Improving Children's Health through Interventions: A Quasi-Experiment of GAVI

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Abstract

Impact evaluation of important public health programs in developing countries are limited in the literature. We evaluate the impact of Global Alliance for Vaccines and Immunisation (GAVI) on children's health outcomes among developing countries. Using a difference-in-difference identification strategy we find that GAVI has significantly reduced short term health outcomes such as neonatal mortality and infant mortality. We do not find any statistically significant impact of GAVI on children stunting. Our findings also show that GAVI has a significant impact on long term health of children such as under-five mortality. We further analyse the heterogeneity in the impacts of GAVI and our findings show that the impact of GAVI on children's health is highest for countries with very low per capita income compared to recipient countries with high per capita income. These results are robust after conducting a falsification test and testing for omitted variable bias. Our findings underscore the relevance of public health interventions in improving children health in developing economies.

Keyword*:* Children's health outcomes; GAVI; difference-in-difference; developing countries

JEL: I14, I15

1. Introduction

Impact evaluation of health intervention policies has been a growing concern because donors' overtime has been interested in linking health aid with performance. Despite the clarity of this, the evidence on the effectiveness of targeted health interventions in promoting children's health outcomes in developing countries is still insufficient. We contribute to the aid literature by evaluating the impact of Global Alliance for Vaccines and Immunization (GAVI) support on children health outcomes among developing countries. GAVI is one of the health interventions that provides vaccines and immunization assistance to the world poorest countries.[1]

In spite of the many intervention from governments and international organizations to improve children's health, available statistics show that children health continue to be poor. For example, in 2015, global population of children who died before their fifth birthday stood at 5.9 million. This situation was more severe in low- and middle-income countries. In sub-Saharan Africa, for example, children are about 14 times more likely to die before their fifth birthday (WHO, 2016). During the same year, the total number of stunted, wasted and overweight children was 156 million, 50 million and 42 million respectively (WHO, 2016). The World Health Organization (WHO) reports that the main causes of neonatal and under-five mortalities are pneumonia, diarrhea and malaria. Pneumonia alone contributed to 16% of under-five mortality in 2015 (WHO, 2016). Further, WHO states, Pneumonia which is caused by a virus, bacteria or fungi, can be prevented by adequate immunization intervention that can significantly eliminate Hib, pneumococcus, measles, and whooping cough (pertussis).

Our study is within the spirit of the effectiveness of health aid on health outcomes and contributes to the longstanding debate about the effectiveness of aid in general. Since, health aid and health outcomes are more closely linked, the relationship between the two may be easier to detect statistically (see Mishra and Newhouse, 2009). Aid for health is broadly believed to promote health outcomes in developing countries. It is often accredited with saving lives by providing vaccines, eliminating communicable and non-communicable diseases, and promoting medical services. This belief can be associated, in part, with successful large-scale health interventions funded by international development agencies. For example, health aid is successful in eliminating measles in southern Africa, in eradicating smallpox globally, in preventing STDs in Thailand, in reducing child

[1] A detailed discussion about GAVI support is presented in Section 2

mortality through vitamin A in Nepal, in successfully implementing rehydration therapies and reducing diarrheal deaths in Egypt, and many others (see Levine, 2007). In China, Liang et al (2010) found that over the period 1990-2005, the prevalence of hepatitis B among children who receive timely vaccines reduced by 2.1 %. The efficacy of the vaccine was estimated to be 88.3%.

Some studies have shown that health aid has positive impact of health outcomes in the recipient countries. Mishra and Newhouse (2009) shows the impact of overall health aid on infant mortality and concludes that overall aid significantly reduces infant mortality in the recipient countries. Also, Feeny and Ouattara (2013) examines the effect of overall health aid on child health as measured by the two proxies: (a) immunization against measles and (b) immunization against Diphtheria–Pertussis–Tetanus (DPT). The authors find that health aid reduces such health promotion proxies. Afridi and Ventelou (2013) also found that overall health aid significantly reduces adult mortality among selected developing countries. Other studies have shown that aggregate health aid improves public health delivery in developing countries (Wolf, 2007). On the contrary, some studies have shown that health aid do not have any significant impact of health outcome in recipient countries. Bendavid and Bhattacharya (2014) shows that total health aid has insignificant impact on health outcomes. Similarly, findings on the effect of health aid on life expectancy, have found no or almost zero impact on health life expectancy in developing countries (Easterly, 2003; Wilson, 2011). Other studies suggest that total health aid effectiveness is contingent on some preconditions. By applying quantile regression for example, Gomanee et al. (2005) find that income of the recipient countries determines the effectiveness of health aid showing that health aid is more effective in low-income countries. They further suggest that donors need to consider income of the recipient countries before they deliver health-targeted aid. Moullan (2013) finds health aid, particularly technical aid, reduces the emigration of highly educated individuals, mainly doctors from the recipient countries, and this in turn significantly enhances health outcomes.

Although, the literature on health aid and health outcome suggests a mixed finding, little is known of the impact of a specific health intervention from international development agencies on health outcomes. However, such evidence is important because it helps aid-financing institutions to initiate new aid-modalities which involve analysing aid effectiveness in a much-disaggregated approach which in turn enables them identifying the most productive channels of transferring aid to a specific sector. This study evaluates

the impact of the Global Alliance for Vaccine and Immunization (GAVI) support on children's health. An intervention that provides vaccines and immunisation assistance to developing countries with the aim of improving children health among GAVI support recipient. We examine both the short- and long-term impact of the intervention. Our identification strategy utilises a difference-in-difference approach by comparing health outcomes before and after the intervention among GAVI support recipient countries (hereafter recipient) and non-recipient (hereafter non-recipient) countries. More specifically, we examine the impact of this intervention on neonatal mortality, infant mortality, stunting and under-five mortality rates.

Using a difference-indifference strategy, we find that GAVI support is effective in promoting health outcomes. It significantly reduces neonatal infant and under-five mortality rates in the recipient countries. We, however, do not find any significant effect of GAVI support on stunting which could be explained by the fact that stunting is mainly caused by the prevalence of poor nutrition.[2] Also, we find that the impact of GAVI on health outcomes reduces as the level of per capita income of a recipient country increases; a finding which justifies the co-financing model of GAVI. Our contribution to the literature comes from our evaluation of a specific form of health aid (vaccine and immunization) on short-term and long-term children health outcomes. To the best of our knowledge, no study has examined the impact on GAVI on children's health in the manner we do.

The rest of the paper is organised as follows. Section 2 presents an overview about GAVI initiative and its co-financing model. Section 3 and 4 discuss data and empirical identification strategy respectively. In section 5, we present the main results which is followed by discussion in section 6. Finally, Section 7 concludes the study.

