every percentage increase in measles vaccination when an ASHA is available in the village

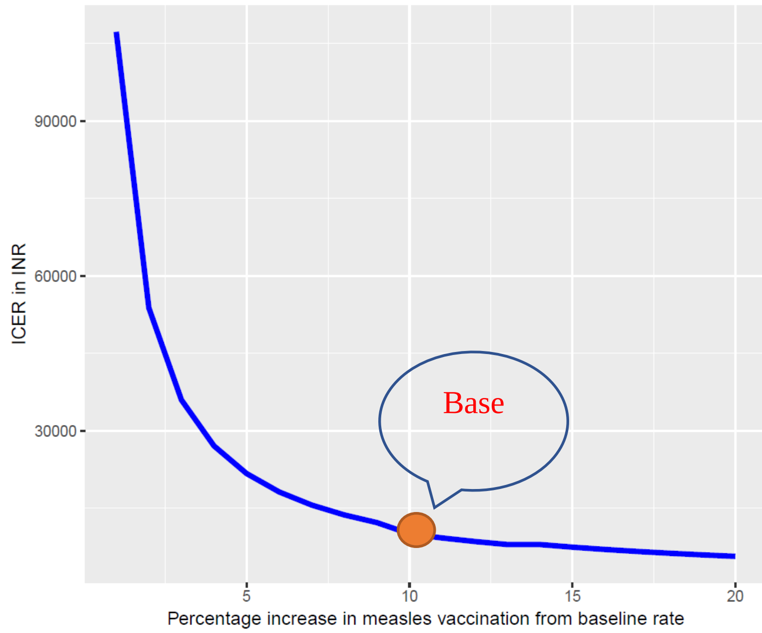


Figure 4.4: Association between ICER and changes in cohort size in villages with and without ASHA

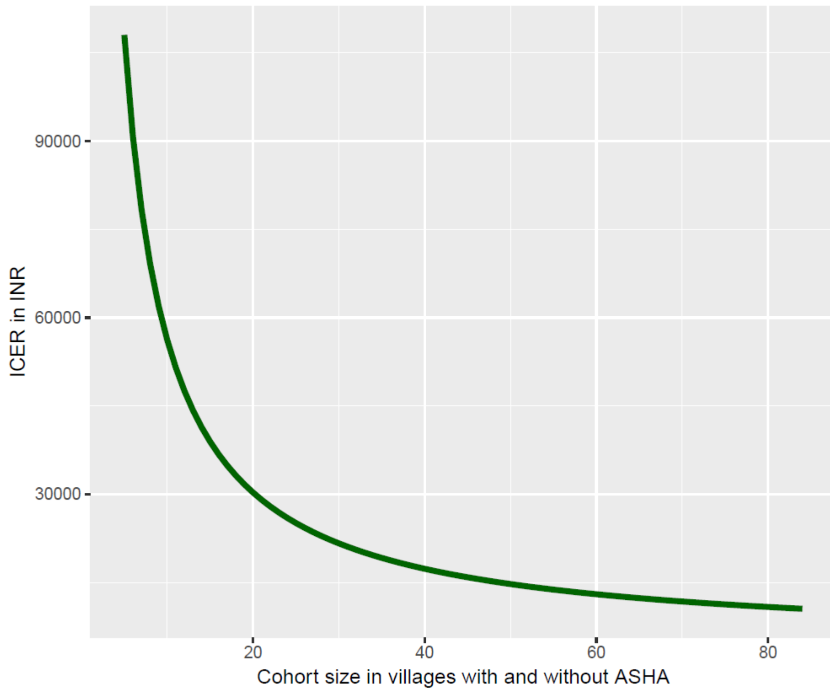


Figure 4.5: 3-D scatterplot of changes in ICER with simultaneous changes in probability of pneumonia in children with measles infection and probability of death among children with pneumonia

