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Impact of immunization on child mortality in Sub-Saharan African countries: System GMM approach

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Abstract
This study was driven by the relatively persistent high under-five mortality rates and declining immunization coverage among children in Sub-Saharan Africa. It explores the relationship between immunization and child mortality in this region by analyzing a panel dataset comprising 44 Sub-Saharan African countries from 2011 to 2019. The study employs the System Generalized Method of Moments (GMM) approach. The results reveal a statistically significant negative association between immunization coverage and under-five mortality, which suggests the potential of immunization to mitigate child mortality in the region. Furthermore, the analysis identifies sanitation, economic development (measured by GDP per capita), food security, urbanization, dependency ratios, access to clean fuel, and technology as significant determinants of under-five mortality. These findings carry substantial implications for the future workforce and the health and well-being of under-five children. To improve immunization rates, the study emphasizes the need for coordinated efforts among governments, non-governmental organizations, and donor agencies to promote public awareness and address barriers impeding immunization coverage in Sub-Saharan Africa.

Keywords: Child Mortality, Immunization, Sub-Saharan Africa, GMM

1. Introduction

Immunization is a critical component of preventive healthcare and has been shown to reduce child mortality and morbidity globally (Li, 2021). It is one of the most cost-effective public health interventions, preventing nearly 4 million deaths yearly (Adesina et al., 2023). Both immunization and under-five mortality perform major roles in public health policy and are being tracked under the Sustainable Development Goals (United Nations, 2022). Despite significant progress in immunization coverage over the last two decades, the report from World Health Statistics shows a concerning trend of decline in universal immunization coverage, which calls for renewed efforts to speed up advancement and make it possible for countries to meet their SDG target of reducing under-five mortality rate to 25 per 1000 live births by 2030 (World Health Organization, 2020).

In its commitments, the World Health Organization (WHO) and the governments have created the Expanded Program on Immunization (EPI) to enhance and reinforce routine immunization coverage throughout member countries to lower infectious and vaccine-preventable illnesses (VPDs) among children (Adeloye et al., 2017). Despite ongoing efforts, more than 20.5 million children globally remained unvaccinated or under-vaccinated in 2022 and about 14.3 million children (also known as "zero-dose children") did not receive any vaccines, a significant rise of 1.4 million from 2019 (UNICEF, 2023). Regionally, there has been a stagnation in the rate of

immunization coverage at the national and sub-national levels, and the African Region continues to trail behind other parts of the world. It is estimated that about 5 percent of African children do not receive all recommended immunizations and as a result, almost 30 million under-five African children still experience vaccine-preventable illnesses (VPDs) each year. Of these, more than 500,000 child deaths are connected to VPDs every year, accounting for over 58% of all VPD-related fatalities worldwide (WHO, 2022).

Poor vaccination adherence remains a problem in many regions of the world particularly in Sub-Saharan Africa with the highest under-five mortality per 1000 live births (Barrow et al., 2023). The high rate of under-five mortality rate in the region was due to the poor immunization rate, which has made children more susceptible to infections like pneumonia, measles, diarrhea, and other illnesses (Adesina et al., 2023). SSA is lagging behind the rest of the globe. Less than 30% of the population had taken at least two doses as of April 2023, and more than 70% had not taken any as of June 2023 (Wollburg et al., 2023). If the current trend continues the region is unlikely to meet the SDG target of reducing under-five deaths to 25 per 1000 live births by 2030 unless concerted efforts are made in addressing the problem.

WHO (2020) predicts that between 2021 and 2030, immunization can avert more than 50 million deaths. Measles immunization is expected to save approximately 19 million lives by 2030 and hepatitis B vaccine has the potential to save 14 million lives. Childhood immunization, in addition to protecting against preventable diseases, connects children and families to health-care systems, providing extra basic medical treatments and laying the framework for primary health care. As such, securing global access to immunizations is a key step towards reducing the under-five mortality rate to 25 per 1000 live births by 2030. The Sustainable Development Goals (SDGs), particularly SDG 3, focus on ensuring healthy lives and promoting well-being for all. Target 3.2 aims to end preventable deaths of children under five years of age by reducing the under-five mortality rate to at least 25 per 1,000 live births by 2030. Improved immunization could expedite achieving this goal. Hence, this study addresses this target by empirically examining the role of immunization in reducing under-five mortality in Sub-Saharan Africa.

