PLOS ONE

RESEARCH ARTICLE

Leave no child behind: Using data from 1.7 million children from 67 developing countries to measure inequality within and between groups of births and to identify left behind populations

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Citation: Ramos AP, Flores MJ, Weiss RE (2020) Leave no child behind: Using data from 1.7 million children from 67 developing countries to measure inequality within and between groups of births and to identify left behind populations. PLoS ONE 15(10): e0238847. https://doi.org/10.1371/journal.pone.0238847

Editor: Bruno Masquelier, University of Louvain, BELGIUM

Received: September 12, 2019

Accepted: August 25, 2020

Published: October 14, 2020

Peer Review History: PLOS recognizes the benefits of transparency in the peer review process; therefore, we enable the publication of all of the content of peer review and author responses alongside final, published articles. The editorial history of this article is available here: https://doi.org/10.1371/journal.pone.0238847

Data Availability Statement: All relevant data are available on the Demographic and Health Surveys website and publicly accessible upon registering

Abstract

Background

Goal 3.2 from the Sustainable Development Goals (SDG) calls for reductions in national averages of Under-5 Mortality. However, it is well known that within countries these reductions can coexist with left behind populations that have mortality rates higher than national averages. To measure inequality in under-5 mortality and to identify left behind populations, mortality rates are often disaggregated by socioeconomic status within countries. While socioeconomic disparities are important, this approach does not quantify within group variability since births from the same socioeconomic group may have different mortality risks. This is the case because mortality risk depends on several risk factors and their interactions and births from the same socioeconomic group may have different risk factor combinations. Therefore mortality risk can be highly variable within socioeconomic groups. We develop a comprehensive approach using information from multiple risk factors simultaneously to measure inequality in mortality and to identify left behind populations.

Methods

We use Demographic and Health Surveys (DHS) data on 1,691,039 births from 182 different surveys from 67 low and middle income countries, 51 of which had at least two surveys. We estimate mortality risk for each child in the data using a Bayesian hierarchical logistic regression model. We include commonly used risk factors for monitoring inequality in early life mortality for the SDG as well as their interactions. We quantify variability in mortality risk within and between socioeconomic groups and describe the highest risk sub-populations.

via the following URL: https://www.dhsprogram.com/data/new-user-registration.cfm.

Funding: The corresponding author, Dr. Antonio Pedro Ramos, has his worked funded by by the Eunice Kennedy Shriver National Institute of Child Health & Human Development of the National Institutes of Health under Award Number K99HD088727. The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Competing interests: The authors have declared that no competing interests exist.

Findings

For all countries there is more variability in mortality within socioeconomic groups than between them. Within countries, socioeconomic membership usually explains less than 20% of the total variation in mortality risk. In contrast, country of birth explains 19% of the total variance in mortality risk. Targeting the 20% highest risk children based on our model better identifies under-5 deaths than targeting the 20% poorest. For all surveys, we report efficiency gains from 26% in Mali to 578% in Guyana. High risk births tend to be births from mothers who are in the lowest socioeconomic group, live in rural areas and/or have already experienced a prior death of a child.

Interpretation

While important, differences in under-5 mortality across socioeconomic groups do not explain most of overall inequality in mortality risk because births from the same socioeconomic groups have different mortality risks. Similarly, policy makers can reach the highest risk children by targeting births based on several risk factors (socioeconomic status, residing in rural areas, having a previous death of a child and more) instead of using a single risk factor such as socioeconomic status. We suggest that researchers and policy makers monitor inequality in under-5 mortality using multiple risk factors simultaneously, quantifying inequality as a function of several risk factors to identify left behind populations in need of policy interventions and to help monitor progress toward the SDG.

1 Introduction

Goal 3.2 from the Sustainable Development Goals (SDG) requires reductions in under-5 mortality (http://www.un.org/sustainabledevelopment/health/). However, these reductions can co-exist with socioeconomic inequalities within countries where some groups have much higher mortality risk than others. [1] Studies have suggested that some of the Millennium Development Goals, which preceded the SDG, have not been achieved within many countries because of high levels of inequality. [2] Monitoring and reducing inequities in under-5 mortality requires the identification of births that are at highest risk of death such that policy interventions can target them. [3] The United Nations (UN) General Assembly Resolution 68/261, which highlights the Sustainable Development Indicators as a central framework for making progress on reducing early-life mortality, recommends that health indicators should be disaggregated, where relevant, by income, sex, age, and other characteristics. [4, 5] Disaggregation of inequality by several demographic groups has a clear policy implication: leave no one behind.

The literature that monitors progress towards SDG often quantifies gaps in either key health outcomes, such as neonatal or under-5 mortality, or in the coverage of health services, such as prenatal care or sanitation. Researchers and policy makers monitor progress toward SDG by evaluating mortality rates broken down by stratifiers, including wealth quintiles, rural/urban residence, maternal education, maternal age, gender of the child and geographic location (see https://www.equidade.org/indicators). [5] Even outside SDG monitoring, equity based strategies to reduce under-5 mortality usually measure gaps in average mortality rates between large groups of births, such as births from different socioeconomic groups within the same country [6–10]. Studies have also documented significant under-5 mortality inequities across other demographic categories such as race, ethnicity, and geographic location [11–13].

Public health policies seeking to reduce inequality in early-life mortality often target births from an easily defined group with a high average mortality rates, usually the poorest. [9, 14–19] A recent meta-analysis shows that most targeted interventions aiming to improve maternal and child health often address economic disparities through various incentive schemes like conditional cash transfers and voucher schemes. [20] For example, Cash Transfer Programs (CTP), currently implemented in many low and middle income countries (LMIC), often improve infant and child health. [21, 22] In Burkina Faso, families enrolled in conditional cash transfer schemes were required to obtain quarterly child growth monitoring at local health clinics for all children under 60 months of age. [23] In India, the randomized controlled trial (RCT) *Lentils for Vaccines* targeted the poor, as do most RCTs that aim to increase vaccine uptake, good nutrition, or child health more generally [24].

One important assumption underlying these approaches to measure inequality and target populations is that most of the variability in mortality risk exists between groups of births, not within them. If that is the case, (a) comparing average mortality rates between groups provides us with a complete picture of the inequality in mortality risk faced by children in the population and (b) targeting the group with the highest average mortality risk will reach most high risk births in the population and reduce overall inequalities. However, if the grouping factors used to monitor inequality have high levels of within-group variation in mortality risk, then monitoring inequality based solely on between group comparisons will miss most of the variability in mortality risk and monitors will not be able to identify important left behind populations that require intervention. [7] Using data from India a recent study shows that most of the variation in mortality risk exists within groups, not between groups, and that program targeting based on poverty alone can be inefficient. [25] This makes sense as it is well known that multiple risk factors are associated with under-5 mortality risk.