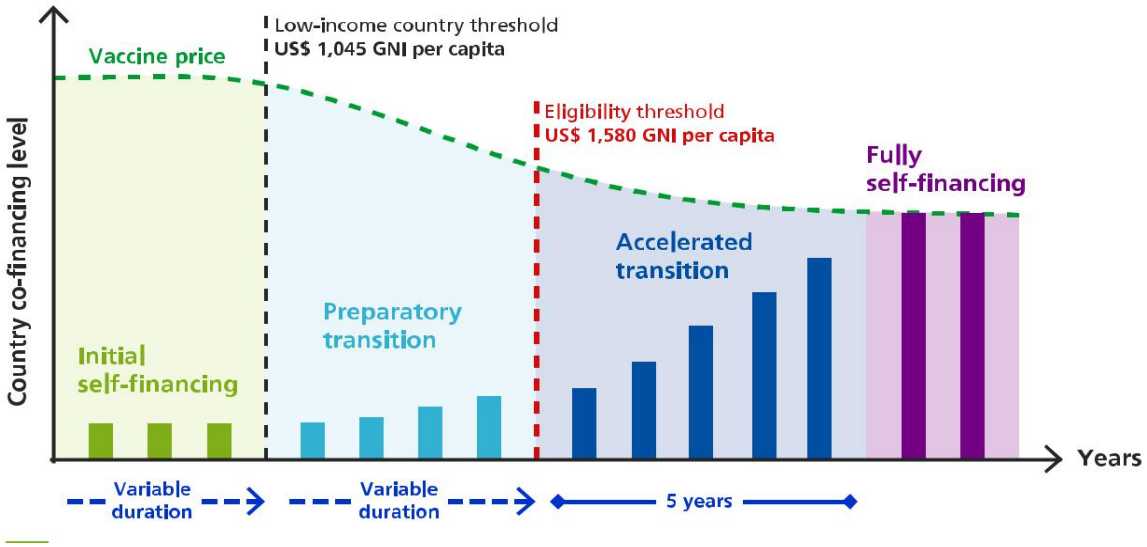
2. The GAVI initiative

GAVI, created in 2000, is an international organization which aims bringing together public and private sectors with the shared goal of creating equal access to new and underused vaccines for children living in the world's poorest countries. GAVI is mainly funded through contributions by government donors, the Bill and Melinda Gates Foundation, International Finance Facility for Immunization, GAVI Matching Fund, and Pneumococcal AMC (Godal, 2000). Eligibility for GAVI support is determined by a

[2] De Onis et al. (2012) state that stunting is an indication of malnutrition or nutrition related disorders. It is caused by poor maternal health and nutrition before, during and after pregnancy, as well as inadequate infant feeding practices especially during the first 1,000 days of a child's life and infection.

country's per capita Gross National Income (GNI) based on the World Bank data.[3] The scale and nature of GAVI's support changes as per capita GNI increases over time (see Figure 1). From the beginning of GAVI support, governments are expected to co-finance vaccines by financing a fraction of the needed doses[4]. Gradually, as per capita GNI grows, co-financing levels for governments increase. Figure 1 shows that once countries have surpassed GAVI's eligibility threshold, they enter an accelerated transition process. This means that they phase out of GAVI support at a faster pace than before, by taking on an increasing share of their vaccine costs. During this period, Gavi intensifies its efforts to help transitioning countries be in a good position to financially sustain their immunisation programmes and new vaccines.

***Figure 1*:** Gavi co-financing model.



Source: GAVI (2015)

[3] List of GAVI countries as of 2014: Afghanistan, Angola, Armenia, Azerbaijan, Bangladesh, Benin, Bhutan, Bolivia (Plurinational State of), Burkina Faso, Burundi, Cambodia, Cameroon, the Central African Republic, Chad, the Comoros, the Congo, Côte d'Ivoire, Cuba, the Democratic People's Republic of Korea, the Democratic Republic of the Congo, Djibouti, Eritrea, Ethiopia, the Gambia, Georgia, Ghana, Guinea, Guinea- Bissau, Guyana, Haiti, Honduras, India, Indonesia, Kenya, Kiribati, Kyrgyzstan, the Lao People's Democratic Republic, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mongolia, Mozambique, Myanmar, Nepal, Nicaragua, the Niger, Nigeria, Pakistan, Papua New Guinea, the Republic of Moldova, Rwanda, São Tomé and Príncipe, Senegal, Sierra Leone, Solomon Islands, Somalia, South Sudan, Sri Lanka, the Sudan, Tajikistan, Timor-Leste, Togo, Uganda, Ukraine, the United Republic of Tanzania, Uzbekistan, Vietnam, Yemen, Zambia, Zimbabwe

[4] The co-financing policy encourages governments in Gavi-supported countries to invest in new vaccines, enhancing country ownership of vaccine financing. It helps them plan for financially sustainable immunisation programmes in preparation for the phasing out Gavi support for these vaccines.

3. Empirical identification strategy

$$Child\_health_{it} = \alpha_i + \gamma_t + \beta\left(Gavi_{receipient_i} * Post\_1999_t\right) + \emptyset Health\_aid_{it-1} + \varphi PCI_{it} + \tau X'_{it} + \varepsilon_{it} \quad (1)$$

$Child\_health_{it}$ is child health outcome of country i in year$t$. We consider both short and long-term impact of vaccination. For short term we consider neonatal mortality, under-five mortality, and stunting. We proxy long term child health outcome with under-five mortality. Our analysis considers neonatal morality rates, infant mortality rates, prevalence of child stunting and under-five mortality rates as the main outcome variables. These variables are broadly accepted as important indicators of the long-run improvements of the health sector in an economy (Thomas et al., 1996). Infant mortality rate is the number of infants dying before reaching one year of age, per 1,000 live births in a given year. Neonatal mortality rate is the number of neonates dying before reaching 28 days of age, per 1,000 live births in a given year. Also, the prevalence of stunting is defined as the percentage of children under age 5 whose height for age is more than two standard deviations below the median for the international reference population ages 0-59 months. For children up to two years old height is measured by recumbent length. For older children height is measured by stature while standing. Finally, under-five mortality rate is defined as the probability per 1,000 that a newborn baby will die before reaching age five. The data are based on the WHOs new child growth standards released in 2006 (see Hill et al. 2012). α_i represents country fixed effects, γ_t shows year fixed effect. $Health\_aid_{it-1}$ is lagged log health aid per capita and PCI_{it} is log per capita income. The most important coefficients of interest of this study is β. If β is significant and negative, then GAVI support is effective in promoting children's health outcomes in the recipient countries after year 1999. X'_{it} indicates a vector of time varying country level characteristics, and ε_{it} denotes a random idiosyncratic error term.

Our empirical identification strategy relies on a comparison of health outcomes of recipient and non-recipient countries before and after the GAVI initiative in 2000. The implicit assumption is that the differences across countries in average health outcome would be consistent overtime across recipient and non-recipient countries in the absence the GAVI intervention. We define pre-GAVI period as 1985-1999 while post-GAVI is defined as 2000-2014. Table 1 shows the mean differences in children's health before and

after the GAVI intervention. It shows significant differences in all four health outcomes (neonatal, infant and under-five mortality rates and stunting) before 2000 among recipient and non-recipient countries. Moreover, the magnitude of the differences reduces after GAVI support was introduced. This evidence is consistent with Figures 2-4 showing that the gaps in children's health outcomes between recipient and non-recipient countries seem to have narrowed after 2000. The statistics in Table 1 suggest that in the absence of GAVI support, children in the recipient countries would have exhibited significantly poorer health on average. The Kernel density plots in figures 5-7 show the distribution of neonatal mortality, infant mortality and under-five mortality among GAVI and non-GAVI countries before and after 2000.[5] There is a significant difference in the gap of the distribution in all health outcomes between GAVI and non-GAVI countries before 2000. However, after 2000 the gaps have significantly narrowed across all indicators, although the incidence of neonatal mortality, infant mortality and under-five mortality remain higher in GAVI countries than non-GAVI countries.

One potential threat to our identification strategy is that the improvement in health could be due to increased total aid committed to health sector of recipient countries but not due the GAVI intervention. To isolate the effect of health aid from the GAVI support, we control for health aid received by both recipient and non-recipient countries.