2. Empirical Literature Review

The existing body of literature predominantly focuses on the determinants of child immunization. For example, Adesin et al. (2023) conducted a cross-sectional study in Nigeria to identify factors influencing child immunization among rural mothers. Through binary logistic regression analysis, they identified variables such as maternal age, residential area, education level, income index, and antenatal care visit frequency as significant predictors of immunization completion. Similarly, Ameyaw et al. (2021) employed multivariate decomposition analysis for a non-linear response model to investigate the rural-urban disparity in full childhood immunization. Their findings emphasized that household wealth substantially contributed to this disparity. Kolawole et al. (2023), using a binary logistic model, examined the relationship between household vulnerability factors, maternal health behaviors, and child immunization status in Nigeria. Their study revealed that children from vulnerable households are less likely to receive full vaccination compared to those from non-vulnerable households. In another study, Barrow et al. (2023) applied multivariate logistic regression to evaluate childhood vaccination uptake and determinants among children under one year in Gambia, Sierra Leone, and Liberia. The study concluded that postnatal care attendance by

mothers increased the likelihood of full vaccination, whereas factors such as limited paternal education, lack of television access in households, and fewer antenatal visits reduced vaccination rates. Onsomu et al. (2015) explored the association between maternal education and child immunization in Kenya using retrospective cross-sectional data. Their analysis demonstrated that mothers with higher levels of education were significantly more likely to immunize their children compared to those with minimal education.

Regarding the relationship between immunization and child mortality, McGovern and Canning (2015) assessed the impact of vaccination coverage on under-five mortality risk at the survey cluster level. Using modified Poisson regression, the study identified significant decreases in child mortality associated with immunization coverage, with children in clusters of full vaccination exhibiting lower mortality risk compared to those in clusters with no vaccination coverage. Nayir et al. (2020) examined the outcomes of an immunization program in Turkey, reporting a marked decline in pertussis mortality rates. Adeoti and Oni (2018 investigated the connection between child immunization and child mortality in rural Nigeria, uncovering a strong inverse relationship. Bhargava et al. (2013), utilizing District Level Health and Facility Survey data, examined the role of vaccination cards in promoting vaccine uptake against diseases such as diphtheria, pertussis, tetanus (DPT), polio, tuberculosis (BCG), and measles. Their findings indicated that maternal education, household assets, and healthcare facility access positively influenced vaccination uptake, with significant interaction effects between maternal education and healthcare availability on vaccination timing. Wong et al. (2019) studied measles immunization programs in India using nationally representative data, finding greater declines in measles mortality rates in campaign states compared to non-campaign states. Andersen et al. (2018) utilized Cox regression models to evaluate mortality rates before and after oral polio vaccine (OPV) campaigns, revealing a reduction in mortality rates following campaigns and further decreases with successive OPV doses. Santosh (2009) explored the impact of immunization programs on child mortality and educational attainment through district-by-cohort variance analysis, demonstrating reductions in infants and under-five mortality rates associated with program exposure.

While most studies have concentrated on identifying the determinants of immunization (Adesin et al., 2023; Ameyaw et al., 2021; Kolawole et al., 2023; Barrow et al., 2023; Onsomu et al., 2015), relatively few have investigated the relationship between immunization and child mortality at the individual country level (Nayir et al., 2020; Adeoti & Oni, 2018; Bhargava et al., 2013; Wong et al., 2019; Andersen et al., 2018). Importantly, no one has examined the association between childhood immunization and under-five mortality across multiple countries in Sub-Saharan Africa. Addressing this gap, the present study aims to investigate the impact of immunization on under-five mortality in Sub-Saharan Africa, recognizing the critical need for multi-country empirical analyses in this region.