In this paper we develop a novel framework to monitor disparities in mortality risk and to identify high risk subpopulations that cannot be identified otherwise. Our novel approach uses data from several demographic variables and a Bayesian hierarchical model to estimate mortality risk for each birth in our data set. We use these estimates to investigate within and between group variability across several commonly used demographic stratifiers that are used to monitor progress toward the SDG's and make international comparisons in inequality in under-5 mortality. We identify children with the highest mortality risk in the population and show how to construct a targetable group that contains more deaths than other targetable groups of the same size that are based on only one risk factor, such as poverty. We identify the groups at highest risk in each country to gain insight on their needs. Our methodology supports UN recommendations to disaggregate health indicators by demographic stratifiers to guide inequality monitoring so that countries can meet SDG targets with equity. We offer a more comprehensive approach that considers the effects of multiple risk factors and their interactions on mortality risk.

2 Methods

Births are the units of our analysis. We first estimate mortality risk for each child in our data and then we use these estimates as inputs in our subsequent equity analysis.

2.1 Data sources

The data used in this study comes from multiple Demographic and Health Surveys (DHS) (https://dhsprogram.com/). These are nationally representative surveys that have been conducted in more than 100 low and middle income countries since 1984 [26, 27]. We analyze under-5 mortality and we exclude births that did not occur at least five years prior to the survey. We exclude all births that happen 10 years or more before the date of the survey to minimize measurement error and censoring issues. The final data set includes information on 1,691,039 births from a total of 182 different surveys from 67 countries, 51 of which had at least two surveys.

2.2 Estimating mortality risk

Mortality risk is a latent variable that must be estimated from data. Given our goal to improve inequality monitoring of the SDG, we base our estimation on predictors that are commonly used in studies that quantify progress toward SDG (https://www.equidade.org/indicators): maternal age, wealth, gender, year of birth, place of residence (urban/rural), maternal education in years.

The probability density functions (pdf) of the the original wealth index scores do not have a common range across countries. To make them more comparable across surveys we transform these pdf's into cumulative distribution functions (cdf). This approach gives wealth scores from different countries and surveys a common range, the unit interval (0,1) and makes the results interpretable in terms of relative wealth, a proxy for socioeconomic status within the countries. Details of the transformation are given in the appendix.

We also include three other variables that are available in DHS surveys and could aid inequality monitoring and targeting. Geographical locations are well known risk factors for mortality, as mortality risk tends to be geographically clustered. Using sampling clusters from DHS in our model allows us to capture unmeasured variables at the local level that were not otherwise recorded in the data. Further, geographic locations can potentially be targeted by policy makers. Similarly, we also construct a $0-1$ indicator variable for whether a child was born to a mother that had already experienced a death of a previous child. Prior death summarizes a number of risk factors at the maternal level that are not measured by existing variables. It is a forward looking variable because it only uses information on prior births to inform risk for the current birth. In particular, information on future siblings deaths are not used to predict past deaths and it is coded zero for a mother's first birth. It is also an actionable risk factor because policy makers can potentially target births from those mothers, as they are identifiable. Finally, we include birth order, coded as a continuous variable.

We estimate child mortality for each birth in our data as a function of these predictors and their interactions in a Bayesian hierarchical logistic regression model. We fit one model to the data from each survey. To avoid model misspecification and allow for all important interactions among the risk factors, we include all two-way, three-way, and four-way interaction terms for all covariates in the model. We include piecewise linear splines to capture non-linear trends in mortality as a function of the continuous variables. To aid in the estimation and avoid overfitting, we place increasingly restrictive priors on the variance parameters of the random effects for the higher order interaction terms, which shrink effects toward zero. We incorporate a location random effect to model differences in risk between births from different locations.

2.3 Equity analysis

We use estimates of the posterior distribution of mortality risk for each child in our data to feed our equity analysis. We use 1000 Markov Chain Monte Carlo (MCMC) samples from our model todo so. For the boxplots we use these samples to calculate the expected mortality risk for each child and then we plot these quantities.

We use box plots to display the within and between group variability in fitted mortality risk stratified by the DHS-assigned wealth quintile. We formally quantify how much of the variability in mortality risk is explained by the wealth quintiles using a Bayesian ANOVA, which allows us to get point and interval estimates of the R^2. Details of the ANOVA methods are given in the appendix.

Finally, we investigate whether using multiple risk factors simultaneously can help to identify high risk births that should be targeted by policy interventions. Using the last survey from each country, we compare how many actual deaths occur among the 20% highest risk births from our model versus the 20% poorest births based on the wealth CDF variable. Under the assumption that intervention has the same cost for each birth, we calculate the efficiency gain in targeting the highest risk births versus the poorest births by dividing the difference in mortality rates between highest risk births and poorest births by mortality rates among the poorest times 100. We thus define the efficiency gain as $\frac{(\text{HRDeaths}-\text{PoorDeaths})}{\text{PoorDeaths}} \times 100$, where "HRDeaths" is mortality among the 20% highest risk births and "PoorDeaths" is defined as mortality among the poorest 20% of births. For each survey, we compare births in the high risk group to births not in the high risk group based on the following covariates: wealth, maternal education, maternal age, place of residency (urban/rural), whether the birth was born to a mother who has experienced a prior death of another child. We compare lower and higher mortality risk groups by using either risk ratios for categorical risk factors or mean risk difference for continuous risk factors.

2.3.1 Incorporating uncertainty in the equity analysis. We use estimates of the posterior distribution of mortality risk for each child in our data to feed our equity analysis. We use 1000 Markov Chain Monte Carlo (MCMC) samples from our model to do so. For the boxplots we use these samples to calculate the expected mortality risk for each child and then we plot these quantities. For ANOVA and other tabulations, we calculate a quantity for each MCMC sample so that we have a distribution of these quantities that can be used to calculate posterior means and intervals. These also allow us to implement significant tests.

2.4 Role of the funding source

We acknowledge financial support from the Eunice Kennedy Shriver National Institute Of Child Health & Human Development of the National Institutes of Health under Award Number K99HD088727 and CCPR's Population Research Infrastructure Grant P2C from NICHD: P2C-HD041022. The sponsor of the study had no role in study design, data analysis, data collection, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study; all authors had final responsibility for the decision to submit for publication.

