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Decomposing socioeconomic inequality in child vaccination in the Gambia, the Kyrgyz Republic and Namibia

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ABSTRACT

Extant work suggested pro-rich distribution of vaccination coverage in low- and middle-income countries (LMICs). However, the current literature also suggested pro-poor distribution of vaccination in some countries, including the Gambia, the Kyrgyz Republic and Namibia. This study aimed to explain socioeconomic inequalities in the completion rate of the four-core vaccines (i.e., Bacille Calmette-Guérin [BCG], diphtheria-tetanus-pertussis [DTP, 3 doses], Polio [3 doses] and Measles vaccines) in the three aforementioned countries. We used the most recent available Demographic Health Surveys (DHS) to measure vaccination completion rates among children (aged 0–59 months, n = 16,752) in the three countries. The normalized concentration index (C_n) was used to quantify and decompose socioeconomic inequalities in vaccination coverage in each country. The negative values of the C_n index suggested that children belong to lower socioeconomic status groups were more likely to be immunized than their higher socioeconomic status counterparts in the Gambia ($C_n = -0.101$, 95% confidence interval [CI]: −0.128 to −0.074), the Kyrgyz Republic ($C_n = -0.097$, 95% CI: −0.13 to −0.063) and Namibia ($C_n = -0.161$, 95% CI: −0.199 to −0.124). The decomposition analysis of the C_n suggested that the difference in child vaccination completion rates between rural and urban areas was the main factor contributing to the concentration of child vaccination among the poor in the Gambia and Namibia. The concentration of child vaccination among the poor in the Kyrgyz Republic was chiefly determined by household wealth. These results suggest that there should be strategies to improve child immunization uptake among urban children in the Gambia and Namibia. Since household wealth was the main factor contributing to the observed pro-poor distribution of child vaccination in the Kyrgyz Republic, further studies are required to understand the reasons for lower vaccination rate among the wealthy children in order to implement the most effective strategies to increase child vaccination uptake.

1. Introduction

There have been several international initiatives set out to improve childhood vaccination rates in developing countries over the last four decades. The World Health Organization (WHO) launched the Expanded Programme on Immunization (EPI) in 1974 to develop and expand immunization coverage worldwide. Subsequently, other international initiatives and institutions such as Universal Childhood Immunization (UCI), the Global Alliance for Vaccines and Immunization (GAVI), the United Nations Millennium Development Goal (MDG) 4, the Global Immunization Vision and Strategy (GIVS) and most recently, the Global Vaccine Action Plan (GVAP) 2011 – 2020 have combined with national and regional immunization supports to improve the EPI coverage [1]. These initiatives led to a significant increase in childhood vaccination coverage of more than 80% globally [2], which, in turn, reduced childhood mortality and morbidity due to infectious diseases in several countries [3–5].

Although there has been a significant increase in routine vaccination coverage globally, the per cent of children completing the recommended immunization schedule remains below the expected goal of reaching 90% national coverage with all vaccines in national programmes in many developing countries [6,7]. Extant work also suggested socioeconomic inequalities in child vaccination, favouring the higher socioeconomic children within low- and middle-income countries (LMICs). For example, studies in Asia [8–11], Africa [12–14] and South America [15] indicated that higher level of mother educational attainment and household wealth status (standard of living) are strongly associated with a higher likelihood of child vaccination uptake in developing countries.

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While the literature on the determinants of the child vaccination uptake suggests that lower socioeconomic status (SES) is still a significant barrier to child vaccination in most countries, a recent study by Hajizadeh [16] indicated lower vaccination rate among the wealthier children in the Gambia (a low-income country), the Kyrgyz Republic (a middle-income country) and Namibia (an upper middle-income country). The pro-poor distribution of child vaccination can potentially prevent lower SES children who are at higher risk of infectious diseases against vaccine-preventable diseases. The lower child vaccination rate among higher SES households can be due to refusal or lower acceptance of vaccines despite availability of free vaccination services (vaccine hesitancy) among wealthier parents, which ultimately can lead to an increased risk of vaccine-preventable diseases among all children.