Another potential threat is that there could be other unobservable factors that might be correlated with GAVI. Such factors can be time variant or in variant and might lead to the selection in to GAVI endogenous. To address this problem, we do two things: First, because per capita income is a major decision criterion to become a GAVI member, we present specifications with and without per capita income. As shown in Figure 1, recipient countries become fully self-financing and exit GAVI after an accelerated increase in per capita income. Second, we control country fixed effects in all specification. By controlling for country fixed effects, we allow for unobservable characteristics to vary during the study period with the assumption that such characteristics are fixed over time and are uncorrelated with children health outcomes.

We further control for a set of variables in our models to capture the effects of other factors influencing health outcomes.[6] The following controls are included: fertility rate, log of population, and CO2 emissions in metric tons per capita. It is evident that access to

[5] All values are in log transformed.
[6] Our choice of control variables is also limited to availability of data for the countries and years under consideration in this study.

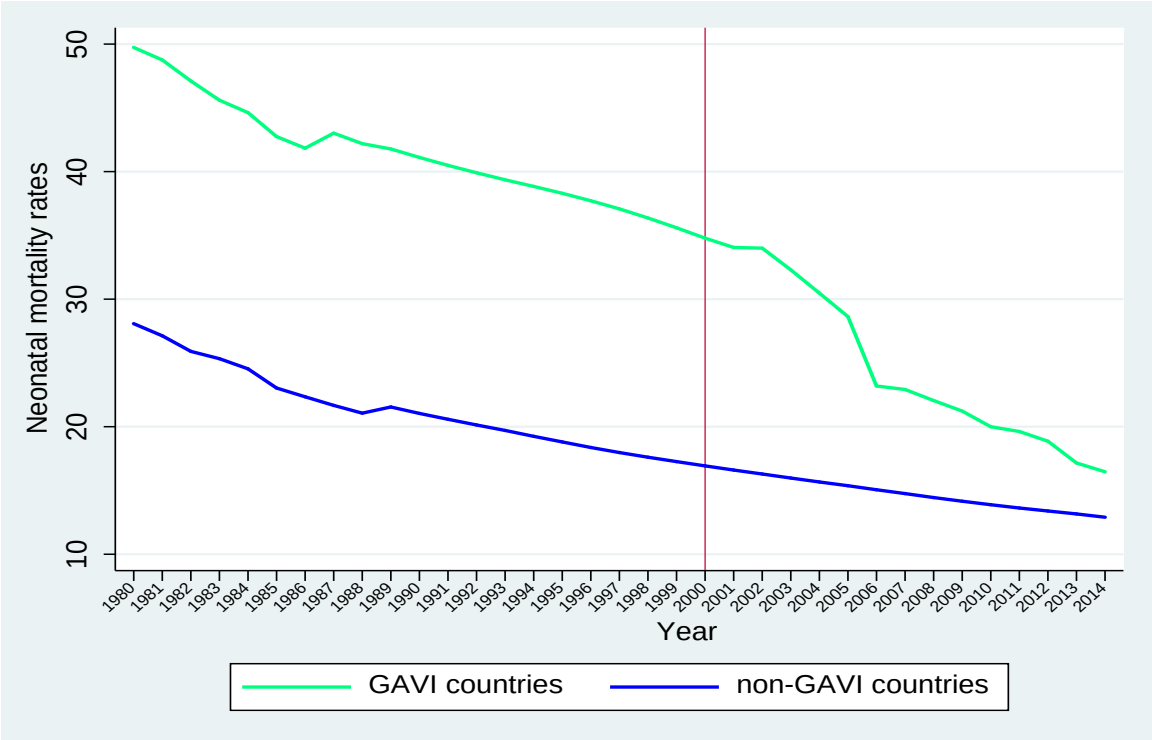
improved sanitation and immunization, adult female literacy, births attended by skilled health staffs, have significantly negative impact on health. Following Woodcock et al. (2009) we also include CO2 emissions in metric tons per capita to capture the effect of climate change on health outcomes.[7] Data for the study is sourced from the World Development Indicators (WDI) as well as AidData database.

Table 1: Summary statistics of outcome variables by time and GAVI status

	Pre-2000			Post-2000		
	Non-GAVI countries	GAVI countries	Diff	Non-GAVI countries	GAVI countries	Diff
Neonatal mortality	19.958	39.651	-19.693***	14.815	28.990	-14.175***
Stunting	21.593	44.731	-23.138***	18.472	33.508	-15.035***
Infant mortality	56.715	67.346	-10.630***	37.581	46.432	-8.851***
Under-five mortality	48.159	127.586	-79.427***	30.150	81.978	-51.828***

Source: Authors' own computation from World Development Indicators.

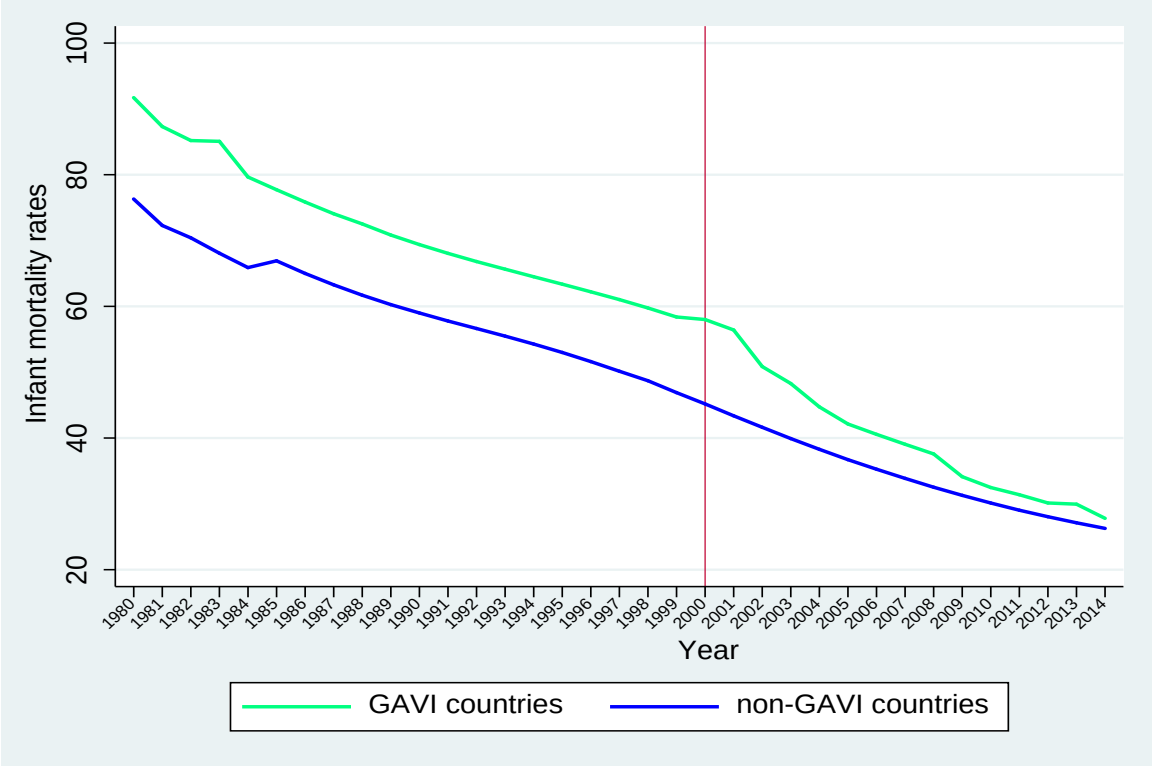
***Figure 2**: Neonatal mortality rates among GAVI and non-GAVI countries over the period 1980-2014.*



