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Disparities in First-to-Second Dose Measles-containing Vaccination Coverage: A Comparative Analysis of the Predictive Power of Three Economic Indices

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Disparities in first-to-second dose measles-containing vaccination coverage: A comparative analysis of the predictive power of three economic indices

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Abstract: While overall mortality from measles has decreased, it is still associated with significant global infant deaths. Studies indicate that a second dose of measles-containing vaccine (MCV) is necessary to produce sufficient immunity to measles, yet several developing countries are deficient of a two-dose schedule. This study examined the efficacy of three economic indices—the Human Development Index (HDI), the Inequality-adjusted Human Development Index (IHDI), and the Multidimensional Poverty Index (MPI)—in predicting first-to-second MCV dosage disparities. Country-level data for MCV coverage were downloaded from the World Health Organization (WHO). Briggsian logarithmic regression models of MCV dosage disparities were calculated to compare the predictive power of the HDI, IHDI, and MPI. The MPI explained the most variance in dosage disparities, $F(1, 54) = 41.835$, $p < 0.001$, $R^2 = 0.437$, $b = 0.938$, followed by the IDHI ($R^2 = 0.361$, $b = -0.935$) and HDI ($R^2 = 0.354$, $b = -1.023$). We suggest the MPI explained the greatest variance because it uses multiple indicators to determine poverty across three dimensions of human development. The MPI predicted larger disparities in more developing countries. Future efforts should be directed toward discovering and reducing barriers to second dose MCV administration in these countries.

Justin McDaniel

ABOUT THE AUTHOR

Justin McDaniel, PhD, a spatial epidemiologist, earned his doctorate from Southern Illinois University and joined the faculty at Charleston Southern University in the fall of 2016. His research highlights disparities in morbidity/mortality and access to healthcare. By using socioeconomic predictors in predictive models and cartographic methods, Justin hopes to solve challenging public health issues. Justin is also the co-founder of a non-profit organization, the International Center for Community Health Promotion and Education (ICCHPE), which seeks to improve the health of people living in underserved countries around the world. He sees ICCHPE as a vehicle for acting practically upon the results of his research.

PUBLIC INTEREST STATEMENT

While the number of deaths per year from Measles has decreased globally, likely as a result of the introduction of the measles-containing vaccination (MCV), said disease still accounts for a significant amount of infant deaths. Immunity from measles is dependent upon the uptake of the first and second dose of the MCV; however, many countries do not have access to the second dose of the MCV—leading to incomplete immunity. We showed, via predictive modeling, that impoverished countries around the world have greater disparities in first-to-second dose MCV coverage. That is, underserved countries experience barriers in access to the second dose of the MCV. Future public health efforts should be directed toward eliminating the barriers that prohibit impoverished countries from gaining access to the second dose of the MCV. Greater second dose MCV coverage may minimize the burden of the measles disease, especially among children.

Subjects: Epidemiology; Public Health - Medical Sociology; Public Health Policy and Practice

Keywords: measles; inequality; access to healthcare; vaccinations; poverty

1. Introduction

Before extensive vaccination measures were introduced, measles occurred in 95–98% of children by the age of 18, was considered an inevitable part of childhood (Perry & Halsey, 2004), and resulted in approximately 2.6 million deaths per year (World Health Organization [WHO], 2015a). However, measles can affect people of all ages and the complications associated with the infection present a rationale for its eradication (WHO, 2009).

Measles, also known as Rubeola, is an acute infection caused by a morbillivirus from the paramyxovirus group (DiPaola, Michael, & Mandel, 2012). Measles is one of the most highly communicable infectious diseases, which can be transmitted through airborne contact by coughing or sneezing. Because the virus can live on a surface or in airspace for up to two hours, transmission requires no direct contact with an infected person (Centers for Disease Control, 2014).

Vaccinations have been effective in reducing the incidence of measles, and measles is no longer endemic in the United States or in many other developed country throughout the world (Perry et al., 2015; Salsibury & Ramsay, 2013). One dose of the combined measles, mumps, and rubella (MMR) vaccine is estimated to be 95% effective in protecting against measles, and infections are extremely unlikely in individuals who have received two doses of the vaccine (Demicheli, Rivetti, Debalini, & Di Pietrantonj, 2012).