Although the previous study [16] has shown the pro-poor distribution of child vaccination in the Gambia, the Kyrgyz Republic and Namibia, there is no study explaining the factors that contribute to the pro-poor distribution of child vaccination in these three countries. Thus, using the most recent nationally representative samples of children aged 0–59 months collected through the Demographic Health Surveys (DHS) this study aimed to identify factors explaining the higher coverage of the four-core vaccines (i.e., Bacille Calmette-Guérin [BCG], diphtheria-tetanus-pertussis [DTP, 3 doses], Polio [3 doses] and Measles vaccines, see Table A.1 in the supplementary materials) among the poor in these countries. The results can be used to develop strategies to improve vaccination coverage among children in the countries under study.

2. Health system and vaccination program in the Gambia, the Kyrgyz Republic and Namibia

The main priorities of healthcare in the Gambia are to reduce maternal and child mortality, decrease disease burden and enhance the quality of care. To achieve these priorities, the health system emphasizes capacity-building, equitable distribution of resources and staff retention [17]. Primary health care (PHC) in the Gambia is delivered through the PHC strategy, adopted in 1979 to improve accessibility and affordability of health care services to the majority of Gambians [18]. The village health workers and traditional birth attendants who work under the supervision of trained community nurse attendants are the key providers of PHC in the Gambia [17]. As part of the Gambia's PHC strategy, particular attention has been devoted to improving access to health care services in rural areas with a population of more than 400 people. Maternal and child health services are provided in static and mobile health clinics with the main objectives to improve high immunization coverage and child nutrition and reduce maternal mortality. Child immunization and other health care services are free for children under-five since 2009 [18].

The main priorities of healthcare in the Kyrgyz Republic are developing PHC, family medicine and guaranteeing access to healthcare services provided by the State Guarantees Programme [19]. The two major national healthcare reforms *Manas* (1996–2006) and *Manas Taalimi* (2006–2010) in the country resulted in significant changes to the healthcare system with the aim of strengthening PHC [20]. The PHC is the main component of the healthcare delivery in the Kyrgyz Republic, and the PHC services are provided by Family Medicine Centres [19]. The vaccination program in the Kyrgyz Republic is integrated into the public health component of the *Manas Taalimi*. Public health services in the country are delivered by Health Promotion Centers (HPCs) and Sanitation and Epidemiologic Surveillance Service (SES). Immunization programs are an important component of public health services and integrated into PHC activities. All citizens and many migrants have access to free primary care and vaccinations [21].

Healthcare services in Namibia are based on the principles of equity, accessibility availability and affordability of services as well as community participation. According to the Namibian Constitution and the National Health Policy of the Ministry of Health and Social Services (MoHSS), all Namibians should have equal access to public healthcare services without any financial barrier [22]. As part of its PHC strategy, the MoHSS considers equity as one of the key principles in resource allocation in the healthcare system. This is reflected in the desire to increase health outcomes among socioeconomically disadvantaged groups [23]. Immunization against the main vaccine-preventable infectious diseases is one of the major components of the PHC in Namibia. The EPI was formally established in 1990 within the MoHSS to strengthen routine immunization. The MoHSS has recently introduced the Reach Every District Approach (REDA) strategy to ensure all children in the country to have the opportunity to receive vaccines against preventable diseases [24].

3. Methods

3.1. Data

DHS surveys collected through the MEASURE DHS project in the three countries (the Gambia DHS 2013, the Kyrgyz Republic DHS 2012 and Namibia DHS 2013) used in this study. The DHS surveys are nationally representative and cross-sectional surveys [25] that use a multistage sampling procedure [26] to collects comparable and reliable data on a various maternal and child health and health services utilization in LMICs, including child vaccination uptake [27]. Further detail about the DHS surveys can be found elsewhere [27]. To have an adequately large sample of observations in each country we included all the children aged 0 to 59 months in the DHS in the analysis. Table 1 presents the sample size, infant mortality rate, life expectancy at birth, gross domestic products (GDP) per capital, per capita health care expenditure (extracted from the World Bank's World Development Indicators database [28]) for the three countries under investigation.