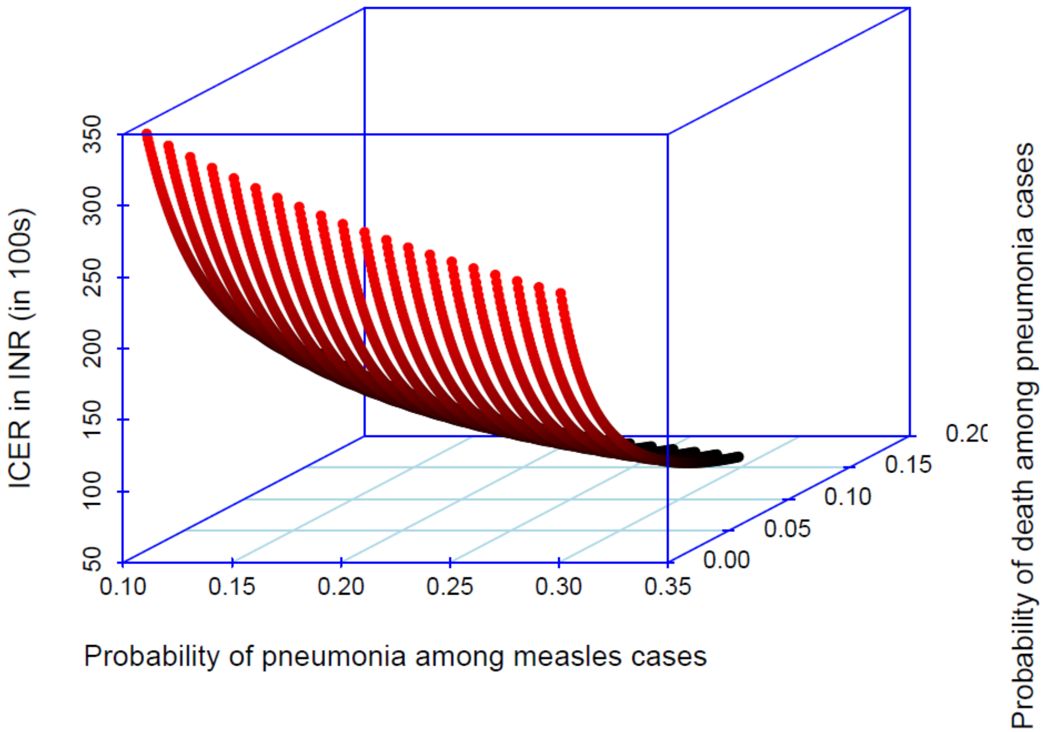


Figure 4.6: 3-D scatterplot of changes in ICER with simultaneous changes in variable cost (incentives) of ASHAs and probability of death among children with pneumonia