3. Methodology

This study follows the empirical model of McGovern and Canning (2015) as expressed in equation 1:

$$\lambda c = exp\,(\alpha + \beta\, Vaccination\ Rate + Xc\,\gamma + \mu c) \quad \ldots\ldots (1)$$

Where λ_c denotes the number of children in the cluster who have died in a cluster. α is a constant. β represents the associated parameter measuring the relative risk of vaccination coverage. Vaccination Rate

denotes the average vaccination rate in the cluster, X_c represents the independent variables measured at the cluster level, γ signifies the parameter vector associated with the control variables, and μ_c is an error term. The current study adopted and expanded on McGovern and Canning's (2015) model. Hence, equation 2 is developed to model the functional relationship between immunization and health outcomes:

$$U5M = f(IMM, SANT, GDPP, FA, URB, DR, CFT) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

U5M represents under-five mortality, while IMM stands for immunization. The acronyms SANT, GDPP, FA, URB, DR, and CFT refer to sanitation, GDP per capita, food availability, urbanization, dependency ratio, and clean fuel and technology, respectively. Using a panel framework to present the functional relationship in an econometric model, equation 3 was developed:

$$U5M_{it} = \alpha_0 + \alpha_1 IMM_{it} + \alpha_2 SANT_{it} + \alpha_3 GDPP_{it} + \alpha_4 FA_{it} + \alpha_5 URB_{it} + \alpha_6 DR_t + \alpha_7 CFT_{it} + \eta_t + \lambda_i + \Pi_{it} \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where i denotes the number of SSA nations included in the study and t denotes time in years. t stands for the time-invariant country-specific impact that accounts for differences among the panel nations, whereas η_t denotes the country-specific temporal variation effect. While λ_i is a time-variant error term that represents all other factors that may have an impact on the under-five mortality rate in developing countries but are not considered by the model.

The Generalized Method of Moment (GMM) model developed by Arellano and Bond (1991) and Arellano and Bover (1995) was applied in the study to address the drawbacks of the fixed panel OLS model in dealing with heterogeneity issues such as time-invariant inequalities in the sample countries. Because the model is dynamic, it can help to solve the problem with fixed panel models. The GMM model specifications are presented in equation 4:

$$U5M_{it} = \alpha_0 + \ell U5M_{it-1} + + \alpha_1 IMM_{it} + \alpha_2 SANT_{it} + \alpha_3 GDPP_{it} + \alpha_4 FA_{it} + \alpha_5 URB_{it} + \alpha_6 DR_t + \alpha_7 CFT_{it} + \eta_t + \lambda_i + \Pi_{it} \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

In equations 4, the dependent variable for the study is represented by $U5M_{it}$ in SSA which stands for under-five mortality. While U5Mit-1 is lagged dependent variables, it accounts for the panel GMM model's dynamic behavior. The coefficients of all the log form-independent variables in model equation *are* α_1, α_2, α_3, α_4, α_5, α_6, and α_7 respectively.

The under-five mortality rate, expressed per 1,000 live births, represents the number of children who die before reaching the age of five. Immunization, measured as the average number of children aged 12 to 23 months who received immunization, is expected to be negatively associated with under-five mortality. GDP per capita, expressed in constant US dollars, is also predicted to have a negative relationship with under-five mortality. Additionally, food availability, measured by the food production index, is expected to show a negative association with under-five mortality. Access to basic sanitary facilities, clean cooking fuel, and technology are anticipated to be negatively related to under-five and infant mortality. Urbanization, represented as the percentage of the population living in cities, is expected to be negatively associated with under-five mortality. The dependency ratio, expressed as a percentage of the working-age population, is expected to have a positive relationship with under-five mortality. Clean fuel and technology, defined as the proportion of the population with access to clean fuel such as electricity, are expected to show a negative association with under-five mortality. Data for all variables were sourced from the World Development Indicators of the World Bank (2022). The study covered 46 Sub-Saharan African

countries from 2011 to 2019, selected based on data availability and adherence to acceptable panel data rules.

4. Results Presentation and Discussion

Prior to estimating the main model, the study conducted preliminary tests, including descriptive statistics and a correlation matrix. Descriptive statistics encompass the mean, standard deviation, minimum, and maximum values. Table 1 provides a summary of the descriptive statistics for all variables considered in assessing the impact of immunization on under-five mortality in Sub-Saharan African countries.