3.2. Variables

The outcome variable of interest in this study, child vaccination, is binary variable indicating whether or not the child completed the WHO recommended immunization schedules for four routine vaccines (see Table A.1 in the supplementary materials): BCG, Polio (3 doses), DTP (3 doses) and Measles vaccines. Vaccination status of children was obtained using vaccination record cards. In the absence of vaccination cards, the verbal reports of mothers/caregivers were used to assess children's vaccination coverage. Although mothers/caregivers reports may subject to recall bias, previous work [29] suggested that maternal recall reports are valid when we assess child vaccination status.

A wealth index (WI) constructed for each household in the DHS surveys was used as an indicator of childhood SES. The DHS uses a principal components analysis (PCA) method to construct the WI based on selected household's assets, water source, types of sanitation facilities and building materials [30]. The WI contains negative values; thus, similar to previous studies (e.g. [31–33]), we normalized the WI to a scale of 0 to 100 points to allow the decomposition of socioeconomic inequality in child vaccination.

Based on the current literature (e.g. [8,12]) and availability of information in the DHS surveys, several factors related to birth and household composition (e.g. sex, child age, birth order, mother's age at birth and household size), ethnicity, household SES (the WI and mother's education), residential area (rural vs urban) and skilled birth attendant were used as the determinants

Table 1
The sample size, infant mortality rate, life expectancy at birth, gross domestic products (GDP) per capital, and health expenditure per capita in the Gambia, the Kyrgyz Republic and Namibia.

Country	Survey year	Sample size		Infant mortality rate (per 1000 live births)[†]	Life expectancy at birth (years)[†]	GDP per capita (current US$)[†]	Health expenditure per capita (current US$)[†]
		Household	Children (0–59 months)				
The Gambia	2013	6217	7742	45.4	60.5	735	30
The Kyrgyz Republic	2012	8040	4241	23.2	70	1178	100
Namibia	2013	9849	4769	37	62	5490	474

[†] The reported values are for the corresponding survey year.

of child vaccination in the decomposition analysis of socioeconomic inequality in child vaccination. Table A.2 in the supplementary materials reports the definition of all the variables used in the study.

3.3. Statistical analysis

The concentration index (C) approach was used to measure and decompose socioeconomic inequality in vaccination coverage in each country. As a summary measure of inequality that accounts for inequality throughout the whole socioeconomic distribution, the C is a modification of the Gini coefficient and can be calculated in reference to the concentration curve. The concentration curve for child vaccination plots the cumulative proportion of children ranked by ascending order of SES variable, such as the WI, on the x-axis versus the cumulative proportion of child vaccination rate on the y-axis [34,35]. The concentration curve, for example, can suggest that the least socioeconomically disadvantaged 20% of children have 25% of the cases of children who are in completion with the full child immunization schedule. If the concentration curve lies above (below) the line of perfect equality (i.e., the 45-degree diagonal), it indicates inequality favoring children of a lower (higher) SES [34,35].

The C is calculated as twice the area between the concentration curve and the line of perfect equality. It ranges from −1 to +1, with the values less (higher) than zero suggesting that childhood vaccination concentrated among lower (higher) SES children. The value of zero suggests perfect socioeconomic equality in child vaccination. The C was computed using the "convenient regression" method [34].

$$2\sigma_r^2\left(\frac{y_i}{\mu}\right) = \alpha + \delta r_i + \varepsilon_i, \quad (1)$$

where y_i is child i's vaccination status, μ is the rate of child vaccination for the total sample, r_i is the child i's fractional rank in the distribution ($i = 1$ and n for the poorest and wealthiest individuals, respectively). The r_i is calculated as $r_i = i/n$. The σ_r^2 indicates the variance of fractional rank. The ordinary least squares (OLS) estimate of δ is the value of the C [36].

The C was decomposed to find the contribution of each determinant to the observed socioeconomic inequality in child vaccination. If we have a linear regression model that relates child vaccination status, y, to $k$explanatory factors,x_k as:

$$y = \alpha + \sum_k \beta_k x_k + \varepsilon, \quad (2)$$

the C for child vaccination can be decomposed as [37]:

$$C = \sum_k \left(\frac{\beta_k \bar{x}_k}{\mu}\right) C_k + \frac{GC_\varepsilon}{\mu} \quad (3)$$