1.1. Vaccination disparities in developing countries

The WHO recommends children receive their first dose of measles-containing vaccine (MCV-1) at the age of nine months or one year and the second dose (MCV-2) between 15 and 18 months. For countries where measles mortality is high, a two-dose schedule is particularly important, as MCV-2 has been shown to reduce the rate of accretion and the possibility of an occurrence (WHO, 2015c). In impoverished countries, infectious diseases—such as measles—still account for a significant proportion of deaths. Accordingly, developing countries continue to hold lower levels of immunization, especially as regards the second dose of MCV. Meheus and Van Doorslaer (2008) examined the distribution of measles immunization and the socioeconomic trends for 21 countries and found that, among impoverished countries, socioeconomic inequalities in measles immunization rates are higher for the underprivileged and individuals living in impoverished areas (Meheus & Van Doorslaer, 2008).

Various hypotheses have been suggested to explain immunization inequalities among populations. Research has highlighted socioeconomic status, education (Desai & Alva, 1998), and indirect costs, such as transportation (Jordan et al., 2006), as predictors of vaccination inequality. Lower vaccination coverage in children has also been linked with parental unemployment, less parental education, (Vandermeulen et al., 2008), single parent households, mothers under the age of 20, (Pearce et al., 2008), lack of health insurance coverage, lower overall household income (Bates, Fitzgerald, Dittus & Wolinsky, 1994), and greater levels of residential mobility (Nagaoka, Fujiwara, & Ito, 2012). Overall, a confluence of factors likely influence vaccination uptake, many of which undoubtedly are linked with poverty. Research has continually reminded us that individuals negatively affected by poverty are generally the most deprived in society, and this lack of resources can—and often does—have an adverse affect on an individual's health (Murtaza, Mustafa, & Awan, 2015).

1.2. Poverty indices

Health can be influenced by many factors, such as education, income, access to healthcare services, and employment. The level of development—or conversely, the amount of poverty—in a population should hence predict vaccination coverage in a population. The Human Development Index (HDI) is a composite statistic of income per capita, education, and life expectancy indicators, which are used to rank countries (United Nations Development Programme [UNDP], 2015). The HDI specifically focuses on three dimensions of human development: the ability to acquire knowledge (measured by average years and expected years of schooling), an individuals' capability to lead a long and healthy life (measured by life expectancy at birth), and an individual's ability to achieve a decent standard of living (measured by the gross national income per capita) (UNDP, 2015). The Inequality Adjusted Human Development Index (IHDI) adapts the HDI to the magnitude of inequality. According to Ruiz et al. (2015), "The IHDI takes into account how education, health, and income achievements are distributed among the population of each country and the difference between the IHDI and HDI informs the loss of human development due to inequality" (p. 2). Lastly, the Multidimensional Poverty Index (MPI) measures non-income dimensions of poverty (UNDP, 2015). The MPI evaluates poverty at the individual level. The MPI can be used to construct a comprehensive picture of individuals living in poverty, allowing for comparisons across regions, countries, and the world. It can also display comparisons within countries by urban/rural location, as well as significant household and community characteristics.

The three economic indicators previously described (i.e. the HDI, IHDI, and the MPI) are all used to determine the level of poverty in a country. The objective of the present study, then, was to examine which of these three economic indicators could explain the most variance in first to second dose measles vaccination coverage disparities among the most impoverished countries. Like many other composite measures and indices, the HDI, IHDI, and MPI have limitations. So as to keep these indices interpretable to the public, the factors and dimensions used to calculate the indices have been kept to a minimum; therefore, these indices provide only a snapshot of human development and poverty in a country, not a comprehensive picture (UNDP, 2015).

2. Methods

2.1. Data collection

Country-level data was downloaded for the present post-positivist (Phillips & Burbules, 2000), ecological (Jacobson, 2012) study from two sources. First, data on measles-containing vaccination (MCV) coverage in 2014—both first dose and second dose—were retrieved from the *WHO vaccine preventable diseases monitoring system 2015 global summary* (WHO, 2015b). Second, economic indicators—specifically the HDI, IHDI, and MPI—were downloaded from the UNDP's, 2015 *Human Development Report* (UNDP, 2015).

The following sample sizes were available for each of the aforementioned variables: first dose MCV coverage (MCV-1; $n = 181$), second dose MCV coverage (MCV-2; $n = 134$), HDI ($n = 188$), IHDI ($n = 188$), and MPI ($n = 101$). Because many countries in the data-set did not have data available across all variable categories, the data-set was reduced so as to permit commonality—similar to the methods used in Nuhu, McDaniel, and Ruiz's (2015) paper. After the elimination of countries deficient of data in one or more of the variable categories, the final sample size for the present study was 56. In other words, secondary data were available for all variables in the study among 56 underserved countries. The study population, then, was confined to those countries studied for the creation of the MPI.