3 Results

3.1 Mortality by wealth quintile in the raw data

All results use individual births as the unit of the analysis. Summaries of the Demographic and Health Surveys (DHS) are presented in Table 1. Each row presents data for one survey. From left to right, the columns in Table 1 are the number of births in each survey (N); the under-5 mortality rate (U5MR), defined as the fraction of births who die before age five, both overall and for each wealth quintile; and the proportion of deaths that occurred to the top 80% in wealth, which we call the non-poor deaths (NPD) fraction. If there is perfect equity in mortality across socioeconomic groups, then the NPD would be exactly 80%. If the poorest 20% contain more than their share of deaths, then the NPD would be lower than 80%. Under-5

Table 1. N is the survey sample size used in our analysis. U5MR is the under-5 mortality rates by age five for each survey. Non-poor deaths (NPD) is the fraction of deaths from the top 80% wealth quintile. DRC is Democratic Republic of Congo, DR is Dominican Republic, and CAR is Central African Republic. The first quintile is the poorest births and the fifth quantile is the richest births.

Country (Survey Year)	N	U5MR	U5MR by Wealth Quintile					NPD
			First	Second	Third	Fourth	Fifth	
Albania (2009)	2,481	0.028	0.049	0.022	0.030	0.009	0.023	0.551
Angola (2011)	5,812	0.109	0.149	0.105	0.127	0.103	0.088	0.819
Armenia (2000)	2,602	0.057	0.058	0.059	0.056	0.066	0.043	0.736
Armenia (2010)	1,545	0.028	0.028	0.052	0.023	0.013	0.022	0.814
Azerbaijan (2006)	2,739	0.063	0.071	0.072	0.056	0.052	0.055	0.680
Bangladesh (2000)	9,061	0.127	0.164	0.158	0.110	0.109	0.082	0.717
Bangladesh (2004)	7,261	0.101	0.120	0.112	0.094	0.091	0.080	0.725
Bangladesh (2007)	6,929	0.083	0.100	0.105	0.091	0.073	0.046	0.733
Bangladesh (2014)	14,512	0.061	0.080	0.067	0.058	0.057	0.036	0.687
Benin (1996)	5,386	0.200	0.224	0.213	0.212	0.196	0.116	0.722
Benin (2001)	5,691	0.170	0.211	0.183	0.168	0.141	0.109	0.694
Benin (2006)	16,984	0.152	0.169	0.165	0.161	0.143	0.091	0.728
Benin (2012)	12,904	0.084	0.093	0.100	0.087	0.074	0.043	0.723
Bolivia (1998)	9,334	0.117	0.161	0.125	0.119	0.062	0.044	0.574
Bolivia (2004)	10,546	0.103	0.128	0.126	0.103	0.068	0.046	0.688
Bolivia (2008)	10,048	0.080	0.112	0.087	0.074	0.060	0.029	0.597
Brazil (1996)	6,023	0.071	0.113	0.067	0.045	0.037	0.036	0.477
Burkina Faso (1993)	5,514	0.206	0.206	0.253	0.236	0.221	0.157	0.850
Burkina Faso (1999)	5,702	0.230	0.250	0.249	0.251	0.249	0.152	0.751
Burkina Faso (2003)	12,060	0.200	0.201	0.227	0.204	0.208	0.144	0.804
Burkina Faso (2010)	16,759	0.164	0.186	0.186	0.162	0.157	0.110	0.756
Burundi (2011)	6,016	0.137	0.170	0.163	0.152	0.136	0.074	0.761
Cambodia (2000)	12,071	0.131	0.171	0.144	0.120	0.116	0.072	0.646
Cambodia (2011)	7,258	0.081	0.113	0.104	0.084	0.050	0.038	0.633
Cambodia (2014)	8,272	0.060	0.093	0.073	0.051	0.041	0.029	0.611
Cameroon (1991)	3,140	0.149	0.210	0.204	0.146	0.131	0.088	0.771
Cameroon (1998)	4,080	0.145	0.212	0.176	0.145	0.101	0.096	0.662
Cameroon (2004)	7,535	0.157	0.207	0.181	0.155	0.102	0.090	0.645
Cameroon (2011)	10,812	0.133	0.188	0.148	0.126	0.095	0.076	0.676
CAR (1995)	4,429	0.166	0.204	0.181	0.167	0.166	0.093	0.692
Chad (1997)	6,941	0.201	0.173	0.230	0.227	0.223	0.167	0.854
Chad (2004)	6,260	0.201	0.191	0.215	0.231	0.217	0.178	0.822
Chad (2015)	18,985	0.144	0.160	0.160	0.136	0.132	0.135	0.798
Colombia (1990)	4,087	0.041	0.069	0.055	0.034	0.032	0.025	0.754
Colombia (1995)	5,041	0.040	0.053	0.041	0.029	0.042	0.026	0.655
Colombia (2005)	15,630	0.032	0.047	0.032	0.026	0.020	0.021	0.598
Comoros (1996)	2,208	0.116	0.132	0.139	0.108	0.094	0.091	0.715
Comoros (2012)	3,390	0.050	0.051	0.054	0.052	0.055	0.035	0.725
DRC (2005)	4,419	0.134	0.157	0.141	0.137	0.143	0.081	0.745
DRC (2007)	7,971	0.172	0.207	0.195	0.180	0.155	0.107	0.734
DRC (2012)	7,597	0.097	0.105	0.106	0.082	0.066	0.071	0.501
DRC (2014)	15,132	0.125	0.137	0.137	0.124	0.128	0.077	0.717
Côte d'Ivoire (1999)	2,757	0.158	0.195	0.172	0.189	0.136	0.110	0.789
Côte d'Ivoire (2005)	3,812	0.127	0.149	0.127	0.125	0.115	0.097	0.673
Côte d'Ivoire (2012)	7,224	0.140	0.145	0.145	0.170	0.124	0.087	0.762

(Continued)

Table 1. (Continued)