Source: World Development Indicators

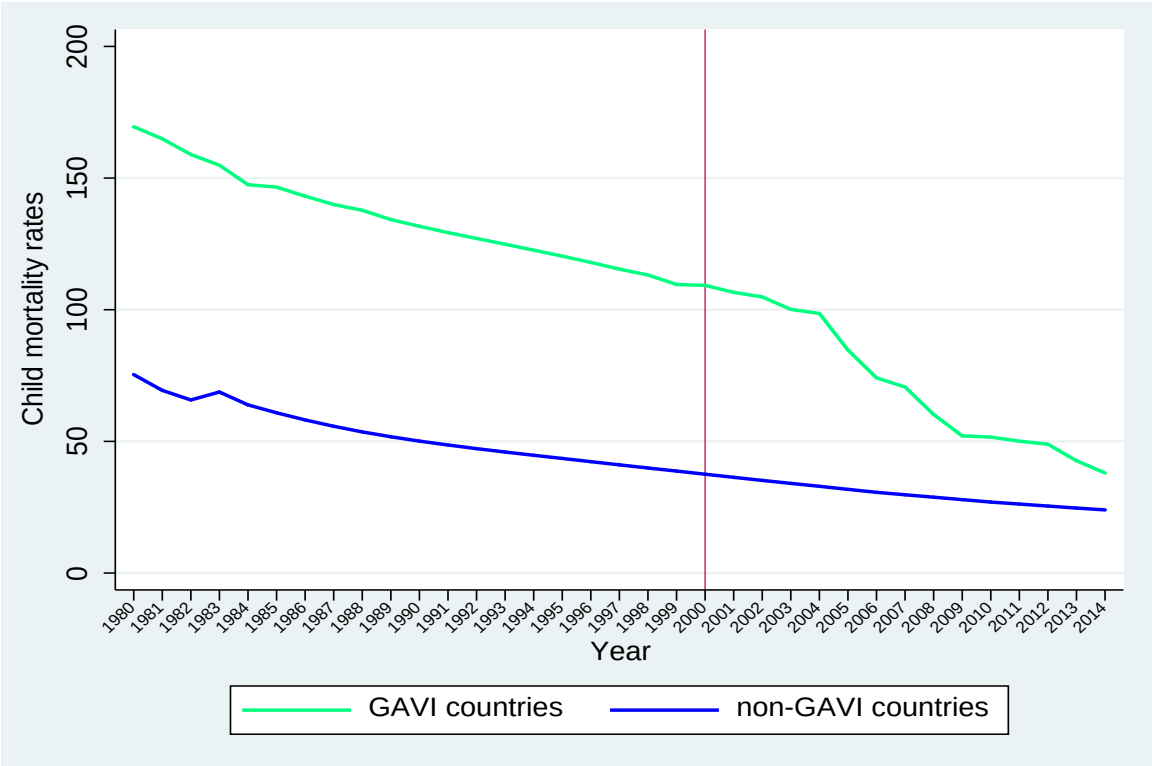
[7] The authors conclude that reduction in carbon dioxide emissions has larger health benefits.

***Figure 3**: Infant mortality rates among GAVI and non-GAVI countries over the period 1980-2014.*



Source: World Development Indicators

***Figure 4**: Under-five mortality rate among GAVI and non-GAVI countries over the period 1980-2014.*



Source: World Development Indicator

***Figure 5**: Kernel density distribution of neonatal mortality among GAVI and non-GAVI countries before and after 2000*