where $\bar{x}_k$ is the mean for x_k, C_k is the concentration index for x_k, defined similarly to the C. The $\frac{\beta_k \bar{x}_k}{\mu}$ is the elasticity of child vaccination status to the x_k. The $\sum_k \left(\frac{\beta_k \bar{x}_k}{\mu}\right) C_k$ shows the contribution of explanatory factor k to the C for child vaccination. Based on Eq. (3), the C for child vaccination equals to a weighted sum of the concentration indexes of all the explanatory variables (C_k). The weight for each C_k is the elasticity of child vaccination status with respect to the x_k. An explanatory factor that has a significant elasticity and distributed unequally by SES will contribute to the overall socioeconomic inequality in child vaccination. A negative (positive) contribution of an explanatory factor to the C for child vaccination suggests that socioeconomic distribution of the explanatory factor (the C_k) and the relationship between the relevant explanatory factor and child vaccination status contributes to a higher probability of child vaccination uptake among the poor (rich). The $\frac{GC_\varepsilon}{\mu}$ in Eq. (3) shows the part of the C that cannot be explained by the explanatory variables included in the decomposition analysis [36].

As the health outcome variable in this analysis is binary, the C normalized, as per Wagstaff's suggestion [38], by multiplying by $1/1 - \mu$ (i.e., $C_n = \frac{C}{1-\mu}$), where μ represents the proportion of children who completed the child immunization schedule. The decomposition of the C_n can be written as:

$$C_n = \frac{C}{1-\mu} = \frac{\sum_k \left(\frac{\beta_k \bar{x}_k}{\mu}\right) C_k}{1-\mu} + \frac{\frac{GC_\varepsilon}{\mu}}{1-\mu} \quad (4)$$

As child vaccination status is a binary variable, marginal effects calculated from a logit model used as β_k in the decomposition analysis. To obtain estimates that are representative of children aged 0–59 months in each country, sampling weights were applied in the calculation and decomposition of socioeconomic inequalities in child vaccination. All analyses performed with STATA software package (version 15, StataCorp, College Station, Tex).

4. Results

4.1. Child vaccination coverage

The descriptive statistics results suggested that 67.1%, 68.6%, and 58.6% of children in the Gambia, the Kyrgyz Republic, Namibia, respectively, completed the child immunization schedule (see Table 2). Higher completion with child vaccination observed in

Table 2
The percentage (%) of children who received all four core vaccines by region in the Gambia, the Kyrgyz Republic and Namibia.

Country	Total	Region		
		Urban	Rural	Urban-Rural[†]
The Gambia	67.1	60.6	73.1	−12.5
The Kyrgyz Republic	68.6	61.7	71.5	−9.8
Namibia	58.6	53.5	63.6	−10.1

[†] All differences are statistically significant at p-value = 5% based on the Chi-squared test.

Table 3
Socioeconomic inequalities in child vaccination coverage in the Gambia, the Kyrgyz Republic and Namibia.

Country	The C_n index			
	Total	Urban	Rural	Urban-Rural[†]
The Gambia	−0.101 (−0.128 to −0.074)	−0.025 (−0.07 to 0.02)	0.06 (0.024 to 0.096)	−0.085 (−0.143 to −0.028)
The Kyrgyz Republic	−0.097 (−0.13 to −0.063)	−0.018 (−0.072 to 0.036)	0.053 (0.009 to 0.098)	−0.071 (−0.141 to −0.001)
Namibia	−0.161 (−0.199 to −0.124)	−0.163 (−0.233 to −0.093)	−0.109 (−0.154 to −0.065)	−0.054 (−0.136 to 0.029)

Note: 95% confidence intervals in parentheses.
[†] A method suggested by Altman and Bland [51] was used to examine the significance of differences in the C_n between urban and rural areas at 95% confidence intervals.

rural areas as compared to their urban areas in the three countries (the Gambia: 73.1% vs 60.6%; the Kyrgyz Republic: 71.5%, vs 61.7%; Namibia: 63.6% vs 53.5%).

4.2. Socioeconomic inequalities in child vaccination coverage

Table 3 reports the magnitude of socioeconomic inequalities in vaccination coverage in the three countries. The negative value of the C_n indicated the pro-poor concentration of child vaccination in the three countries. The concentration of child vaccination among the poor was greater in Namibia (C_n = −0.161; 95% confidence interval [CI] = −0.199 to −0.124) as compared to the Gambia (C_n = −0.101; 95% CI = −0.128 to −0.074) and the Kyrgyz Republic (C_n = −0.097; 95% CI = −0.13 to −0.063). While child vaccination was concentrated among children with higher SES in rural areas in the Gambia and the Kyrgyz Republic, the vaccination rate was greater among the poor children in both rural and urban regions in Namibia.