2.2. Data analysis

The dependent variable in the present study was thus: first to second dose disparities in MCV (calculated by subtracting the percentage of the population with the second dose of the MCV from the percentage of the population with the first dose of the MCV). ESRI ArcGIS was utilized to represent disparities in MCV coverage (Figures 1 and 2). Regarding the maps, graduated symbols were used to represent MCV coverage - where countries with darker colors exhibited lower MCV coverage. As such, larger numbers indicated greater disparity between first and second dose MCV coverage. The HDI, IHDI, and the MPI were used as independent variables in the present study.

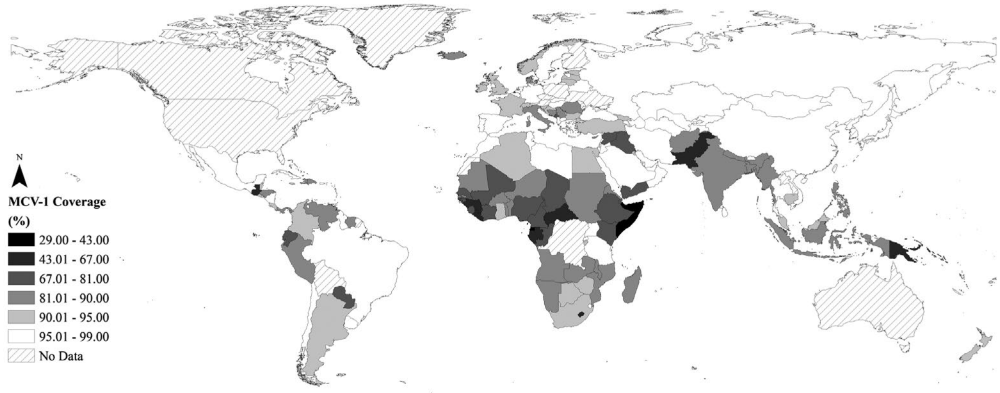

Figure 1. Percentage of the country population with MCV-1 coverage.

Figure 2. Percentage of the country population with MCV-2 coverage.

Means and standard deviations were calculated for each variable in the study. In order to determine which of the three independent variables had the greatest predictive power for first to second dose disparities in MCV coverage among underserved countries, Ordinary Least Squares (OLS) regression was used (Hoy, Livernois, McKenna, Rees, & Stengos, 2001). Because the residuals for each regression model did not conform to the Gaussian distribution, a Briggsian logarithmic transformation, with a constant of 30, was applied to the dependent variable (Gonzalez-Velasco, 2010). Slight departures from normality were present after the data transformation. Therefore, each regression model was bootstrapped with 1,000 resamples and bias-corrected (BCa) 95% confidence intervals (CI) were developed around each beta value (Mooney & Duval, 1993). The equation used to model the data in the present study is shown below:

$$\log_{10}\left(Y_i + 30\right) = \alpha + \beta X_i + \varepsilon_i$$

3. Results

3.1. Descriptive results

Descriptive results (Figures 1 and 2) revealed significant range, even among primarily poverty stricken countries, in 2014 MCV coverage. Regarding the maps, graduated symbols were used to represent MCV coverage, where countries with darker colors exhibited lower MCV coverage. The Kingdom of Lesotho, which is characterized by high rates of HIV (a virus known to advance the course of measles), exhibited the lowest vaccination rate, with 58% of the population having received the first dose and 54% of the population having received the second dose. MCV-1 coverage was highest in Belarus, Guyana, Kazakhstan, Maldives, Morocco, Saint Lucia, the United Republic of Tanzania, Thailand, and Uzbekistan. While each of these countries exhibited at least 99% MCV-1 coverage, many demonstrated significant declines in the percentage of the population with MCV-2. For

Table 1. Descriptive statistics for MCV coverage and economic indicators

Variable	*N*	*M*	BCa 95% CI (*M*)		*SD*	BCa 95% CI (*SD*)	
			Lower	Upper		Lower	Upper
MCV-1 (%)	56	90.553	[88.211	92.756]	9.494	[7.179	11.370]
MCV-2 (%)	56	75.518	[68.500	81.446]	25.716	[20.785	29.622]
Coverage disparity[a]	56	15.036	[9.369	21.488]	23.363	[18.151	27.271]
MPI	56	0.105	[0.072	0.142]	0.142	[0.110	0.168]
HDI	56	0.651	[0.001	0.015]	0.117	[0.097	0.132]
IHDI	56	0.508	[0.473	0.540]	0.129	[0.114	0.141]

[a]Coverage disparity was calculated by subtracting the percentage of the population in each country that received the MCV-2 from the percentage of the population in each country that received the MCV-1.

example, only 29% of the population in the United Republic of Tanzania received MCV-2. Overall, consistent declines in MCV coverage between first and second dose were observed across many countries in the study (Table 1).