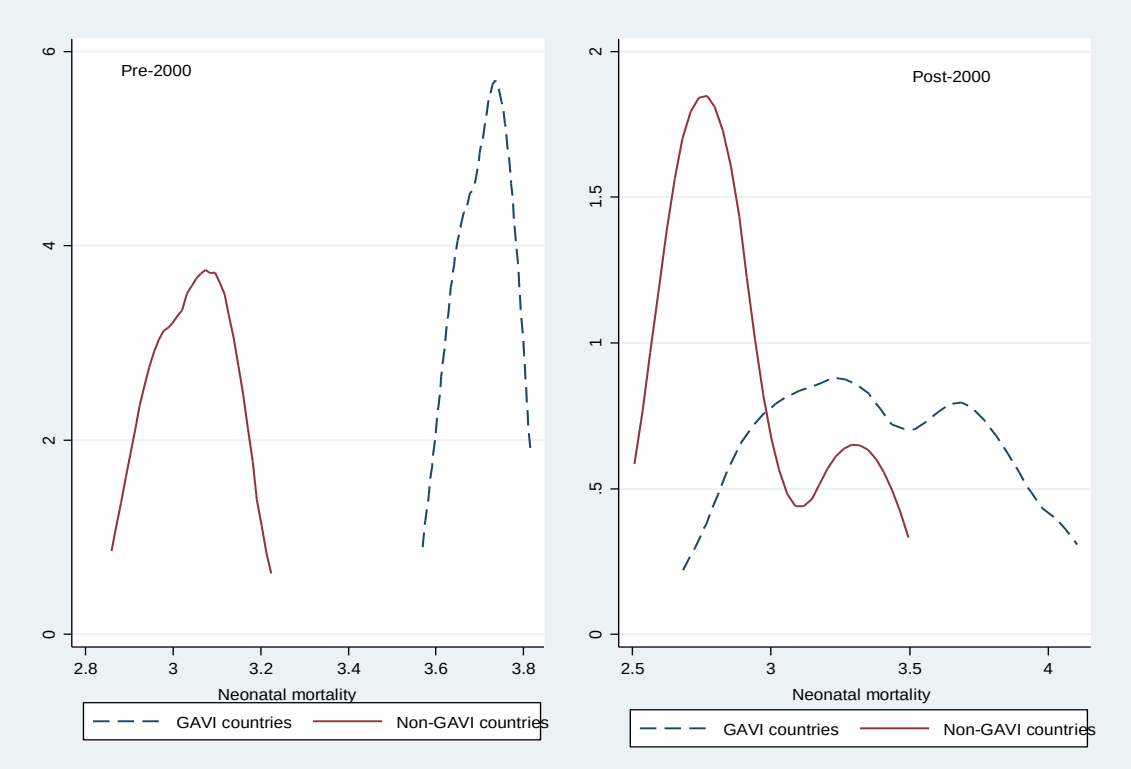


***Figure 6**: Kernel density distribution of infant mortality among GAVI and non-GAVI countries before and after 2000*

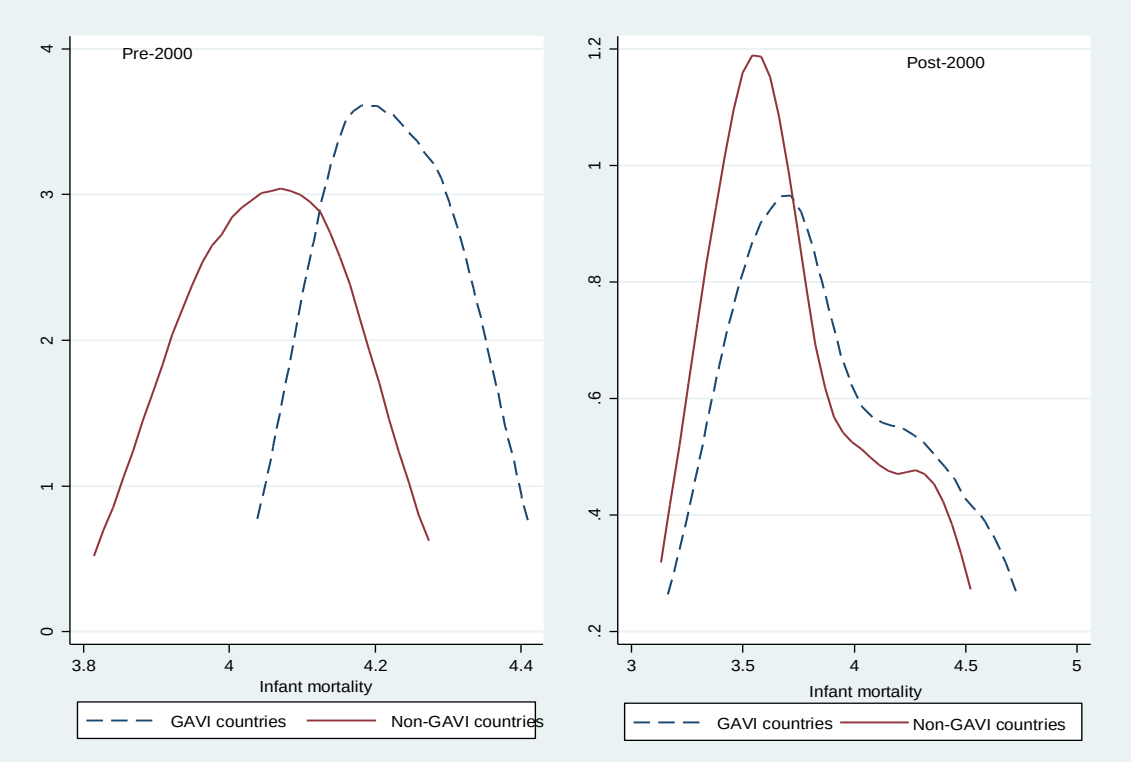
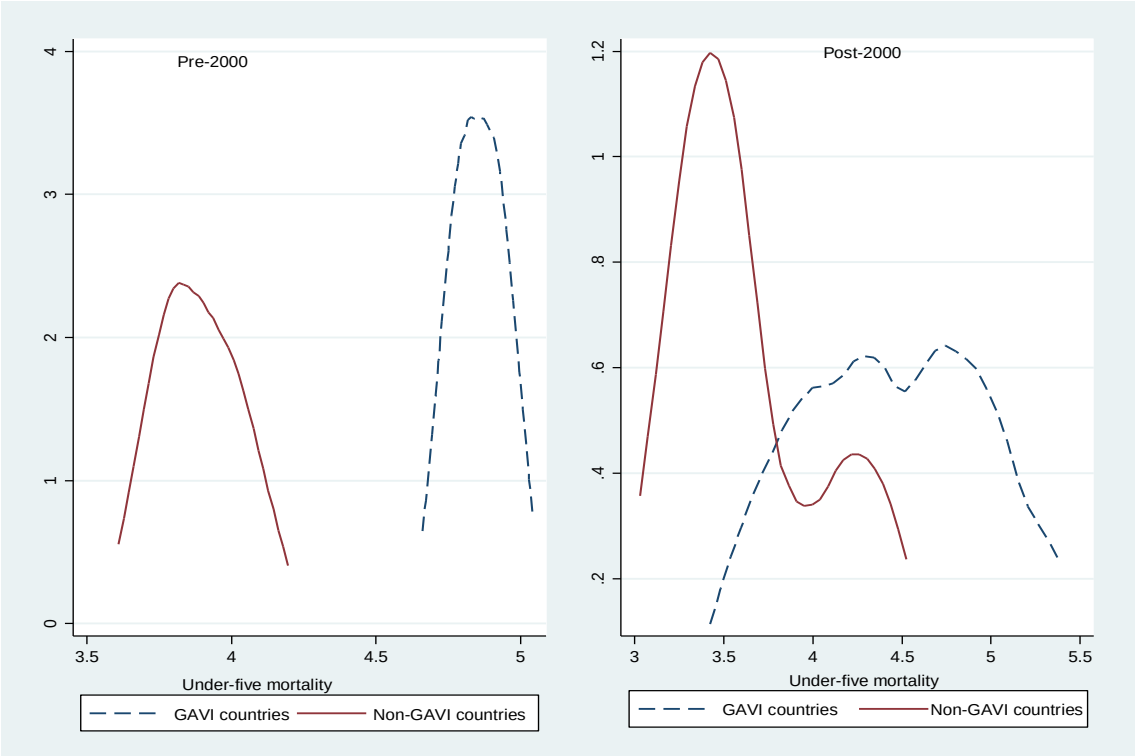


***Figure 7**: Kernel density distribution of under-five mortality among GAVI and non-GAVI countries before and after 2000*



4. Empirical Results

4.1 Difference-in-difference estimation

As discussed in the introductory section, we analyse both short and long-term impacts of the GAVI intervention on children's health outcomes. We use three proxies for short term health outcomes; neonatal and infant mortality rates and stunting. Tables 2-4 report the results for the short -term impacts. Long- term health is proxied by under-five mortality rate and is presented in Table 5. All regressions include country and year fixed effects as well as control for fertility, population and carbon dioxide emission. In Specification 1, we do not include health aid and per capita income. Health aid is included in specification 2 but without per capita income. Specification 3 presents the full model with health aid and per capita income. This method enables us to isolate the impact of GAVI support from general health aid received by recipient countries and improvement in per capita income. We first examine the effect of GAVI intervention on the pooled group

of countries irrespective of their level of per capita income[8]. In Table 2, we find that countries which received GAVI support experience an average reduction of 11.3 percentage points in neonatal mortality rate. In specification 2, we find that the effect reduces to10.7 percentage points, which shows that in the presence of general health aid, recipient countries gain extra percentage points reduction in neonatal mortality. In specification 3, this reduces to 7.6 percentage point reduction in neonatal mortality. Specifications 2 and 3 show that adding general health aid and per capita income does not affect the standard errors or the R-squared. This suggests that omitted-variable bias might not be a serious threat for our identification strategy. This is consistent across all health outcomes. Relying on estimates from specifiaction3, we conclude that the GAVI initiative has significantly reduced neonatal mortality by 8.1 percentage points among recipient countries.

We do not find any significant impact of the GAVI initiative of stunting children among recipient countries as shown in Table 2. Although the effect is negative in specification 3, it is not significant. This result is somehow expected because GAVI support is mainly targeted for vaccine and immunisation activities in the recipient countries. Hence stunting, which is an impaired development mainly caused by poor nutrition, would be less affected by GAVI support. Table 3 shows the effect of GAVI support on infant and under-five mortality rate. We find that countries which received GAVI support experience an average reduction of 7.6 percentage points in infant mortality rate as show in specification 1. In specification 3, this effect is reduced to 6.9 percentage points due to the inclusion of health aid and per capita income.

The largest impact of GAVI is found for long term health outcome, proxied with under-five mortality. Table 3 shows that GAVI countries witnessed a significant reduction in under-five mortality rate by 15.5 percentage points. The impact reduces to 10.5 percentage points as shown in specification 3.