4.3. Decomposition of socioeconomic inequalities in child vaccination

The estimated negative values of C_n for child vaccination was statistically significantly different from zero in all countries; thus, the C_n was decomposed to identify factors explaining the concentration of child vaccination among the poor. Table 4 contains the decomposition results of the C_n for child vaccination. The table reports the estimated marginal effects and mean values of explanatory variables obtained from logit model, mean values, elasticities, the C of the explanatory variables, and the contribution of independent variables to the overall C_n for child vaccination for each country.

Based on the marginal effects of the explanatory variables, while older children had a higher probability of being vaccinated

Table 4
Decomposition of socioeconomic inequalities in child vaccination coverage in the Gambia, the Kyrgyz Republic and Namibia.

	Marginal effects	Mean ($\bar{x}$)	Elasticities	C_k	Contribution to the C_n		
					Absolute	Sum	Sum (%)[†]
The Gambia							
Birth and household composition							
Sex							
Male	0.0160	0.5080	0.0121	0.0036	0.0001		
Female (Ref.)							
Child age (years)	0.0381***	2.3725	0.1349	0.0052	0.0021		
Birth order							
Birth order# 1 (Ref.)							
Birth order# 2	0.0424*	0.1858	0.0117	0.0964	0.0034		
Birth order# 3 and above	0.0550**	0.5983	0.0491	−0.0609	−0.0091		
Mother's age at birth (years)							
19 and below	0.0110	0.0929	0.0015	−0.0973	−0.0005		
20 to 39 (Ref.)							
40 and above	0.0490	0.0530	0.0039	−0.1144	−0.0013		
Household size	0.0009	14.436	0.0200	0.0352	0.0021	−0.0030	3
Ethnicity							
Mandinka/Jahanka (Ref.)							
Wollof	−0.0198	0.1273	−0.0037	0.0024	0.0000		
Jola/Karoninka	−0.0742***	0.0971	−0.0107	0.0219	−0.0007		
Fula/Tukulur/Lorobo	−0.0437**	0.2341	−0.0152	−0.1970	0.0091		
Non-Gambian	−0.1229***	0.0650	−0.0119	0.1407	−0.0051		
Others	0.0062	0.1411	0.0013	0.1753	0.0007	0.0040	−3.94
Socioeconomic status							
Wealth index	−0.0011	42.4716	−0.0670	0.2112	−0.0430	−0.0430	42.46
Mother's education (year)	0.0049**	3.3379	0.0242	0.2806	0.0206	0.0206	−20.37
Region							
Rural (Ref.)							
Urban	−0.1125***	0.4806	−0.0806	0.4263	−0.1043	−0.1043	103.13
Health care use							
Skilled birth attendance	0.0248	0.5735	0.0212	0.1336	0.0086	0.0086	−8.51
Sum						−0.1171	115.76
Residual						0.0159	−15.76
The C_n						−0.1012	100

Table 4 (*continued*)