Like the disparities in MCV coverage among the countries selected for study, significant variation was also observed across economic indicators. Poverty, as measured by the MPI, was highest in Niger (MPI = 0.584) and lowest in Belarus (MPI = 0.001). Niger also exhibited the lowest human development, as measured by the HDI and the IHDI; however, correspondence between the MPI and the HDI was not present for the underserved countries with the least amount of poverty, as relative to this study's population. Specifically, the HDI was highest in Jordan, not Belarus. IHDI was highest in Belarus, a result was comparable to the MPI. Means and standard deviations, with BCa 95% CI, for the aforementioned variables are shown in Table 1.

3.2. Inferential results

Table 2 displays the results of the inferential analysis. Significant relationships were found between MCV-1 and MCV-2 disparities (dependent variable) and the three economic indices selected for comparison in the present study. The first regression model, using MPI as the regressor, explained 43.7% of the variance in the dependent variable, F (1, 54) = 41.835, p < 0.001. The MPI—which provided the most robust explanation of MCV coverage disparities when compared to the other two economic indices—exhibited a positive regression weight, indicating that countries with greater multidimensional poverty experienced greater disparities in first to second dose MCV coverage.

Table 2. OLS regression models for the prediction of first to second dose disparities in MCV coverage

Model	B[a]	Bias	SE (B)	BCa 95% CI (B)		*F*	df	*p*	R^2
				Lower	Upper				
1									
Constant	1.507	−0.002	0.027	[1.457	1.556]	41.835	(1, 54)	<0.001	0.437
MPI	0.938	0.008	0.122	[0.715	1.198]				
2									
Constant	2.272	−0.010	0.120	[2.048	2.458]	29.627	(1, 54)	<0.001	0.354
HDI	−1.023	0.014	0.184	[−1.398	−0.558]				
3									
Constant	2.080	−0.003	0.087	[1.908	2.236]	30.468	(1, 54)	<0.001	0.361
IHDI	−0.935	0.005	0.167	[−1.266	−0.598]				

[a]Bootstrap results were based on 1,000 resamples. All regression models were calculated with a Briggsian logarithmic transformation to the dependent variable with a constant of 30 applied to each observation.

The second regression model, using HDI as the regressor, also provided excellent prediction of first to second dose disparities in MCV coverage, albeit less than the first regression model. Specifically, the HDI model accounted for 35.4% of the variance in the dependent variable, F (1, 54) = 29.627, $p < 0.001$. To the extent that the HDI beta weight was negative, the model indicated that first to second dose disparities in MCV coverage were greatest in countries with relatively low human development. The third regression model, using IHDI as the regressor, accounted for a greater percentage of the variance in the dependent variable than the second model but less than the first model, $R^2 = 0.361$, F (1, 54) = 30.468, $p < 0.001$. The IHDI exhibited a negative beta weight, indicating that countries with lower inequality-adjusted human development experienced greater first to second dose disparities in MCV coverage.

4. Discussion

Poverty is often associated with lack of adequate resources, and it is likely this inequity partially explains undervaccination among the countries examined herein. The present research, therefore, fills a gap in the literature by exploring how three different poverty indices might each predict the drop-off in Measles-Containing Vaccine (MCV) coverage from first to second dose. The findings from this study confirm that multidimensional poverty has a powerful impact on individuals living in impoverished countries receiving the second dose of MCV.