Country (Survey Year)	N	U5MR	U5MR by Wealth Quintile					NPD
			First	Second	Third	Fourth	Fifth	
Dominican Republic (1999)	3,250	0.070	0.093	0.074	0.071	0.049	0.019	0.575
Dominican Republic (2002)	12,941	0.049	0.071	0.045	0.039	0.039	0.019	0.541
Dominican Republic (2007)	13,945	0.037	0.047	0.037	0.032	0.025	0.028	0.558
Dominican Republic (2013)	4,782	0.042	0.057	0.042	0.032	0.024	0.023	0.505
Egypt (1996)	12,791	0.110	0.158	0.133	0.107	0.070	0.038	0.605
Egypt (2003)	11,850	0.070	0.099	0.079	0.067	0.047	0.036	0.611
Egypt (2008)	11,394	0.039	0.061	0.035	0.035	0.026	0.025	0.592
Egypt (2014)	14,486	0.035	0.051	0.043	0.033	0.028	0.021	0.700
Eswatini (2007)	2,421	0.102	0.118	0.108	0.097	0.102	0.091	0.782
Ethiopia (1997)	12,984	0.141	0.134	0.168	0.153	0.158	0.104	0.743
Ethiopia (2003)	13,218	0.129	0.149	0.132	0.132	0.135	0.084	0.636
Gabon (2001)	3,783	0.093	0.095	0.117	0.099	0.083	0.040	0.685
Gabon (2012)	5,149	0.070	0.082	0.073	0.061	0.047	0.035	0.453
Ghana (1994)	3,281	0.147	0.181	0.188	0.155	0.114	0.078	0.751
Ghana (1999)	3,226	0.126	0.156	0.142	0.126	0.103	0.048	0.565
Ghana (2003)	4,134	0.127	0.155	0.120	0.125	0.112	0.088	0.603
Ghana (2008)	3,258	0.096	0.114	0.093	0.105	0.076	0.068	0.620
Ghana (2014)	6,370	0.084	0.107	0.077	0.067	0.062	0.080	0.570
Guatemala (1999)	7,083	0.078	0.085	0.087	0.081	0.065	0.034	0.637
Guatemala (2015)	11,719	0.041	0.057	0.043	0.038	0.030	0.021	0.623
Guinea (1999)	6,867	0.195	0.235	0.218	0.196	0.182	0.128	0.721
Guinea (2005)	7,807	0.201	0.219	0.230	0.220	0.172	0.125	0.741
Guinea (2012)	8,010	0.143	0.180	0.151	0.152	0.122	0.073	0.684
Guyana (2005)	1,268	0.046	0.030	0.052	0.029	0.038	0.088	0.828
Guyana (2009)	2,464	0.037	0.027	0.042	0.030	0.065	0.036	0.700
Haiti (1995)	3,020	0.157	0.194	0.182	0.147	0.139	0.100	0.722
Haiti (2000)	7,063	0.152	0.185	0.140	0.151	0.137	0.114	0.655
Haiti (2006)	5,907	0.107	0.130	0.115	0.098	0.098	0.067	0.655
Haiti (2012)	6,944	0.096	0.101	0.102	0.102	0.091	0.065	0.691
Honduras (2006)	12,380	0.045	0.055	0.052	0.041	0.029	0.022	0.606
Honduras (2012)	10,065	0.031	0.041	0.027	0.028	0.025	0.020	0.553
India (1993)	65,681	0.113	0.162	0.157	0.115	0.085	0.055	0.723
India (2000)	53,079	0.099	0.146	0.122	0.104	0.070	0.045	0.686
India (2006)	59,240	0.080	0.128	0.099	0.080	0.061	0.037	0.699
Indonesia (1997)	23,155	0.085	0.111	0.101	0.084	0.060	0.031	0.565
Indonesia (2003)	16,049	0.064	0.091	0.068	0.056	0.043	0.027	0.515
Indonesia (2007)	20,592	0.067	0.100	0.072	0.054	0.042	0.034	0.529
Indonesia (2012)	19,788	0.054	0.087	0.057	0.038	0.037	0.019	0.490
Jordan (1990)	9,308	0.046	0.061	0.056	0.043	0.038	0.034	0.796
Jordan (1997)	6,408	0.036	0.046	0.040	0.036	0.026	0.029	0.707
Jordan (2002)	7,098	0.037	0.040	0.041	0.037	0.031	0.029	0.708
Jordan (2009)	13,691	0.029	0.035	0.022	0.028	0.029	0.026	0.611
Jordan (2012)	11,205	0.024	0.029	0.023	0.021	0.024	0.015	0.670
Kazakhstan (1999)	2,651	0.057	0.069	0.062	0.067	0.052	0.038	0.762
Kenya (1993)	6,514	0.097	0.138	0.129	0.078	0.067	0.060	0.681
Kenya (1998)	5,789	0.104	0.140	0.119	0.104	0.076	0.058	0.668

(Continued)

Table 1. (Continued)