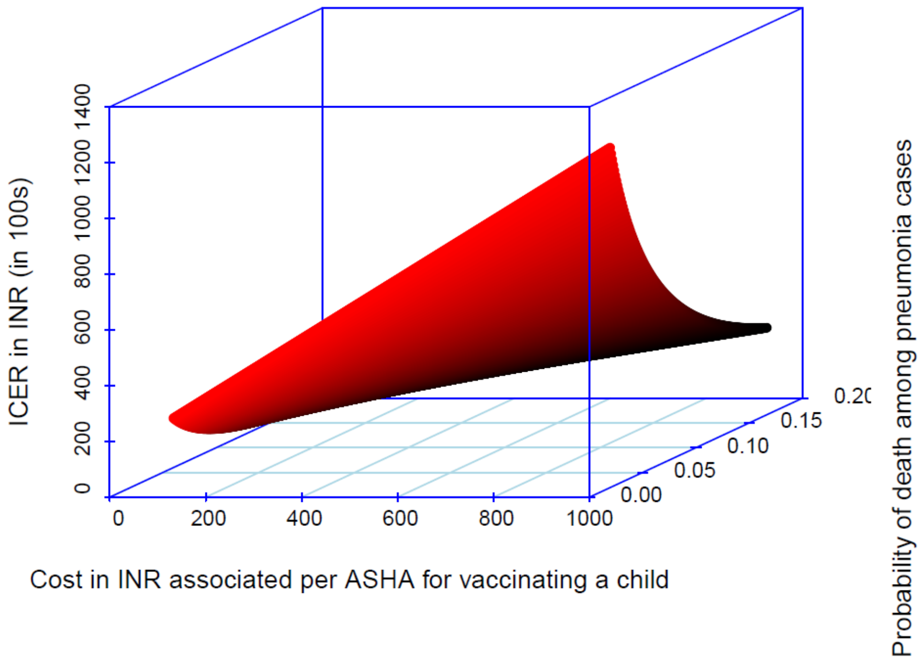
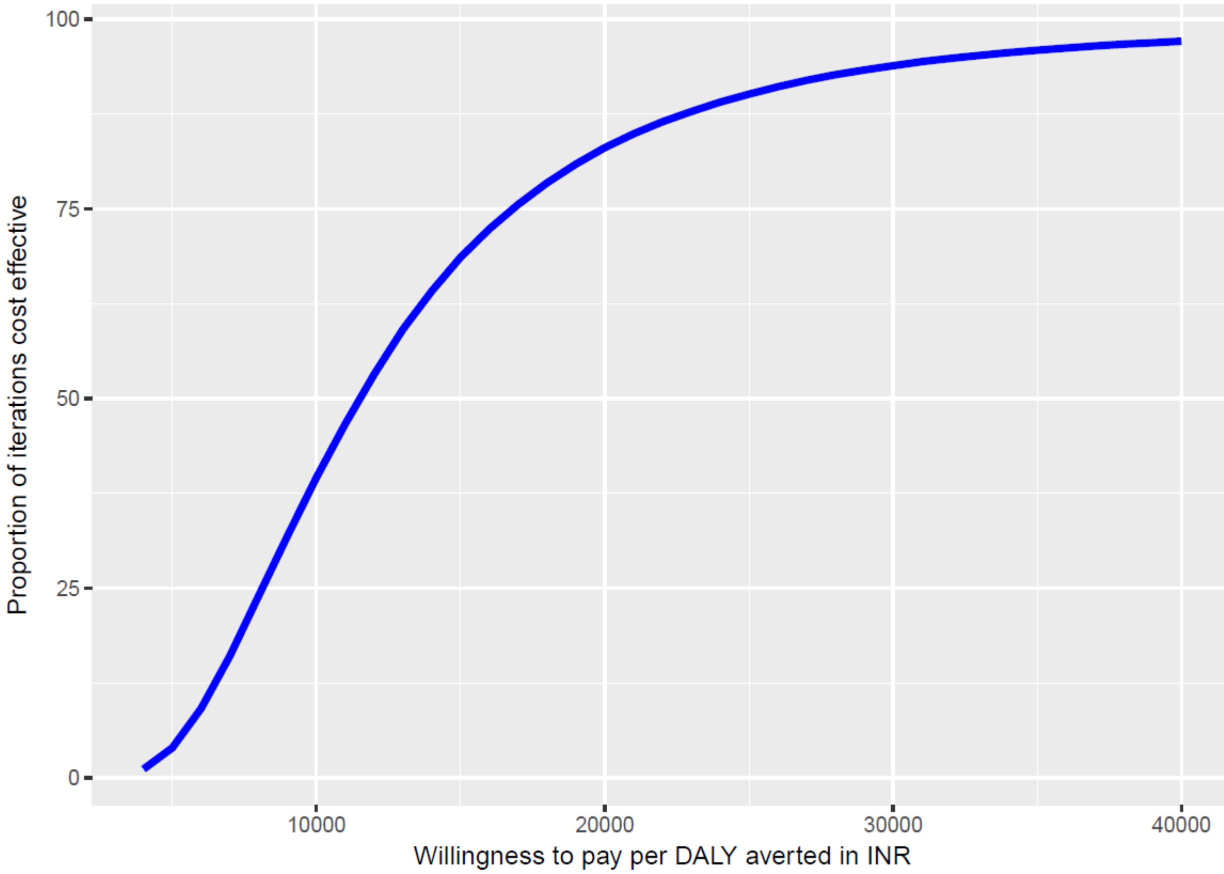