Table 1

Descriptive statistics on the impact of immunization on under-five mortality in Saharan African countries

VARIABLE	MEAN	STD. DEV.	OBS
$U5MR_{it}$	71.84928	30.88255	414
IMM_{it}	78.43478	16.04033	414
$SANT_{it}$	46.5095	19.93875	414
$GDPP_{it}$	113.2542	192.2178	414
FA_{it}	101.0918	11.16548	414
URB_{it}	38.498	14.91468	414
DR_{it}	5.775411	1.724407	414
CFT_{it}	44.38066	25.12425	414

The statistical analysis in Table 1 highlights key socioeconomic and health indicators across Sub-Saharan African countries. The annual mean under-five mortality rate is 71.85, indicating that approximately 72% of children die before reaching the age of five. Immunization coverage for children aged 12 to 23 months has a mean of 78.43, suggesting that 78% of children in this age group are immunized. Access to adequate sanitation services averages 46.51%, meaning that nearly 47% of the population has access to basic sanitary facilities. The average GDP per capita is $113.25, reflecting low-income levels, while the food production index averages 101.09, equating to household consumption of 101 tons of food annually. Urbanization is at 38.50%, signifying that about 38% of the population resides in urban areas. The dependency ratio for individuals aged 65 and above is 5.78%, indicating that 6% of the elderly population are dependent. Access to clean fuel and technology averages 44.38%, showing that 44% of the population uses clean energy sources such as electricity.

Among the variables, GDP per capita exhibits the highest standard deviation (192.22), while the dependency ratio shows the lowest (1.72), indicating significant variations across countries. With 414 observations per variable, these differences justify the use of the panel GMM estimation approach for robust analysis. To assess the strength of the relationship and prevent an excessively high correlation between the explanatory variables, a correlation matrix was performed and presented in Table 2.

Table 2
Correlation matrix on the impact of immunization on under five mortality in Saharan African countries

	$U5MR_{it}$	IMM_{it}	$SANT_{it}$	$GDPP_{it}$	FA_{it}	URB_{it}	DR_{it}	CFT_{it}
$U5MR_{it}$	1							
IMM_{it}	-0.6043	1						
$SANT_{it}$	-0.4077	0.0759	1					
$GDPP_{it}$	0.1394	0.1812	0.0974	1				
FA_{it}	-0.114	0.0814	-0.0711	0.0204	1			
URB_{it}	-0.3087	0.239	0.07	0.0486	-0.0021	1		
DR_{it}	-0.157	0.1471	0.1326	-0.0855	-0.0145	0.1086	1	
CFT_{it}	-0.6166	0.2488	0.702	0.0073	-0.0199	0.0355	0.2809	1

Statistics in Table 2 show that all of the variables used in analyzing the impact of immunization on under-five mortality were not highly correlated, as their degree of correlation was less than 0.80. The highest correlation coefficient is 0.702 for SANT and CFT, while the lowest is -0.0021 for FA and URB. It is generally recommended that the correlation coefficient must not exceed 0.80 (Sulaiman et al., 2017; Waziri et al., 2018). This shows that the estimates would be stable as the model is saved from multicollinearity.

Table 3 presents the System GMM estimates on the effect of immunization on under-five mortality in Sub-Saharan African countries. The positive and significant coefficient of the lagged-dependent variable at the 1% level indicates the dynamic nature of the panel model. The model successfully passed several diagnostic tests, including the Hansen J-test for over-identifying restrictions and the difference in Hansen test for additional instruments, both of which failed to reject the null hypothesis. Additionally, the serial correlation test confirmed the absence of second-order autocorrelation and the presence of first-order autocorrelation, indicating no autocorrelation issues in the residuals. Notably, the number of instruments is fewer than the number of groups, further affirming the reliability of the instruments.

Table 3: GMM estimation on the impact of immunization on under five mortality in Saharan African countries

Variables	**System GMM**
	Coefficient
$lnU5MR_{it}$	0.860 (0.032) ***
$lnIMM_{it}$	-0.152 (0.039) ***
$lnSANT_{it}$	-8.3 (4.71) *
$lnGDPP_{it}$	0.004 (0.001) **
$lnFA_{it}$	-0.064 (0.028) **
URB_{it}	-0.051 (0.030) *
$lnDR_{it}$	0.265 (0.011) ***
$lnCFT_{it}$	-0.052 (0.029) *
AR (2)	0.086
Hansen test of ORR	0.648
Difference-in-Hansen	0.292
Number of observations	368
Number of groups	44
Number of instruments	42

Note: Values in parenthesis represent the standard error, while *, ** and * represent significant level at 1%, 5% and 10% respectively.**

The estimated results presented in Table 3 corroborate our initial hypothesis that immunization significantly reduces under-five mortality in Sub-Saharan Africa. The elasticity of the primary variable, immunization, is -0.152, indicating that a 1% increase in the proportion of the population receiving immunization leads to a 0.15% reduction in the under-five mortality rate. This negative association underscores the critical role of immunization in improving child health outcomes in Sub-Saharan African countries. Immunization not only enhances overall health but also contributes to the future labor force and, consequently, the standard of living in these countries. Children who receive immunizations are less likely to succumb to vaccine-preventable diseases (VPDs) such as polio, whooping cough (pertussis), smallpox, rubella, coronavirus, diarrhea, cholera, mumps, hepatitis B, influenza, and other preventable illnesses. Consequently, the incidence of mortality among children under the age of five, particularly within the most vulnerable groups, is significantly reduced.