	Marginal effects	Mean ($\bar{x}$)	Elasticities	C_k	Contribution to the C_n		
					Absolute	Sum	Sum (%)†
The Kyrgyz Republic							
Birth and household composition							
Sex							
Male	−0.0016	0.5110	−0.0012	0.0066	0.0000		
Female (Ref.)							
Child age (years)	0.0986***	2.3757	0.3418	−0.0033	−0.0036		
Birth order							
Birth order# 1 (Ref.)							
Birth order# 2	−0.0287	0.2625	−0.0110	0.0665	−0.0023		
Birth order# 3 and above	0.0219	0.3983	0.0127	−0.0679	−0.0027		
Mother's age at birth (years)							
19 and below	−0.0003	0.0313	0.0000	−0.0638	0.0000		
20 to 39 (Ref.)							
40 and above	0.0366	0.0383	0.0020	0.0156	0.0001		
Household size	0.0005	6.0624	0.0045	−0.0700	−0.0010	−0.0096	5.94
Ethnicity							
Kyrgyz (Ref.)							
Others	0.0314	0.2317	0.0106	0.1004	0.0034	0.0034	−2.10
Socioeconomic status							
Wealth index	−0.0049***	67.85	−0.4830	0.0859	−0.1320	−0.1320	81.80
Mother's education (year)	0.0017	12.1674	0.0301	0.0181	0.0017	0.0017	−1.07
Region							
Rural (Ref.)							
Urban	0.0046	0.2956	0.0020	0.5695	0.0036	0.0036	−2.21
Health care use							
Skilled birth attendance	0.2033***	0.9882	0.2930	0.0011	0.0010	0.0010	−0.61
Sum						−0.1319	81.74
Residual						−0.0295	18.26
The C_n						−0.1614	100
Namibia							
Birth and household composition							
Sex							
Male	−0.0048	0.4897	−0.0040	0.0030	0.0000		
Female (Ref.)							
Child age (years)	−0.0636***	2.4887	−0.2703	0.0090	−0.0059		
Birth order							
Birth order# 1 (Ref.)							
Birth order# 2	0.0444*	0.2510	0.0190	0.0729	0.0033		
Birth order# 3 and above	0.0858***	0.4112	0.0602	−0.1425	−0.0207		
Mother's age at birth (years)							
19 and below	−0.0541*	0.1103	−0.0102	−0.0966	0.0024		
20 to 39 (Ref.)							
40 and above	0.0284	0.0546	0.0026	−0.0865	−0.0006		
Household size	0.0079***	6.4121	0.0866	−0.0430	−0.0090	−0.0305	46.07
Ethnicity							
Ovambo (Ref.)							
White Namibians	0.0846*	0.0796	0.0115	0.6832	0.0190		
Kavango	0.0542	0.1185	0.0110	−0.3272	−0.0087		
Herero	−0.1917***	0.0790	−0.0259	0.2391	−0.0149		
Damara/Nama	0.1190***	0.1120	0.0227	0.2353	0.0129		
Others	0.0356***	0.1122	0.0068	−0.2297	−0.0038	0.0045	−6.82
Socioeconomic status							
Wealth index	−0.0008	32.587	−0.0437	0.4019	−0.0424	−0.0424	64.12
Mother's education (year)	0.0116***	8.5170	0.1681	0.1300	0.0528	0.0528	−79.85
Region							
Rural (Ref.)							
Urban	−0.0998***	0.4919	−0.0838	0.3570	−0.0722	−0.0722	109.26
Health care use							
Skilled birth attendance	0.0355	0.8818	0.0534	0.0573	0.0074	0.0074	−11.18
Sum						−0.0804	121.60
Residual						0.0143	−21.60
The C_n						−0.0661	100

*** P-value < 0.01.
** P-value < 0.05.
* P-value < 0.1.
† The percentage contributions were calculated by dividing the corresponding "summed" contribution by the absolute values of C_n and multiplying by 100. The sum of all the percentage contributions (both positive and negative) should add up to 100 per cent. Percentage contribution for region in the Gambia, for example, indicates that if we were to increase child vaccination uptake in urban areas to the level of rural areas, pro-poor inequalities in child vaccination in this country could potentially be eliminated, *ceteris paribus*; the value of the C_n would have changed from −0.1012 to 0.0031 (=−0.1012 + 0.1043).

in the Gambia and the Kyrgyz Republic, younger children in Namibia had a higher probability to be vaccinated. Compared to children with birth order one, children with a higher birth order had higher probabilities to follow the recommended child vaccination in the Gambia and Namibia. The probabilities of child vaccination varied by different ethnic groups in the Gambia and Namibia. While household wealth negatively associated with child vaccination completion in the Kyrgyz Republic, maternal education positively associated with child vaccination in the Gambia and Namibia. The probability of vaccination was found to be lower in children living in urban areas than children living in rural areas in the Gambia and Namibia. Skilled birth attendance was found to be positively associated with higher child vaccination uptake in the Kyrgyz Republic. Turning to the results of the C for explanatory variables, it is evident that variables such as birth order three and above and mother's age at birth 19 and below were more prevalent among lower SES children, whereas variables such as birth order two, wealth, mother's urban and skilled birth attendance were concentrated among the higher SES children.