Figure 4.7: Probabilistic Sensitivity Analysis



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Chapter 6 Discussion

Summary of findings

Immunization is generally considered to be one of the most effective primary preventive measure undertaken by public health. The World Health Organization estimates that vaccines prevent around 1.5 million deaths annually among children aged less than 5 years globally.[1] India has the largest number of infants and young children in the world so childhood vaccination has the potential to be highly impactful in improving health there. However, the CDC estimated in 2015 that around 22% of the 19.6 million children who had not received the third dose of diphtheria-pertussis-tetanus vaccine, a key indicator of immunization systems performance of a country, were living in India.[2]

Performance of a nation's immunization system is determined not only by overall vaccination rates, but also by the equity in utilization of vaccination, especially among the socially and economically disadvantaged populations of a country.[3] India has been striving to improve childhood vaccination among both these groups and has met with some success through a number of targeted public health programs. The longstanding Universal Immunization Program (UIP) of India provides vaccines covered under its schedule free of cost to all children at all public health facilities.[4,5] The Indian government introduced initiatives such as the National Rural Health Mission, launched in 2005, to improve public health sector service delivery, especially in the underserved rural areas, by improving healthcare infrastructure and healthcare workforce, and encouraging community participation to boost community acceptance of public health care services.[6,7] Given that more than 90% of vaccinations are administered in public health facilities,[8] improving public health sector service delivery has the potential to make vaccination services more accessible and improve childhood vaccination coverage. Overall, the Indian government has taken measures to improve vaccine availability and affordability. However, there is a paucity of literature examining how successful these measures have been in more recent years, especially after 2008, when the district level household and facility survey (DLHS) 3 was conducted highlighting the need for a more contemporary assessment of the impact of these measures on improving childhood vaccination coverage.

This main objective of this dissertation was to study the evolution of socioeconomic disparities in childhood vaccination and related pathways over the last decade. In addition, this dissertation also aimed to study the effectiveness of an intervention aimed at reducing these disparities. Four nationally representative datasets were used to obtain data for three time-periods: DLHS-2 for 2002-2004, DLHS-3 for 2007-2008, and DLHS-4 and Annual Health Survey (AHS) for 2012-2013. Regression modeling, structural equation modeling, and cohort simulation models were used to analyze the data.

In chapter 2, we examined the socioeconomic disparities in childhood vaccination stratified by empowered action group (EAG) states and non-EAG states. We also conducted a state-by-state analysis of vaccination rate trends between 2002 and 2013 and SES based-disparities in 2012-2013. We found that while full vaccination rates had generally improved in EAG and non-EAG states, full vaccination rate decreased in non-EAG states between 2007 and 2013. Historically, rural areas were known to have lower childhood vaccination rates compared to urban areas in India. Rural-urban disparities decreased in both EAG and non-EAG states. The gap between rural and urban areas in full childhood vaccination decreased between 2002 and 2013 but persisted; non-EAG states experienced a reversal of rural-urban disparity where children from rural areas had significantly better full vaccination rates than children from urban areas. Maternal education remained a strong indicator of full childhood vaccination in EAG states. Full vaccination rates improved among Muslim children compared to Hindu children in both EAG and non-EAG states, though Muslim children still had significantly lower vaccination rates than Hindu children in 2012-2013 after adjusting for other socioeconomic indicators. The disparity in vaccination between children belonging to socially disadvantaged scheduled castes and scheduled tribes and children belonging to other relatively socially advantaged castes decreased across the three time-periods but remained statistically significant. Economic status of the household, measured by asset index, remained a significant predictor of childhood full vaccination in all three-time-periods though the magnitude of the association decreased. In general, EAG states had higher SES based-disparities than non-EAG states in all three time-periods although the gap between EAG and non-EAG states reduced over time.

Improvement in vaccination rates did not always accompany SES based-equality in vaccination. Indian states of Rajasthan, Punjab and Kerala which had full vaccination rates exceeding 60% also had high degrees of SES-based inequality. In contrast, states such as Meghalaya and Tripura with less than 40% full vaccination rate were characterized by lower levels of SES-based inequality. Overall, this study found that full vaccination rates increased in EAG states and decreased in EAG states, and improvement in vaccination rate was not equally experienced by all subgroups of populations in individual states.