Country (Survey Year)	N	U5MR	U5MR by Wealth Quintile					NPD
			First	Second	Third	Fourth	Fifth	
Kenya (2009)	5,412	0.095	0.103	0.106	0.098	0.074	0.084	0.686
Kenya (2014)	23,924	0.055	0.053	0.066	0.054	0.053	0.044	0.674
Kyrgyzstan (1997)	2,400	0.074	0.094	0.092	0.079	0.051	0.043	0.669
Kyrgyzstan (2012)	3,705	0.036	0.031	0.037	0.048	0.032	0.031	0.799
Lesotho (2005)	3,115	0.093	0.113	0.107	0.090	0.075	0.077	0.746
Lesotho (2010)	3,107	0.087	0.077	0.095	0.098	0.090	0.079	0.737
Lesotho (2014)	3,250	0.100	0.080	0.103	0.117	0.120	0.087	0.791
Liberia (2009)	6,871	0.173	0.195	0.176	0.158	0.173	0.149	0.713
Liberia (2013)	8,220	0.132	0.147	0.131	0.123	0.108	0.126	0.618
Madagascar (1997)	5,960	0.165	0.208	0.186	0.178	0.137	0.098	0.675
Madagascar (2004)	5,268	0.106	0.163	0.142	0.114	0.095	0.058	0.699
Madagascar (2009)	12,686	0.087	0.111	0.098	0.093	0.070	0.045	0.651
Malawi (1992)	4,746	0.231	0.273	0.242	0.259	0.256	0.154	0.799
Malawi (2005)	9,663	0.180	0.216	0.192	0.193	0.167	0.124	0.777
Malawi (2010)	20,677	0.129	0.145	0.136	0.133	0.115	0.110	0.748
Malawi (2016)	16,793	0.079	0.094	0.082	0.088	0.076	0.053	0.756
Mali (1996)	9,960	0.259	0.310	0.292	0.262	0.238	0.175	0.757
Mali (2001)	13,031	0.257	0.264	0.271	0.287	0.271	0.148	0.776
Mali (2006)	15,201	0.222	0.248	0.261	0.229	0.210	0.134	0.773
Mali (2013)	9,249	0.113	0.120	0.140	0.130	0.108	0.063	0.779
Moldova (2005)	1,744	0.033	0.036	0.031	0.044	0.036	0.018	0.789
Morocco (1992)	5,422	0.088	0.110	0.094	0.092	0.074	0.050	0.695
Morocco (2004)	6,493	0.061	0.085	0.069	0.048	0.046	0.027	0.602
Mozambique (1997)	6,834	0.200	0.262	0.213	0.210	0.183	0.120	0.674
Mozambique (2004)	8,942	0.195	0.229	0.222	0.227	0.168	0.115	0.716
Mozambique (2011)	10,379	0.112	0.137	0.112	0.126	0.100	0.093	0.783
Namibia (1992)	3,692	0.109	0.137	0.100	0.103	0.120	0.079	0.718
Namibia (2000)	4,354	0.063	0.073	0.090	0.072	0.058	0.033	0.778
Namibia (2007)	4,668	0.069	0.097	0.078	0.064	0.062	0.032	0.703
Namibia (2013)	4,691	0.058	0.065	0.074	0.060	0.056	0.023	0.745
Nicaragua (1998)	8,665	0.062	0.067	0.070	0.060	0.054	0.041	0.661
Nicaragua (2001)	9,008	0.049	0.063	0.053	0.048	0.036	0.018	0.600
Niger (1998)	7,644	0.306	0.294	0.376	0.356	0.329	0.194	0.823
Niger (2006)	9,820	0.206	0.189	0.237	0.248	0.227	0.151	0.812
Niger (2012)	13,573	0.151	0.153	0.175	0.175	0.162	0.099	0.805
Nigeria (1990)	8,696	0.190	0.247	0.243	0.213	0.165	0.105	0.729
Nigeria (2003)	5,848	0.221	0.246	0.291	0.213	0.201	0.092	0.721
Nigeria (2008)	30,182	0.185	0.224	0.226	0.169	0.137	0.091	0.657
Nigeria (2013)	34,186	0.158	0.204	0.202	0.146	0.109	0.085	0.685
Pakistan (1991)	8,356	0.110	0.109	0.140	0.128	0.110	0.074	0.864
Pakistan (2007)	9,531	0.089	0.112	0.097	0.076	0.085	0.060	0.698
Pakistan (2013)	11,854	0.093	0.122	0.099	0.091	0.082	0.057	0.673
Paraguay (1990)	4,375	0.053	0.069	0.055	0.054	0.045	0.018	0.597
Peru (1992)	9,085	0.112	0.155	0.133	0.083	0.055	0.035	0.553
Peru (1996)	19,554	0.088	0.121	0.097	0.067	0.058	0.026	0.527
Peru (2000)	17,334	0.081	0.112	0.094	0.060	0.037	0.016	0.536

(*Continued*)

Table 1. (Continued)

Country (Survey Year)	N	U5MR	U5MR by Wealth Quintile					NPD
			First	Second	Third	Fourth	Fifth	
Peru (2008)	13,739	0.040	0.063	0.047	0.037	0.025	0.019	0.720
Peru (2012)	31,443	0.033	0.046	0.035	0.026	0.020	0.013	0.544
Philippines (1993)	9,340	0.075	0.101	0.088	0.068	0.038	0.052	0.625
Philippines (1998)	8,361	0.065	0.091	0.070	0.052	0.039	0.031	0.530
Philippines (2003)	7,863	0.045	0.073	0.048	0.033	0.020	0.023	0.526
Philippines (2008)	7,480	0.044	0.066	0.043	0.030	0.032	0.024	0.535
Philippines (2013)	8,159	0.033	0.051	0.032	0.025	0.018	0.017	0.485
Rwanda (1992)	6,071	0.174	0.165	0.218	0.155	0.211	0.134	0.795
Rwanda (2005)	9,139	0.202	0.223	0.224	0.200	0.224	0.132	0.744
Rwanda (2008)	4,865	0.149	0.176	0.166	0.159	0.159	0.087	0.824
Rwanda (2015)	8,096	0.071	0.082	0.082	0.077	0.068	0.040	0.731
Sao Tome and Principe (2009)	1,685	0.081	0.087	0.076	0.082	0.106	0.034	0.728
Senegal (1997)	7,311	0.157	0.189	0.192	0.165	0.109	0.076	0.706
Senegal (2005)	10,284	0.162	0.210	0.186	0.158	0.100	0.079	0.677
Senegal (2009)	13,229	0.124	0.154	0.135	0.107	0.063	0.067	0.575
Senegal (2015)	12,606	0.084	0.110	0.089	0.075	0.054	0.046	0.596
Sierra Leone (2008)	6,413	0.179	0.214	0.184	0.163	0.173	0.155	0.739
Sierra Leone (2013)	13,981	0.187	0.206	0.197	0.192	0.179	0.142	0.746
South Africa (1998)	5,564	0.057	0.085	0.073	0.048	0.031	0.022	0.610
Tanzania (1999)	6,715	0.150	0.159	0.167	0.167	0.169	0.098	0.764
Tanzania (2005)	7,200	0.143	0.166	0.158	0.160	0.124	0.101	0.755
Tanzania (2010)	11,262	0.101	0.126	0.110	0.098	0.092	0.071	0.737
Tanzania (2016)	8,745	0.079	0.085	0.081	0.076	0.084	0.062	0.755
Timor-Leste (2010)	9,499	0.089	0.096	0.102	0.095	0.091	0.059	0.758
Togo (1998)	7,211	0.155	0.174	0.181	0.159	0.119	0.102	0.720
Togo (2014)	6,901	0.109	0.131	0.122	0.112	0.084	0.045	0.588
Turkey (1993)	4,998	0.090	0.144	0.095	0.087	0.073	0.030	0.639
Turkey (1998)	4,162	0.064	0.096	0.065	0.058	0.045	0.033	0.615
Turkey (2004)	4,765	0.058	0.087	0.065	0.051	0.034	0.031	0.587
Uganda (1995)	6,244	0.159	0.199	0.183	0.158	0.163	0.114	0.778
Uganda (2001)	5,933	0.154	0.192	0.194	0.170	0.136	0.102	0.784
Uganda (2010)	5,912	0.142	0.168	0.149	0.138	0.134	0.104	0.690
Uganda (2011)	7,852	0.117	0.137	0.137	0.110	0.112	0.080	0.684
Ukraine (2007)	1,494	0.021	0.021	0.015	0.021	0.041	0.011	0.806
Uzbekistan (1996)	2,656	0.054	0.064	0.039	0.054	0.065	0.049	0.776
Vietnam (2002)	4,060	0.039	0.055	0.045	0.031	0.030	0.023	0.643
Zambia (1997)	5,614	0.192	0.214	0.226	0.192	0.169	0.126	0.660
Zambia (2002)	6,027	0.171	0.204	0.188	0.196	0.142	0.084	0.722
Zambia (2007)	5,808	0.147	0.125	0.171	0.172	0.142	0.102	0.821
Zambia (2014)	12,324	0.088	0.109	0.091	0.087	0.069	0.072	0.728
Zimbabwe (1994)	4,622	0.066	0.073	0.084	0.050	0.073	0.045	0.702
Zimbabwe (1999)	3,713	0.078	0.085	0.087	0.081	0.081	0.043	0.697
Zimbabwe (2006)	4,357	0.062	0.064	0.071	0.069	0.055	0.047	0.748
Zimbabwe (2011)	4,374	0.067	0.075	0.075	0.074	0.052	0.057	0.718
Zimbabwe (2015)	5,726	0.093	0.118	0.102	0.103	0.084	0.062	0.726