These findings align with the research conducted by McGovern and Canning (2015), which demonstrated a strong association between vaccination coverage and the reduction in the risk of mortality between birth and five years of age. The implications of this study are profound, as they highlight the importance of immunization programs in mitigating child mortality and improving public health in Sub-Saharan Africa. Furthermore, the results of the study emphasize the need for continued investment in immunization initiatives and public health infrastructure. Policymakers, non-governmental organizations, and international agencies must collaborate to enhance immunization coverage, address barriers to access, and educate communities about the benefits of vaccination. By doing so, they can ensure that more children receive life-saving immunizations, ultimately reducing under-five mortality and fostering healthier, more resilient populations.

Interestingly, all of the model's control variables (SANT, GDPP, FA, URB, DR, and CFT) produced statistically significant results, which corresponds to our earlier expectations. The elasticity of SANT (-8.3) indicates that a 10% increase in access to sanitation will reduce under-five mortality by 8.3%. This is consistent with the findings of Waziri et al. (2018). GDP per capita (GDPP) showed statistically significant negative coefficients at the 5% level, implying that a 5% increase in GDP per capita reduces under-five mortality by 0.004%. This finding aligns with Irfan (2018), who demonstrated that income per capita reduces under-five mortality. Similarly, the coefficient of food availability (FA) (-0.064) indicates that a 1% increase in food availability reduces under-five mortality by 0.064%. This agrees with the findings of Sulaiman et al. (2017) for Sub-Saharan African countries. The elasticity of urbanization (URB) (-0.051) indicates that a 10% increase in urbanization reduces under-five mortality by 0.051%, which is consistent with the theoretical expectations. The coefficient of the dependency ratio (DR) corresponds to our earlier prediction, with an elasticity of 0.265, indicating that a 1% increase in the dependency ratio increases under-five mortality by 0.265%. Lastly, the elasticity of access to clean fuel and technology (CFT) (-0.052) indicated that a 1% increase in access to clean fuel and technology reduces under-five mortality by 0.052%.

These findings further reveal the determinants of under-five mortality in Sub-Saharan Africa and highlight the importance of addressing various socio-economic and environmental factors to improve child health outcomes. The significant impact of sanitation, GDP per capita, food availability, urbanization, dependency ratio, and access to clean fuel and technology on under-five mortality

emphasizes the need for comprehensive and integrated policy interventions. By addressing these determinants, policymakers can create a more conducive environment for reducing under-five mortality and enhancing the overall well-being of children in Sub-Saharan Africa.

5. Conclusion and Policy Recommendations

This study provides an empirical assessment of the impact of immunization on under-five mortality in Sub-Saharan African (SSA) countries. The findings, based on estimations using the System Generalized Method of Moments (GMM), reveal a statistically significant negative association between immunization coverage and under-five mortality. Specifically, the results indicate that increased immunization coverage contributes to a reduction in under-five mortality rates, underscoring the pivotal role of immunization in improving child health outcomes within SSA countries.

The implications of these findings are substantial, particularly regarding the development of a healthier future labor force and the overall well-being of children under the age of five. By mitigating under-five mortality, immunization serves as a critical strategy in fostering the growth of a robust and capable workforce, thereby promoting the socio-economic advancement of SSA countries. Moreover, improved child health outcomes enhance the quality of life and elevate life expectancy, contributing to higher living standards in the region. To address challenges associated with immunization coverage, the study recommends a collaborative approach involving governments, non-governmental organizations (NGOs), and donor agencies. These stakeholders should jointly undertake efforts to raise public awareness about the benefits of immunization and to eliminate barriers to vaccine access. Public education campaigns, community engagement initiatives, and targeted interventions are vital strategies for expanding immunization coverage.

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