[8] Countries' level of per capita income is a major requirement to receive GAVI support and also determines the exit point from GAVI. For example, countries such Bhutan, Honduras, Mongolia, Sri Lanka exited GAVI in 2016 while Ukraine exited in 2015

Table 2: The effect of GAVI on neonatal mortality and stunting among developing countries

	Neonatal mortality			Stunting		
	(1)	(2)	(3)	(1)	(2)	(3)
GAVI*Post_1999	-0.113***	-0.107***	-0.076***	0.027	0.008	-0.001
	(0.012)	(0.013)	(0.014)	(0.042)	(0.047)	(0.048)
Lagged log health aid per capita	No	Yes	Yes	No	Yes	Yes
Log per capita income	No	No	Yes	No	No	Yes
Country fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Years fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
N	1656	1326	1281	309	264	257
R-Squared	0.945	0.951	0.953	0.916	0.922	0.920

Source: Authors' own computation using data from WDI and AidData database. All specifications include control variables for fertility rate, log of population, and CO2 emissions in metric tons per capita.
Robust standard errors adjusted for heteroskedasticity are in parentheses. *, **, *** Significant at 10, 5 and 1%, respectively

Table 3: The effect of GAVI on infant and under-five mortality among developing countries

	Infant mortality			Under-five mortality		
	(1)	(2)	(3)	(1)	(2)	(3)
GAVI*Post_1999	-0.076***	-0.095***	-0.069***	-0.155***	-0.145***	-0.105***
	(0.013)	(0.013)	(0.012)	(0.015)	(0.016)	(0.016)
Lagged log health aid per capita	No	Yes	Yes	No	Yes	Yes
Log per capita income	No	No	Yes	No	No	Yes
Country fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Years fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
N	1714	1368	1323	1714	1714	1323
R-Squared	0.953	0.959	0.965	0.957	0.963	0.967

Source: Authors' own computation using data from WDI and AidData database. All specifications include control variables for fertility rate, log of population, and CO2 emissions in metric tons per capita.
Robust standard errors adjusted for heteroskedasticity are in parentheses. *, **, *** Significant at 10, 5 and 1%, respectively

4.2 Heterogeneous impact of GAVI based of per capita income of recipient country

In this section, we bifurcate recipient countires based on their per capita income and then examine and compare theeffects of GAVI support on children's helath outocme among the the receipient counries. We do so by putting countires into three counries; those below the 25th percentile value of per capita income; those between the 25th and 75th percentile value of per capita income; and those above the 75th percentile value of per capita income. This analysis is important because as part of GAVI's co-financing strategy, countries will exit and become self financing when receipient countries' per capita income grows significantly over time. These estimates are based on dpecifiaction 3. Tables 4-7 report the difference-in-difference results for all our proxies for children's health outcomes (neonatal, infant and under-five mortality rates and stunting).

Table 4 shows that the impact of GAVI support on neonatal mortality rate reduces as per capita imcome increases. For countries below the 25th percentile value of per capita income, GAVI supoort reduces neonatal moratality rate by 12.9 percentage points. Among those between the 25th and 75th percentile value of per capita income, the corresponding reduction in neotal mortality is 10.3 percentage points while for those above the 75th percentile per capita income value, GAVi leads to 8.1 percentage reducetion in neonatal mortality.

Results for the impact of GAVI support on stunting is reported in Table 5 and shows that GAVI has a significant impact of stunting only for countries below the 25th percentile value of per capita income. Among such countries GAVI intervention has led to a 12.9 percentage reducetion in thn incidence of stunting children. We do not find any significant impact of GAVI support on stunting among countries whose per capita income is above the 25th percentile value of per capita income.

Table 6 reports the impact of GAVI on infant mortality and shows that GAVI support is effective in reducing infant mortality rate among countries with per capita income between the 25th percentile and 75th percentile per capita income range. Intringingly, no significant effect is found for countries whose per capita income is below the 25th percentile value of per capita income, although negative.

With regards to the long term impact of GAVI support on children's health outocmes, Table 7 shows that the impact of GAVI support on under-five mortality is different among countries of different per capita income. Consitent with the findings on neonatal mortality, the impact of GAVI support on under-five mortality rate is largest among countries whose per capita income is below the 25th percentile. The impact ranges from 17.7 percentage points to 6.7 percentage points reduction in under-five mortality.

Table 4: The effect of GAVI on neonatal mortality by per capita income of recipient country

Variables	Neonatal moratlity		
	Below 25th percentile value of per capita income	Between 25th and 75th percentile valuse of per capita income	Above 75th percentile value of per capita income
GAVI*Post_1999	-0.129***	-0.103***	-0.081***
	(0.033)	(0.014)	(-3.17)
Country fixed effect	Yes	Yes	Yes
Years fixed effect	Yes	Yes	Yes
N	269	599	413
R-Squared	0.954	0.981	0.964

Source: Authors' own computation using data from WDI and AidData database. All specifications include control variables for fertility rate, log of population, and CO2 emissions in metric tons per capita. Robust standard errors adjusted for heteroskedasticity are in parentheses. *, **, *** Significant at 10, 5 and 1%, respectively

Table 5: The effect of GAVI on stunting by per capita income of recipient country

Variables	Stunting		
	Below 25th percentile value of per capita income	Between 25th and 75th percentile valuse of per capita income	Above 75th percentile value of per capita income
GAVI*Post_1999	-0.172***	0.052	0.207
	(0.075)	(0.061)	(0.158)
Country fixed effect	Yes	Yes	Yes
Years fixed effect	Yes	Yes	Yes
N	50	111	96
R-Squared	0.967	0.925	0.950

Source: Authors' own computation using data from WDI and AidData database. All specifications include control variables for fertility rate, log of population, and CO2 emissions in metric tons per capita. Robust standard errors adjusted for heteroskedasticity are in parentheses. *, **, *** Significant at 10, 5 and 1%, respectively

Table 6: The effect of GAVI on infant mortality by per capita income of recipient country

Variables	Infant moratlity		
	Below 25th percentile value of per capita income	Between 25th and 75th percentile valuse of per capita income	Above 75th percentile value of per capita income
GAVI*Post_1999	-0.048	-0.107***	0.045
	(0.033)	(0.017)	(0.036)
Country fixed effect	Yes	Yes	Yes
Years fixed effect	Yes	Yes	Yes
N	305	605	413
R-Squared	0.960	0.981	0.977

Source: Authors' own computation using data from WDI and AidData database. All specifications include control variables for fertility rate, log of population, and CO2 emissions in metric tons per capita. Robust standard errors adjusted for heteroskedasticity are in parentheses. *, **, *** Significant at 10, 5 and 1%, respectively

Table 7: The effect of GAVI on under-five mortality by per capita income of recipient country

Variables	Under-five moratlity		
	Below 25th percentile value of per capita income	Between 25th and 75th percentile valuse of per capita income	Above 75th percentile value of per capita income
GAVI*Post_1999	-0.177***	-0.145***	-0.067**
	(0.037)	(0.018)	(0.033)
Country fixed effect	Yes	Yes	Yes
Years fixed effect	Yes	Yes	Yes
N	305	605	413
R-Squared	0.975	0.982	0.976

Source: Authors' own computation using data from WDI and AidData database. All specifications include control variables for fertility rate, log of population, and CO2 emissions in metric tons per capita. Robust standard errors adjusted for heteroskedasticity are in parentheses. *, **, *** Significant at 10, 5 and 1%, respectively

4.3 Falsification test

In order to provide validity of our analysis, we perform a falsification test. A major threat to our empirical analyses is the fact that countries' health outcome might improve overtime as the economy expands. Although, we have isolated such effects by controlling for per capita income and time fixed effect it is important to perform a falsification analysis to demonstrate that the estimated impact indeed, occurred after 1999. We, therefore, redefined the pre-GAVI time period as 1960-1979 and post-GAVI time period as 1980-1999. The argument is that if GAVI has no significant impact on children's health during post-1999, then β in equation (1) should be negative and significant. Table 8 reports results from all specifications. The results show that over the falsified control period, although the difference-in-difference estimator is negative but insignificant.[9] The interpretation is that the vaccine and immunisation support from GAVI since 2000, has played a significant role in reducing neonatal mortality, infant mortality and under-five mortality.