In chapter 3, we explored the roles of availability of health services and acceptability of health services as mediators of the association between socioeconomic status and full vaccination during 2007-2008 and 2012-2013 in rural areas of 20 Indian states and union territories. The indirect effect of socioeconomic status mediated by availability and acceptability of health services was positive while the direct effect of socioeconomic status was negative on full childhood vaccination in both 2007-2008 and 2012-2013. The total effect of socioeconomic status on full vaccination was significantly positive in 2007-2008, and negative and statistically not significant in 2012-2013.

The decrease in the total effect of SES on full childhood vaccination between the two time-periods mirrored findings from previous studies which have shown reduction in SES based-disparities over time. The negative direct effect-estimate can be spurious due to measurement error of availability and acceptability of health services or may reflect underlying true effect which may be due to vaccine hesitancy among richer households which reduces vaccination rate. Another potential cause may be due to increased use of private health sector for vaccination services by more affluent households. Studies have shown that measles vaccination tended to be lower among households that used private healthcare providers for vaccination. Private healthcare providers also tended to have lower accountability to provide all the vaccines in the UIP schedule and report to the government the vaccination coverage among the children they immunized.

In chapter 4, we quantitatively assessed the performance of accredited social health activists, who are community health workers in India, in terms of measles vaccination among children aged between 12-60 months. We found that ASHAs were cost effective even when their financial incentives for delivering childhood immunization services was increased 10 times. ASHAs especially tended to be cost effective in areas where complications and hospitalizations due to measles tended to be high. Even on a long-term basis, when the cohort size available for measles vaccination in a village decreased to less than five children, ASHAs remained cost effective which provides evidence that governmental incentives for ASHAs to provide immunization services could be increased without compromising their cost effectiveness.

Policy implications

Most of the public health initiatives and programs of the Indian government have been focused on EAG states who comprise largely rural and socioeconomically disadvantaged population groups.[6] This dissertation shows that while SES-based disparities and the gap between EAG and non-EAG states in terms of childhood vaccination have been decreasing, previously well-performing groups have more recently shown stagnation of or even decline in vaccination rates over time. In fact, previously well performing non-EAG states were shown to have lower full vaccination rates in 2012-2013 compared to 2007-2008 so that once availability and acceptability were accounted for, higher SES was negatively associated with full vaccination. This indicates a need for the Indian government to reconsider their priorities and uniformly ensure high levels of immunization systems performance for all people living in all states of India, so that improvement in vaccination rates remains sustainable in all population groups.

The proportion of population utilizing private sector for healthcare services including vaccination has shown to be increasing.[9] However, based on previous literature and our findings, private healthcare providers appear to be less likely than public healthcare providers to provide all the UIP schedule recommended vaccines.[10,11] This highlights the need for the Indian government to institute measures to increase accountability of private healthcare providers to cover all the required dosages of important vaccines such as BCG, diphtheria-tetanus-pertussis, polio and measles vaccines and ensure full vaccination of children immunized by them. Introduction of mandatory immunization registry for both public and private health practitioners and public-private partnerships to ensure full vaccination coverage of children are some of the potential measures that could improve vaccination service provision of private healthcare professionals.

Accredited Social Health Activists (ASHAs) are community health workers introduced throughout India through National Rural Health Mission launched by the Indian government's ministry of health and family welfare in 2005.[12,13] Introduction of ASHAs is a part of the global wave community health worker (CHW) programs to reach out to socioeconomically disadvantaged populations and improve utilization of health services.[14] Both in India and globally, there have been only a few studies that have quantitatively assessed CHW initiatives. Most of the studies about ASHAs has assessed them qualitatively, mostly regarding their knowledge, attitude, skills, and practice. One common thread among most of these papers is that most of the ASHAs were dissatisfied with their incentives and felt that they were not being paid proportionately to the amount of work they do.