https://doi.org/10.1371/journal.pone.0238847.t001

mortality rates are generally higher for the poorest wealth quintiles, reflecting a socioeconomic gradient in mortality. Some countries, such as Egypt, exhibit a consistent decrease in mortality with increasing wealth quintile. In a few countries, mortality increases from the poorest to the second poorest quintile, such as in Burkina Faso (2003). In general, the NPD are typically between 50% and 75%. These results show that there are high risk children in all socioeconomic groups.

3.2 Quantifying within and between group variability

Fig 1 presents box plots showing the distribution of mortality risk for the last survey of each country. Countries are ordered from the highest median mortality risk (Sierra Leone) to the lowest median mortality risk (Ukraine). As the median mortality risk gets smaller, variance decreases as well. There is considerable overlap in mortality risk across countries. This suggests that country of birth explains only a small fraction of mortality risk and that all countries have some children with very high mortality risk.

Fig 2 presents the distribution of mortality risk across countries stratified by wealth quintile. Only the most recent survey is shown, and countries are ranked from highest to lowest median mortality risk, from top left to bottom right. Outliers are not shown and all graphs are presented on the same scale. For all countries and surveys in our sample, there is considerable overlap in mortality risk across socioeconomic groups within countries and this is true irrespective of a country's average mortality level. Among higher mortality countries, Sierra Leone and the Central African Republic have clear socioeconomic gradients in mortality risk. Among lower mortality countries, Bolivia, Brazil, Nigeria, and Cameroon have the largest socioeconomic gradients in mortality risk. High mortality countries like Niger and Lesotho exhibit no socioeconomic gradients in mortality, and this is also true for some lower mortality countries, such as Ukraine, Armenia and Jordan. Conclusions from Fig 2 are thus consistent with those from Table 1.

Table 2 presents results from our analysis. The first column gives the country and year in which the survey was taken, and first row presenting the results across all surveys combined. Columns two through five show the mean, median, and standard deviation of the mortality risk distribution from our analysis, and the R^2 of our ANOVA, which quantifies how much of the variance in mortality risk is explained by wealth quintile.

Globally, wealth quintile only explains about 3% of the variability in mortality risk. However, there is substantial country to country heterogeneity. The countries with the highest R^2 values are India (23%), Nigeria (17%), Indonesia (14%), and Cameroon (14%). In contrast, Eswatini, Lesotho, Tanzania, Moldova, Sao Tome and Principe, Kyrgyzstan, Uzbekistan, Kenya, Ukraine, and Comoros all have R^2 point estimates that are less than 1%. Further there is not a clear relationship between R^2 and mean/median mortality risk. Using country of birth in the ANOVA gives a posterior mean R^2 of 19%. Thus the ANOVA results confirm the findings from the boxplots of mortality rates in Figs 1 and 2 which show that while there is substantial country to country heterogeneity, within a given country wealth does not explain much of the variability in mortality risk.

Mortality risk distributions have a long right tail and in Table 2 the mean mortality risk is always higher than the median. In every country, there are individuals that face much higher mortality risk than the national average.

3.3 Comparing mortality among highest risk and poorest children

Poverty status alone is often used to decide which families will be targeted by health interventions. However, high within group variability for socioeconomic groups suggests that targeting