Table 8: The effect of GAVI on children's health

Variables	Neonatal	Stunting	Infant mortality	Under-five mortality
DID	-0.056	0.716	-0.183	-0.098
	(0.036)	(0.857)	(0.114)	(0.070)
Controls	Yes	Yes	Yes	Yes
Country fixed effect	Yes	Yes	Yes	Yes
Years fixed effect	Yes	Yes	Yes	Yes
N	614	120	614	614
R-Squared	0.982	0.96	0.984	0.980

Source: Authors' own computation using data from WDI and AidData database. All specifications include control variables for fertility rate, log of population, and CO2 emissions in metric tons per capita, log per capita health aid, and logged per capita income. Robust standard errors adjusted for heteroskedasticity are in parentheses. *, **, *** Significant at 10, 5 and 1%, respectively

4.4. Testing for omitted variable bias

Another possible threat to establishing the causal effect of GAVI on children's health is omitted variable bias. There may be time variant unobservable factors associated with GAVI such as health governance, institutional development, and health systems factors in child health and the effect of GAVI. All these are time variant and might be correlated with our intervention variable and children's health. If any of these holds, then $\left(Gavi_{receipient_i} * Post\_1999_t\right)$ will be correlated with the error term in equation 1.

[9]The results are for the percentile analyses are qualitatively similar to those in Table 8 and are available upon request.

Because we cannot capture all these unobserved time variant variables in our model, we use the Oster (2017) to formally test for the relevance of these unobservable variables. This approach relies on the movement of the coefficient to conclude on the possible bias that might arise due our inability to control for such unobservable factors. The Oster (2017) approach works under the assumption that the selection of the observed controls is proportional to the selection of the unobserved controls. Because the R-squared is an increasing function of the number of control variables included in the model, if successive inclusion of controls does not significantly change the sign and magnitude of the main coefficients, then omitted variable bias is not a major threat. To perform this exercise, we rely on delta (δ) bound to determine the relevance of unobserved covariates relative to the observed variables.

$$\delta = \frac{\hat{\beta}(\widehat{R^2} - \widetilde{R^2})}{(\hat{\beta} - \tilde{\beta})(R^2_{max} - \widehat{R^2})}$$

Where $\hat{\beta}$ is the coefficient from the full model (specification 3), $\tilde{\beta}$ is the coefficient after correcting for omitted variable bias. $\widehat{R^2}$ is the R-squared from the full model and $\widetilde{R^2}$ is the R-squared from the parsimonious model. R^2_{max} is the maximum R-squared that can be obtained assuming all possible control variables are captured in the models. For consistency, we set the maximum R-squared as 0.980 in all models. δ is the coefficient of proportionality, $\delta = 1$ means that the unobservables are equally as important as the observables while $\delta > 1$ suggests that the unobservables are more important than the observables. The results in Table 9 show that the unobservable variables are not of more importance than the observed variables. It is also evident from the corrected effects that the economic significance of GAVI is not compromised by omitted variable bias. The conclusion therefore is that omitted variable bias is not a major threat to our identification strategy.

Table 9: Testing for omitted variables bias following Oster (2017)

Outcome variables	Baseline effect, $\dot{\beta}$ (se), [$\dot{R^2}$]	Controlled effect,$\hat{\beta}$ (se), [($\widehat{R^2}$]	Delta, δ	Corrected effect, $\tilde{\beta}$
Neonatal mortality	-0.113 (0.012) [0.945]	-0.076 (0.014) [0.953]	-0.309	-0.069
Stunting	0.027 (0.042) [0.916]	-0.001 (0.048) [0.920]	-0.009	-0.0002
Infant mortality	-0.076 (0.013) [0.953]	-0.069	-0.551	-0.071
Under-five mortality	-0.155 (0.015) [0.957]	-0.105 (0.016) [0.967]	-0.421	-0.0990

Note: Baseline effects are results from specification 1 whereas controlled effects are results from specification 3. Delta is computed using Oster (2017) and show how important unobservable variables are relative to the observed covariates. Corrected effects show the impact of GAVI after accounting for omitted variable bias. Robust standard errors adjusted for heteroskedasticity are in parentheses.

5. Discussion of the GAVI impact mechanisms

Our results suggest that GAVI intervention has positive impact of children health outcomes among developing coutries. For the short term impact, countries who received vaccine and immunisation support from GAVI after 1999 experienced a significant reduction in neonatal mortality and infant mortality and under-five mortality. The impact of GAvi is found to be sizeable for countries with low per capita income. We do not find any significant impact of GAVI on stunting, however, for countires we do find a negative and statistically significant impact of stunted children. GAVI improves children's health in developing countries through the following potential direct and indirect channels.

First, its direct investment in vaccines and immunisation in reciepient counries. GAVI routinely immunise children against hepatitis B, Haemophilus influenzae type b (Hib) and pertussis (whooping cough) as well as its one-off immunisation of children against measles, polio and yelow fever (GAVI, 2010). For example, in 2008, GAVI reached out to about 79 % of children in low-income countries with three doses of diphtheria-tetanus-pertussis (DTP-3) (GAVI, 2010). In Africa, the coverage of diphtheria-tetanus-pertussis-3 (DTP-3) increased from 49 percent in 2000 to 74 percent in 2004 (Arevshatian et al, 2007). As shown in Appendix 1, the Africa and South-East Asia regions have witnessed a significant increase in percentage of children who had received Diphtheria tetanus toxoid and pertussis (DTP3) immunization.

Second, GAVI indirectly creates a competition for the demand for vaccines which reduce vaccine prices. As a major player in the vaccine market GAVI creates economies of scale for manufacturers to expand their production capacity while opening door for suppliers to enter the vaccine market and eventually reducing price. (GAVI, 2010). For example, the price of DTP-HepB-Hib vaccine in a two dose lyophilsed presentation which is mainly supplied by GlaxoSmithKline Biologicals S.A. has dropped from US$ 3.5 in 2001 to US$ 2.95 in 2014. Similarly, the price of DTP-HepB-Hib vaccine in a single does liquid presentation has significantly dropped from USD 3.63 in 2006 to US$ 0.80 (UNICEF, 2016). Also in 2015, the weighted average price of Pneumococcal Conjugate Vaccine (PCV) was significantly lower for GAVI funded countries compared all other coutries including non-GAVI funded lower middle income countries as shown in Apeendix 2. The fall in price of vaccines makes it affordable for developing countries to patronise them which leads to improved children's health.

The third channel is the improvement in global standards for safe injection. GAVI offers an injection safety support programme to developing countries by providing them national immunisation programmes with three years funds for auto disable syringes. This support indirectly ensures safety and improves the coverage rate of vaccines. In Madagascar, Drain et al. (2003) found that the use of auto-disables syringes significantly increased the administration of vaccine on non-routine immunization days by 4.3 percent. Thus, improvement in the standards for safe injection leads to a larger coverage of vaccines among countries, thereby improving children health.