In our cost-effective analysis, we showed that under the assumptions of our model, ASHAs were cost-effective even when their financial incentives were increased by 10 times and under a wide range of values for the parameters used in our model, which was relatively conservative since only one of the multitude of the responsibilities of ASHAs was considered. This suggests that the Indian government should consider improving the financial compensation of ASHAs to improve their retention and ensure that the ASHA program is able to recruit more skilled women. This will further strengthen the ASHA program in India, which is the largest of its kind in the world.

Strengths

Overall, our dissertation has many strengths. We utilized national datasets containing data from around 29 states covering more than 90% of India's population. Together, the four datasets used in our analyses had more than 2 million observations, which enabled us to stratify our analyses to be able to detect the nuances in associations between sociodemographic and economic factors and full childhood vaccination. We incorporated survey design in our analyses where we could, which minimized the biases in our parameter estimates and made our results more generalizable to the underlying population. We used conservative estimates in our cost effectiveness analyses which reduced the possibility of false positive results. Structural equation modeling was used for our mediation analysis which allowed us to use latent variables as mediators and calculate indirect and direct effects for a binary outcome.

Limitations

Our dissertation has some limitations. The main limitation is the use of cross-sectional data which precludes us from making causal assumptions about underlying associations. We could assess the cost-effectiveness of ASHAs regarding only one outcome, which is likely to underestimate the cost-effectiveness of ASHAs. We could not incorporate the complex survey design of the utilized datasets in our structural equation models which limited the generalizability of our results to the underlying population. AHS had a different survey methodology than the DLHS datasets. We have tried to mitigate these limitations by stratifying our analyses wherever possible and request our readers to interpret the results of our dissertation considering these caveats.

Future directions

In our dissertation, we explored the changes in associations between socioeconomic indicators and full childhood vaccination between 2002-2013 and the degree of mediation of these associations by availability and acceptability of health services. However, to establish causal relationships, prospective cohort studies are required to avoid common pitfalls associated with using cross-sectional data such as reverse causation bias and selection bias. Intersectionality between different sociodemographic and economic factors such as interactions between residing in rural area and being a female child, religion and caste, and economic status and maternal education can be explored further to recognize sub-groups of population that are likely to be the most disadvantaged to access preventive health services such as vaccination towards whom interventions can be focused.

Availability of health services at the right place and the right time refers to not only physical availability of health centers and vaccine providers but also other factors such as availability of cold chain maintained viable vaccines. If such information is available, they can be used to create the availability variable in analyses exploring the pathways. In our dissertation, we assumed that maternal acceptability of health care services translated into acceptability of health care services for the child based on previous literature. However, more direct measures of acceptability such as receipt of health services for the child in life-threatening conditions such as diarrhea and pneumonia can be explored. Globally, religious and cultural beliefs are known to influence acceptability of vaccination services. Hence, interaction of religion with acceptability can be explored in mediation analyses. Affordability was not explored in our analyses. Affordability can mean not only affordability of vaccines but ability of family members to spare their time from other activities involving earning livelihood to accompany their children to timely vaccination sessions.[15] This dimension of affordability needs to be explored further since poorer households are less likely to be able to afford skipping a day of work to vaccinate their children.

Globally, CHWs execute a wide range of activities including provision of basic primary preventive services such as providing antimalarial drugs and antitubercular drugs to infected individuals and mobilizing the community to effectively utilize health care facilities.[14] As such, cost effectiveness analysis cannot cover all the activities of CHWs such as ASHAs. Other studies such as cost-benefit analysis and budget impact analysis are better suited to cover all of the activities of CHWs and can be utilized to quantitatively assess the performance of ASHAs in different Indian states. Utilization of techniques such as synthetic controls constructed using Bayesian structural time series models,[16] when adequate data is available, will help researchers to evaluate the impact of policies such as the ASHA program more effectively.