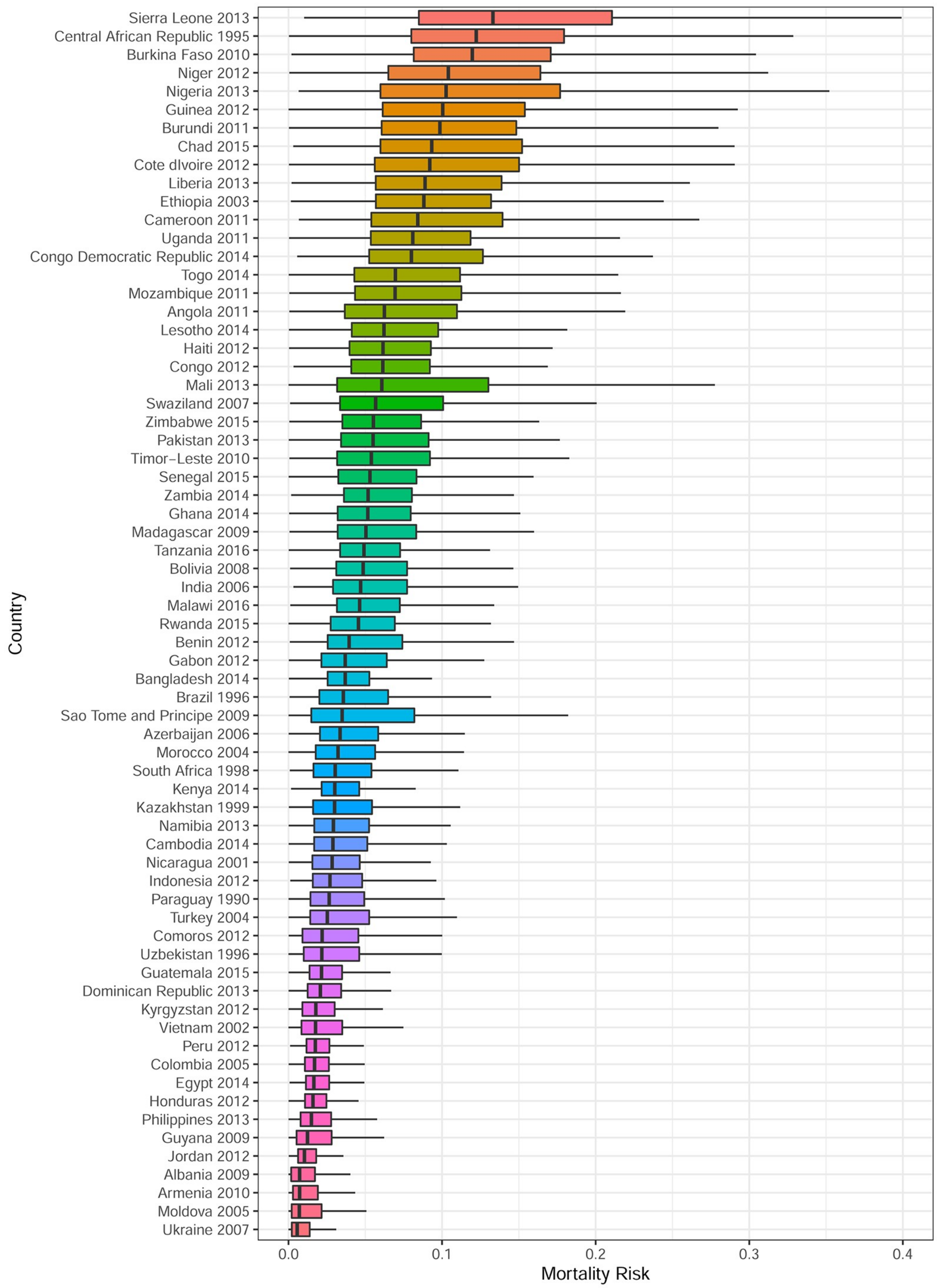

Fig 1. Box plots for mortality risk by country and survey. Lines are ±1.5 times interquartile range, boxes are lower to upper quartile, and dark line is the median mortality risk. Outliers are not shown.

https://doi.org/10.1371/journal.pone.0238847.g001

based on a single demographic variable is inefficient because there are high risk births in all socioeconomic groups. We formally demonstrate the validity of this hypothesis for the last survey of each country, comparing efficiency gains of targeting the 20% poorest compared to targeting the 20% highest risk. Results are presented in Table 3. For all surveys and all countries,

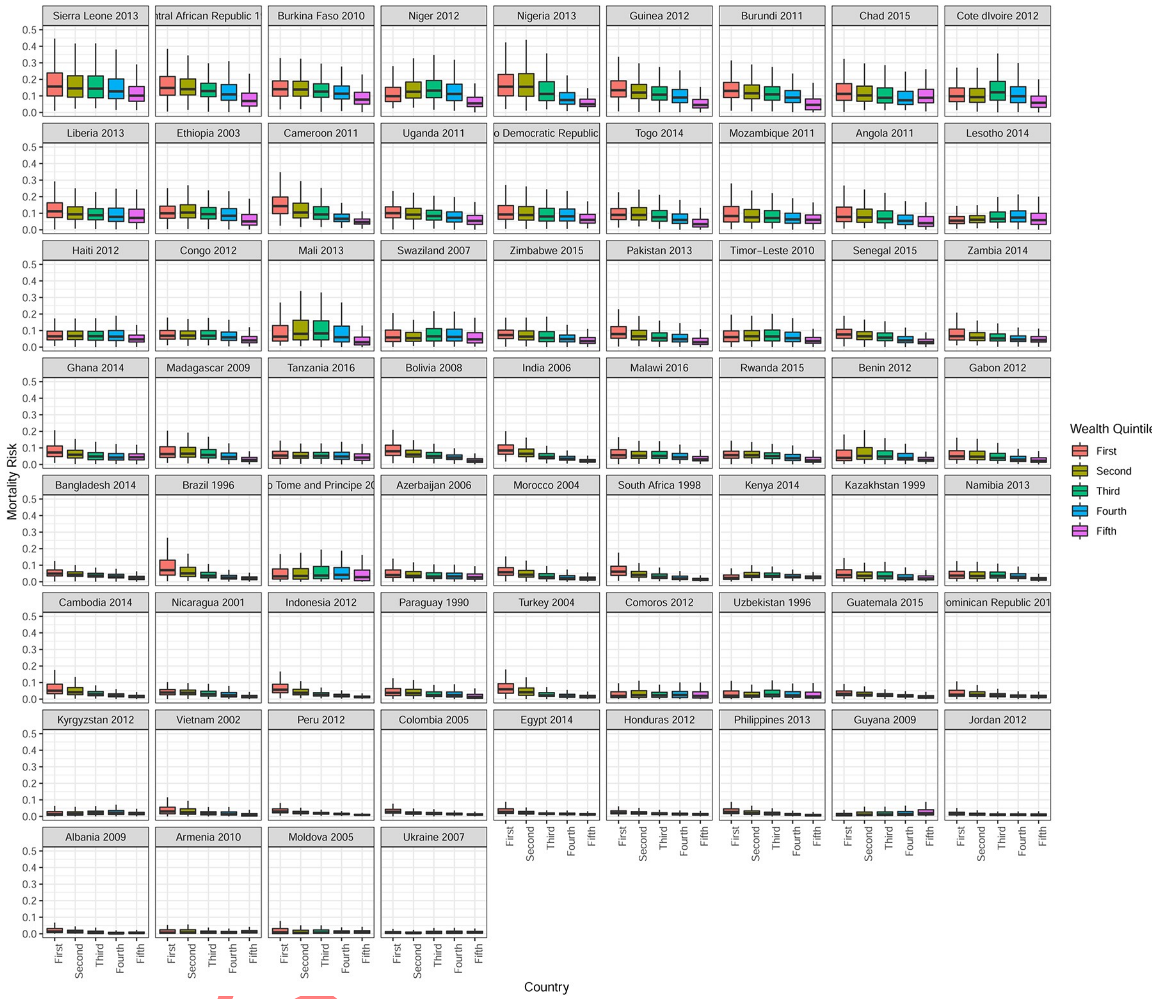

Fig 2. Box plots for mortality risk by wealth quintile, country, and survey. Countries are ranked from lowest to highest mortality. Lines are ±1.5 times interquartile range, boxes are lower to upper quartile, and dark line is the median mortality risk. Outliers are not shown.

https://doi.org/10.1371/journal.pone.0238847.g002

our approach is much more efficient in identifying high risk births than targeting the poor. Efficiency gains range from 26% in Mali (1996), to more than 550% in Guyana (2009). Efficiency gains are not strongly related to a country's average mortality rates.