As reported in Table 4 and illustrated in Fig. 1, the regional difference in child vaccination (i.e. rural vs. urban areas) was the main factor contributing to the concentration of child vaccination among the poor in the Gambia as well as Namibia. The negative contribution of the urban variable is due to the fact, the probability of child vaccination was lower in urban areas as compared to rural areas in these two countries and children living in urban areas are relatively wealthier than children living in rural areas. The percentage contributions of regional difference to the observed socioeconomic inequalities in child vaccination were 103% and 109% in the Gambia and Namibia, receptively. This indicates that if both rural and urban children in these countries had similar probabilities of receiving the vaccination, we would not find pro-poor inequalities in child vaccination in these countries. After adjusting for other factors, household wealth itself is another factor that contributed to the pro-poor distribution of child vaccination, especially in the Kyrgyz Republic. In contrast to the region and household wealth, mother's education contributed positively to the C_n in the Gambia and Namibia. The positive contribution of mother's education to socioeconomic inequalities is because the higher level of mother's education increased the probability of child vaccination and mother's higher education attainment concentrated among the wealthy children. The outcome of these two effects resulted in the positive contribution of the maternal education variable to the C_n in these two countries.

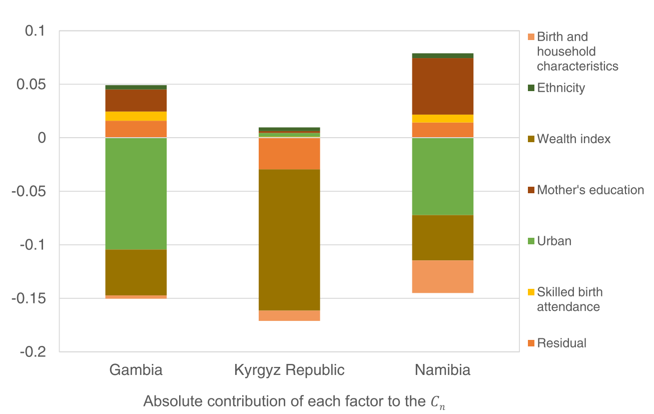

Fig. 1. Contribution of each factor to socioeconomic inequalities in child vaccination coverage in the Gambia, the Kyrgyz Republic and Namibia. **Note:** The y-axis of the chart shows the absolute negative/positive contribution of each determinant to the C_n.

5. Discussion and conclusion

The past four decades have witnessed a great deal of effort in improving child vaccination coverage worldwide. Notwithstanding this, vaccination uptake is not universal even in countries where routine immunization schedule is provided free of charge [39,40]. Our descriptive results showed that vaccination coverage rates in the Gambia, Namibia and the Kyrgyz Republic are much lower than global targets and lower than levels required to achieve herd immunity. The vaccination coverage rates were found to be higher in rural than urban areas in the three countries. The observed rural-urban variation in child vaccination rates may be due to difficulties in effectively ensuring vaccination coverage in urban areas. An extensive focus of vaccination program in rural areas in these countries may have also contributed to the regional gap in child vaccination. For example, the Gambia's PHC strategy, which aims to improve access to health services in rural areas [18] may have contributed to higher vaccination uptake in rural compared to urban areas. The observed lower vaccination rate in densely populated urban settings with pack individuals, many of whom appear unvaccinated, allow infectious diseases to spread rapidly. The results also indicated differences in child vaccination coverage across different ethnic groups persists in the Gambia and Namibia. Previous work has highlighted a variety of factors for ethnic inequalities in vaccination rates, including individual, provider, and system factors [41–44]. The lower vaccination rates, especially among children living in urban areas and some ethnic groups, calls for concerted efforts to improve vaccination coverage in the three countries.

Similar to some studies in other countries (e.g. [45]), the results of this study suggested higher vaccination rate among children from lower SES households than from higher SES households in the Gambia, Namibia and the Kyrgyz Republic. The child vaccination rate was found to be lower among relatively wealthier urban (rural) children than poorer urban (rural) children in the Kyrgyz Republic. Although child vaccination rate was found to be pro-poor at the national level in the three countries, we found relatively wealthier rural children have higher coverage than relatively poorer rural children in the Gambia and Namibia. These regional variations in socioeconomic inequalities in child vaccination rate are important in the design of strategies to improve child vaccination in these countries.