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Appendices

Appendix A: Harmonization of survey weights

We harmonized the survey weights of DLHS-2, DLHS-3, DLHS-4 and AHS in three steps:

Step 1: Harmonization of ever married women survey weights:

Based on 2001 and 2011 census, we calculated the total number of evermarried women for each state and the compounded annual growth rate (CAGR) of this population was obtained per state. Using the CAGR, we estimated the evermarried women population for 2004 (DLHS-2), 2008 (DLHS-3), and 2013 (DLHS-4+AHS). Next, we calculated the total of survey weights per state in each of the four datasets. We obtained the ratio of estimated census population to the total survey weights for each state in each time-period, used it as a scaling factor, and multiplied it by the original survey weights to obtain new weights for evermarried women.

Step 2: Calculation of selection probability of a child of an ever-married woman in the study

Survey weights were available up to the level of ever married woman. To calculate the selection probability for a child, who was the unit observation in our analyses, we first calculated the number of eligible children (aged between 12-60 months) per household in the DLHS datasets. Next, we calculated the number of children per household aged between 12-60 months included in the study. We estimated the selection probability by dividing the number of included children by the number of eligible children per woman. The scaling factor in step 2 was the inverse of selection probability and was multiplied with the scaled ever married woman survey weight obtained from step 1 to calculate the final child weight.

Step 3: Harmonization of child weight

The sum of child weight increased between 2004 and 2013. However, it decreased between 2002 and 2008. To synchronize the child weights during 2008, first, we estimated the CAGR of the sum of child weights per state between 2004 and 2013. Using the CAGRs, we estimated the expected sum of child weights in 2008. Then, we obtained a third scaling factor per state by dividing the expected sum of child weights by the observed sum of child weights. We multiplied this scaling factor with the final child weight in DLHS-3 to obtain the final modified child weight.

Step 4: Downscaling of AHS weight

The sum of AHS weights exceeded the census population for children aged less than five years in 2001 and 2011. Hence, we first estimated the CAGR between 2002 and 2007 based on DLHS-2 and DLHS-3 weights. Based on the CAGR, we calculated the expected sum of weights for each state in AHS. We then obtained the scaling factor by dividing the expected sum of weights by the observed sum of weights for each state. This scaling factor was multiplied by the original weight to obtain the downscaled weight. Then, sensitivity analysis was conducted by checking the distribution of covariates and outcome in our analyses calculated using original and downscaled weights and comparing the results between the two sets of analyses (Table A.1).

Table A.1: Distribution of socioeconomic indicators in AHS, 2012-2013 with new scaling[a]

Variable	N[b]	N-weighted[c]	Proportion (%)[d]
Rural area of residence	1384643	49197358	83.9
Female	763941	27489464	46.91
Maternal Education			
Illiterate	683606	32848465	56.02
Incomplete Primary Education	199914	6819457	11.63
Completed Primary Education	198641	5605334	9.56
Incomplete Secondary Education	374171	8944552	15.25
Completed Secondary Education	87552	2104888	3.59
Higher Education	81510	2314811	3.95
Religion			
Hindu	1328424	46810471	79.89
Muslim	250355	10378252	17.71
Christian	22211	784540	1.34
Sikh	3736	117949	0.2
Buddhist	710	22033	0.04
Others	18967	478244	0.82
Caste			
Scheduled Caste	312039	11819774	20.17
Scheduled Tribe	203148	7653905	13.06
Other castes	1109216	39117810	66.76
Vaccination status			
Full vaccination	987025	32450445	55.34
Partial vaccination	539451	21723428	37.05
No vaccination	98918	4463634	7.61

a. Refer to appendix A
b. Unweighted frequency
c. Weighted frequency
d. Percentage of weighted study population in a given category

Appendix B: Variables included in the calculation of asset index in DLHS-2, DLHS-3, DLHS-4, and AHS datasets

We used the following criteria to select the dummy variables to be used in the creation of 'asset index' variable using principal component analysis:

- Less than 50% of the households had the asset/ facility.
- The facility/asset tended to be owned by relatively affluent households. For example, telephones, black and white televisions and radio transistors were owned by most households during 2007-2008 and 2012-2013. Hence, we did not consider such variables for the creating the 'asset index' variable during these time-periods.