7. Conclusion

This study is the first to measure the impact of GAVI on short- and long-term children health outcomes. More specifically, we have used estimated the counter-factual of GAVI initiative on neonatal mortality, infant mortality, and stunting and under-five mortality. Our identification strategy exploits exogenous variation in increased access to vaccines and immunisation, and the timing of the vaccines and immunisation. Using different measures for children's health outcomes, we find that GAVI has a large negative impact on neonatal mortality, infant mortality and under-five mortality. The effect is significantly larger for recipient countries with per capita income below the 25^{th} percentile. Our main results show in the short term, the impact of GAVI is 3.5 and 6.2 percentage reduction in infant mortality and neonatal mortality respectively. Similarly, the long-term f GAVI is found to reduce under-five mortality by 7.3 percentage points. No significant impact is found for the proportion of stunting children, however, for countries with low per capita income (below the 25the percentile), we do find a significant reduction of 16.2 percentage points. The results in this paper contributes to the literature on health aid and health outcome. Our unique contribution sterns from the evaluation of a specific form of health aid (vaccines and immunisation) which targets children.

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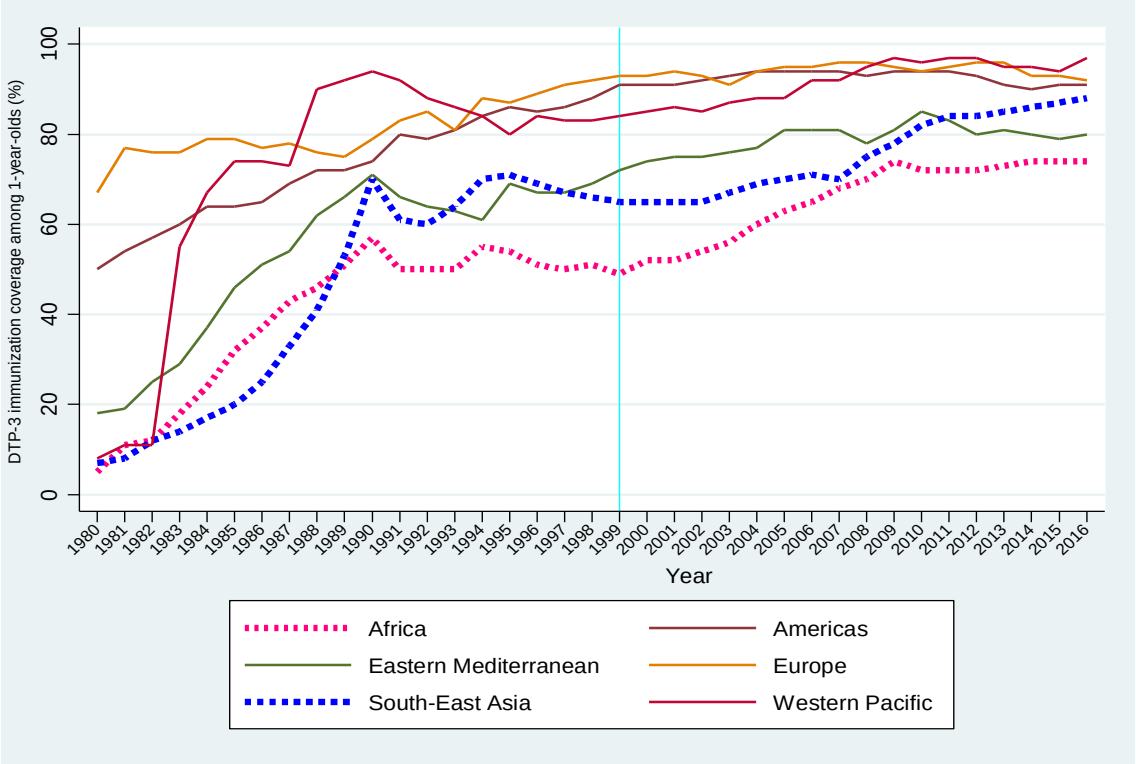
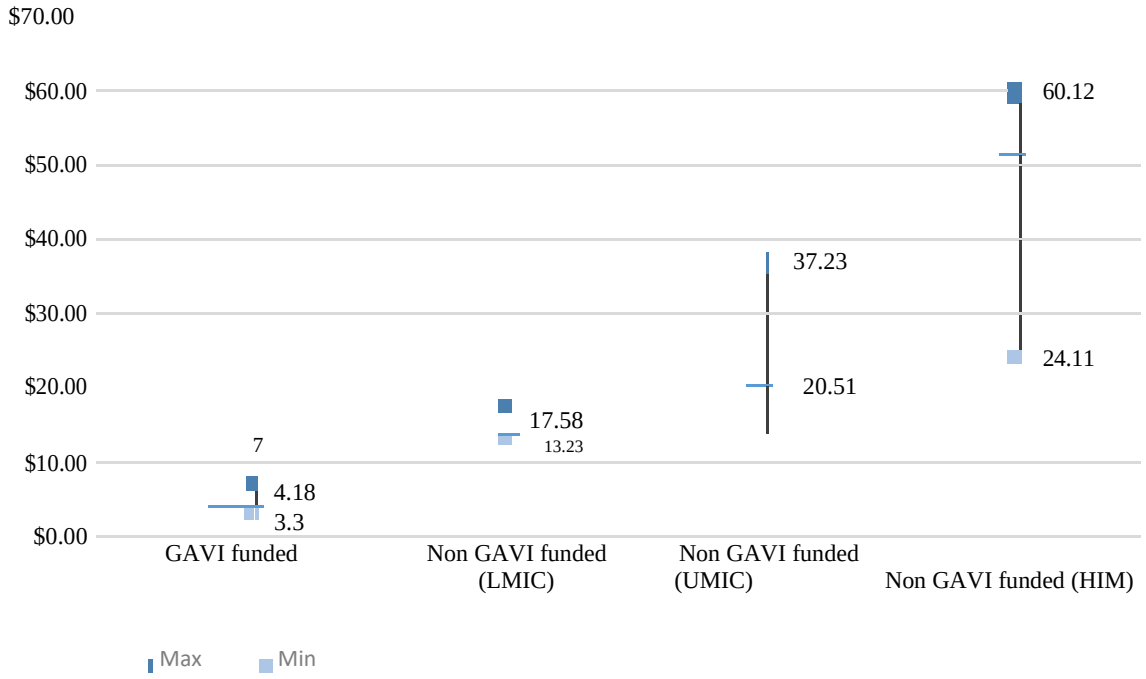
Appendices

Appendix 1: Trends in Diphtheria tetanus toxoid and pertussis (DTP3) immunization coverage among 1-year-olds (%) among WHO regions



Source: WHO Global Health Observatory (GHO) database

Appendix 2. Minimum, maximum by income level for single dose PCV, 2015[10]



Source: WHO Price Report (2016)

[10] LMIC is lower middle-income countries, UMIC is upper middle-income countries and HIM is higher income countries

Appendix 3: List of countries considered in the study

GAVI countries	Non-GAVI countries
Afghanistan	Algeria
Albania	Argentina
Angola	Belarus
Armenia	Belize
Azerbaijan	Botswana
Bangladesh	Brazil
Benin	Colombia
Bhutan	Costa Rica
Bolivia	Croatia
Bosnia and Herzegovina	Cuba
Burkina Faso	Dominica
Burundi	Dominican Republic
Cambodia	Ecuador
Cameroon	Egypt, Arab Rep
Central African Republic	El Salvador
Chad	Equatorial Guinea
China	Fiji
Comoros	Gabon
Congo, Dem. Rep	Grenada
Congo, Rep	Guatemala
Cote d'Ivoire	Iran, Islamic Rep
Eritrea	Iraq
Ethiopia	Jamaica
Gambia, The	Jordan
Georgia	Kazakhstan
Ghana	
Guinea	
Guinea-Bissau	
Guyana	
Haiti	
Honduras	
India	
Indonesia	
Kenya	
Kiribati	