The decomposition of socioeconomic inequalities in child vaccination suggested that the regional difference in vaccination uptake in favor of children living in rural areas was the main factor contributing to the observed pro-poor inequalities in child vaccination in the Gambia and Namibia. Pro-poor distribution of child vaccination in the Kyrgyz Republic mainly determined by household wealth. Household wealth also contributes significantly to the concentration of child vaccination among the poor in the Gambia, Namibia. Recent studies [45–47] have pointed out factors such as the reduction in the incidences of vaccine-preventable diseases and scientifically unfounded doubts about vaccine safety that have led to a decline in child vaccination uptake among wealthier children. The substantial reduction in the incidences of vaccine-preventable illnesses in recent years may have altered wealthier parents' perception about the effectiveness of childhood immunization; they may not perceive the benefits of childhood immunization outweigh the risks of rare adverse events. Also, some scientifically unfounded doubts about vaccine safety (e.g. linking some vaccines to autism, sudden infant death syndrome and multiple sclerosis) may have also changed the perception of wealthier parents about the importance of childhood immunization and the seriousness of the illnesses prevented by the vaccines. The higher child vaccination coverage among the poor can be attributed to more trust in vaccines as well as governmental services among poorer households. It can also be the case that because poorer (or rural dwelling) children face a higher burden of vaccine-preventable diseases, parents are therefore more aware of the importance of childhood immunization. Although theses factor may have contributed to the pro-poor inequalities in the Gambia, Namibia and the Kyrgyz Republic, further studies are needed to clarify the impact of these factors on the observed inequality in child vaccination in each of these countries.

The current literature on the measurement and analysis of inequalities in health suggested reporting both relative and absolute measures of inequality to ensure appropriate monitoring of inequalities in health [48]. Accordingly, socioeconomic inequalities in vaccination coverage were also measured and decomposed using a modified generalized (absolute) concentration (AC) index (see [49,50] for further information about the AC) in the three countries. The results were similar to those obtained using the C_n index when we used the AC to measure and decompose socioeconomic inequalities in child vaccination in three countries (see Table A.3 and Figure A.1 in the supplementary materials).

There are some limitations to this study. First, due to the unavailability of some data in the DHS, we could not include some of the main determinants related to regional access to resources (e.g. distance to a health center or access to prenatal care) in the decomposition analysis. Second, although the validity of maternal report to determine child vaccination status was confirmed in previous studies (e.g. [29]), it would be ideal to obtain vaccination status of children using a written record to avoid the potential for recall bias. Third, the DHS collects vaccination status of still living children; thus, the results are generalizable for those who were alive during the survey period. Fourth, as the DHS is a cross-sectional survey, it was not possible to establish temporality between explanatory factors and child vaccination, precluding causal inference.

Caveat considered, this study indicated that higher child vaccination rate in rural compared to urban areas was the main factors explaining the pro-poor distributions of child vaccination in the Gambia and Namibia. The higher rate of child vaccination coverage in rural areas can be due to more trust in vaccines programs and/or better vaccination program among rural dwelling children. The lower rates of vaccination coverage, particularly among children living in urban areas in the Gambia and Namibia emphasize the need to improve and strengthen the childhood immunization program these countries. Household wealth was the main factor contributing to the observed inequality in child vaccination in the Kyrgyz Republic. The contribution of wealth index can be due to the fact that wealthier children face a lower burden of vaccine-preventable diseases; thus, parents are less aware of the importance of vaccination. Nevertheless, further studies are required to understand the reasons for the lower vaccination rate among the wealthy children in the Kyrgyz Republic in order to implement the most effective strategies to increase child vaccination uptake.

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Author's contribution

MH is the single author of the paper.

Ethics statement

Ethical approval was not required for this study, because it did not involve data concerned with human participants. The study used secondary data from Demographic Health Surveys (DHSs, http://www.dhsprogram.com/). The DHS are fully available upon request from the MEASURE DHS without restriction.

Declaration of Competing Interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.vaccine.2019.09.054.

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