We stratified the calculation of asset index by time-period and rural/urban area of residence.

Table A.2: List of variables used in the creation of asset index variable in DLHS-2, DLHS-3, DLHS-4 and AHS

DLHS-2	DLHS-3	DLHS-4	AHS
Piped water into the dwelling	Piped water into the dwelling	Piped water into the dwelling	Pukka house
Pukka house	Water treatment in any way	Toilet with flushing into piped sewer system	Piped water into the dwelling
Availability of flush toilet	Toilet with flushing into piped sewer system	LPG/ PNG used as the main cooking fuel	Water filtration in any way
LPG/ electricity used as cooking fuel	LPG as the main cooking fuel	Pukka house	Toilet with flushing into piped sewer system
Electric fan	Number of rooms in the household	Number of dwelling rooms in the household	Availability of electricity in the household
Radio/ transistor	Pressure cooker	Computer/ laptop	Electric light as the main source of lighting
Sewing machine	Chair	Washing machine	LPG as the main cooking fuel
Television	Sofaset	Refrigerator	Number of dwelling rooms in the household
Telephone	Table	Motorcycle/ scooter/ moped	Television
Bicycle	Electric fan	Car/ jeep/ van	Computer
Motorcycle/ scooter	Radio/ transistor	Tractor	Washing machine
Car/ jeep	Color television	Water pump/ tube well	Scooter
Tractor	Mobile telephone	Cooler/ air conditioner	Car
	Computer		Tractor
	Refrigerator		Water pump
	Washing machine		Amount of land possessed
	Motorcycle/ scooter		
	Car		
	Tractor		
	Water pump		

Appendix C: Caste system in India

Caste system is a birth-ascribed social stratification system in India.[1] It originated as *varna* – an occupation based class system in Indian society originating around 3000 years ago, where the society was mainly divided into *Brahmins* (priests, teachers), *Kshatriyas* (warriors, royalty), *Vaisyas* (money lenders, traders), and the *Shudras* (laborers and other jobs).[2] This classification was mainly ideological, and had only a rudimentary correspondence to economy in the beginning.[3] With evolution of time, *varnas* morphed into hereditary *jati* or caste system with reduced occupational mobility and increased endogamy – marriages occurring mainly within the same caste.[3] Individuals whose castes involved jobs that had contact with objects considered impure, such as leatherwork, butchering, removal of human waste, animal carcasses etc. were considered as *Dalits* or untouchables.[4] Tribal communities who lived in mountainous areas or remote forests of India, and rejected inclusion into traditional caste system were termed as *Adivasis*, equivalent to the concept of aboriginals. *Dalits* and *Adivasis* formed the lowest social strata of Indian society and were considered as untouchables by the rest of the society.

Many scholars argue that the role of caste as a social identity solidified in India during the British regime, when caste of individuals was recorded in the Census of India.[3,5] During the British regime, secretarial jobs were available to Indians were given to individuals who claimed membership in upper castes, who also had most of the land ownership.[3] Socially disadvantaged classes such as *Dalits* worked mostly as laborers in agricultural fields or performed menial jobs with very low income, while *Adivasis* were termed as criminals by the British regime, and denied most of the jobs.[6] By the time of India's independence from the British, *Dalits* and *Adivasis* were the most backward classes not only in terms of social status, but also educationally and economically, and had the poorest health outcomes compared to other castes.

Post-independence in 1947, affirmative action was introduced for *Dalits* and *Adivasis* by the Constitution of India, termed as Scheduled castes (SCs) and Scheduled tribes (STs) respectively, in the field of education, governmental jobs and political positions at all levels.[3] The legacy of selecting and registering individuals under caste, which was introduced during the British regime, continued post-independence, and was the basis for providing benefits under affirmative action. In the 1970s, the Government of India extended affirmative action to other backward classes (OBCs).[7] OBCs were castes determined to be socially and economically backward based on pre-determined criteria, and the list of OBCs is revised regularly. According to the 61st round of National Sample Survey conducted in 2005-06, SCs and STs constitute about 20% and OBCs constitute about 32% of the population of India.

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