There is a host of extant literature documenting the correlation between underimmunization and poverty-related factors in well-developed countries. Indeed, many of the factors that link poverty with underimmunization in well-developed countries are present, and often magnified, in impoverished countries. Nonetheless, as evidenced by that variance that was *unexplained* in the three regression models presented in this study, factors beyond mere poverty—at least as measured by these three indices—must influence the drop-off from MCV-1 to MCV-2 coverage rates in developing countries. One factor perhaps directly related to the disparity in coverage could be vaccine shortages. In 2014, 50 of the 194 WHO countries reported experiencing a total of 110 national-level shortage of supply of at least one vaccine lasting at least 1 month; in other words, each country experienced an average of 2.2 shortages in 2014. Furthermore, MCV alone accounted for 14% of the reported shortages (Subaiya et al., 2015). Further complicating supply-side matters, as of 2015, 94% of MCV supply was sourced from just one manufacturer, while two other manufacturers supplied the remaining 6% (UNICEF Supply Division, 2015).

Additionally, Gavi—the international organization whose goal is to improve access to vaccines in the world's poorest countries—provides many of the countries in this study financing for vaccines they might otherwise not be able to afford. As of 2015, Gavi-financed country requirements accounted for approximately 30% of total MCV demand through UNICEF. Though both Gavi-financed and non-Gavi financed countries are able to procure MCV at the same prices, more impoverished countries are likely more prone to apply for Gavi funding. Gavi relies on the developing countries themselves to initiate funding proposals, and the countries then choose what specific support they want to apply for and when they wish to receive it (Gavi: The Vaccine Alliance, 2016). This multilayered application process itself (including choosing what support they want from the Gavi board and compiling the variety of materials required by UNICEF's Supply Division) requires leaders of these countries to have a high level of education about infectious diseases, as well as to understand the importance of a particular vaccination schedule; in this case, to receive Gavi funding, country leaders would first need to understand why MCV-2 is recommended as a follow-up to MCV-1. It is possible that a lack of education about the importance of a second dose of MCV, the cumbersome application process itself, or a combination of both factors has contributed to the disparity from MCV-1 to MCV-2 administration among the countries examined in this study. For many of these countries, it is unknown whether they will apply for funding to cover MCV-2 administration or, should they apply, whether the vaccine will even be available (UNICEF Supply Division, 2015).

4.1. Limitations
Though the findings from this study confirm the impact of poverty on undervaccination, some limitations are inherent. While the MPI explained much of the dropoff from MCV-1 to MCV-2 coverage in the countries explored in this study, the unexplained variance suggests there are many other factors that likely influence undervaccination rates. Furthermore, this study did not consider specific factors related to poverty that might be particularly impactful. While we can deduce that countries with greater dimensions of poverty experience greater levels of underimmunization, it would not be appropriate to speculate about the impact of particular dimensions. Every country examined in this research has its own specific set of barriers, and as such, researchers should be hesitant to draw uniform conclusions based on this study's findings.

5. Conclusion

5.1. Key findings
This research suggests more multidimensionally-poor countries experience greater MCV dosage disparities; specifically, the Multidimensional Poverty Index (MPI) provided the greatest predictive power for the dropoff from first to second dose. Nonetheless, as evidenced by the relatively robust predictive power of all three poverty indices—the weakest one accounting for over 35% of the variance in the regression models presented in this study—poverty, no matter how it is measured, is a powerful factor in explaining the drop-off from first to second dose MCV administration.

5.2. Implications
This research provides the impetus to explore the various dimensions of poverty and how each might impact undervaccination in the world's poorest countries. One recent study suggested four factors significantly associated with MCV-2 uptake in an impoverished country, two of which were relevant to the present study: awareness of MCV-2, and time taken to travel to the nearest health facility (Makokha, Wanjala, Githuku, & Kutima, 2015). It is possible that a convergence of barriers together affects MCV-2 administration, including poverty, application-related difficulties, vaccine awareness, and individuals' proximity to available health centers. These factors nonetheless tend to be all exacerbated by poverty, and it is possible that the 56% of unexplained variance in this study is related—if indirectly—to factors related to poverty as well.

5.3. Recommendations
Future efforts should be directed toward uncovering and reducing barriers to second dose MCV administration in the most impoverished countries. It is crucial to emphasize the continued importance of educational efforts that raise awareness of the need for MCV-2. Since the Gavi application process requires country leaders to be aware of specific health issues before applying for funding, it would be worthwhile to examine whether these leaders fully understand the need for MCV-2 among their populations. Additionally, using GIS to map the available health facilities in a country might provide a more robust understanding of how the distance between, and availability of, health facilities influence underimmunization. Nonetheless, all of the dimensions of poverty should be critically examined in the context of individual countries so public health practitioners can better target individualized interventions that address the various factors influencing underimmunization in the most impoverished countries.

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