3.4 Who are the highest risk children?

We define the high risk (low risk) births for a particular country and survey as those in the top 20% (bottom 80%) of all births in terms of mortality risk as estimated by our model. For each of the continuous (categorical) variables, we calculate means of the variable for high and low risk births and the difference (odds ratio). Results are presented in Tables 1-7 in S1 Appendix for the last survey in each country. Higher risk births have younger mothers on average compared to lower risk births, but the differences are not substantively important: mothers from low risk group are usually less than a year older than mothers from the high risk group. High risk and low risk groups are also comparable for birth gender. For maternal education, there is often a significant difference between high risk and low risk births, but the difference is not substantively important. There is on average less than a year of additional education for

Table 2. Results from ANOVA of posterior mean of mortality risk on wealth quintiles. Countries are ordered by median mortality risk. Mean, median, variance, and R^2 are presented as posterior means and 95% intervals.

Country	Mean	Median	Variance	R^2 (Wealth)
Overall	6.9% (6.8%, 6.9%)	4.0% (4.0%, 4.1%)	0.7% (0.7%, 0.7%)	3.3% (3.1%, 3.5%)
Sierra Leone 2013	15.7% (15.1%, 16.3%)	12.7% (12.0%, 13.3%)	1.3% (1.1%, 1.5%)	2.8% (1.3%, 4.7%)
Central African Republic 1995	14.0% (13.0%, 15.1%)	10.8% (9.8%, 12.0%)	1.5% (1.2%, 1.8%)	5.9% (2.7%, 10.3%)
Burkina Faso 2010	13.3% (12.8%, 13.8%)	11.4% (10.8%, 11.9%)	0.8% (0.7%, 0.9%)	5.5% (3.2%, 8.3%)
Niger 2012	12.3% (11.7%, 12.8%)	9.8% (9.2%, 10.4%)	0.9% (0.8%, 1.1%)	2.9% (1.3%, 4.9%)
Nigeria 2013	12.9% (12.6%, 13.3%)	9.9% (9.5%, 10.3%)	1.0% (0.9%, 1.1%)	17.4% (14.9%, 20.0%)
Guinea 2012	11.6% (11.0%, 12.4%)	9.1% (8.4%, 9.8%)	1.0% (0.8%, 1.2%)	7.7% (4.5%, 11.6%)
Burundi 2011	11.2% (10.4%, 12.0%)	8.5% (7.7%, 9.3%)	1.0% (0.8%, 1.3%)	8.7% (4.9%, 13.1%)
Chad 2015	11.6% (11.2%, 12.1%)	8.8% (8.4%, 9.3%)	0.9% (0.8%, 1.0%)	1.2% (0.3%, 2.3%)
Côte d'Ivoire 2012	11.5% (10.8%, 12.2%)	8.2% (7.5%, 9.0%)	1.1% (0.9%, 1.4%)	1.4% (0.2%, 3.2%)
Liberia 2013	10.6% (9.9%, 11.3%)	8.0% (7.4%, 8.6%)	0.9% (0.7%, 1.0%)	1.5% (0.2%, 3.6%)
Ethiopia 2003	10.2% (9.8%, 10.7%)	8.0% (7.5%, 8.5%)	0.7% (0.6%, 0.9%)	3.6% (1.7%, 6.0%)
Cameroon 2011	10.7% (10.1%, 11.3%)	7.8% (7.2%, 8.4%)	0.9% (0.7%, 1.1%)	13.6% (9.7%, 18.1%)
Uganda 2011	9.3% (8.7%, 9.9%)	7.0% (6.4%, 7.7%)	0.7% (0.6%, 0.9%)	3.8% (1.5%, 6.9%)
Congo Democratic Republic 2014	9.9% (9.4%, 10.4%)	7.5% (7.0%, 7.9%)	0.7% (0.6%, 0.8%)	2.5% (1.1%, 4.4%)
Togo 2014	8.7% (8.1%, 9.3%)	6.1% (5.5%, 6.7%)	0.8% (0.6%, 1.0%)	5.5% (2.7%, 8.8%)
Mozambique 2011	8.9% (8.4%, 9.5%)	6.1% (5.6%, 6.6%)	0.8% (0.7%, 1.0%)	2.2% (0.7%, 4.2%)
Angola 2011	8.8% (8.2%, 9.5%)	5.4% (4.8%, 6.0%)	1.0% (0.8%, 1.3%)	2.4% (0.6%, 4.8%)
Lesotho 2014	8.1% (7.3%, 9.0%)	4.6% (3.8%, 5.4%)	1.2% (0.9%, 1.5%)	0.4% (0.0%, 1.6%)
Haiti 2012	7.5% (6.9%, 8.0%)	5.2% (4.7%, 5.8%)	0.6% (0.5%, 0.8%)	0.6% (0.0%, 1.9%)
Congo 2012	7.5% (7.0%, 8.1%)	5.3% (4.8%, 5.8%)	0.6% (0.5%, 0.7%)	1.3% (0.1%, 3.1%)
Mali 2013	9.1% (8.6%, 9.7%)	5.4% (4.9%, 6.0%)	1.0% (0.9%, 1.2%)	2.6% (1.2%, 4.3%)
Eswatini 2007	8.6% (7.6%, 9.6%)	4.0% (3.3%, 4.9%)	1.7% (1.3%, 2.1%)	0.4% (0.0%, 1.5%)
Zimbabwe 2015	7.4% (6.8%, 8.0%)	4.5% (4.0%, 5.1%)	0.9% (0.7%, 1.1%)	3.0% (1.2%, 5.4%)
Pakistan 2013	7.1% (6.7%, 7.6%)	4.9% (4.5%, 5.4%)	0.5% (0.4%, 0.6%)	5.7% (3.2%, 8.7%)
Timor-Leste 2010	6.9% (6.4%, 7.4%)	4.7% (4.2%, 5.1%)	0.5% (0.4%, 0.6%)	1.8% (0.5%, 3.9%)
Senegal 2015	6.3% (5.9%, 6.7%)	4.8% (4.4%, 5.2%)	0.3% (0.3%, 0.4%)	7.6% (4.1%, 11.5%)
Zambia 2014	6.7% (6.3%, 7.1%)	4.5% (4.1%, 4.9%)	0.5% (0.4%, 0.6%)	2.9% (1.2%, 5.1%)
Ghana 2014	6.4% (5.9%, 7.0%)	4.1% (3.7%, 4.7%)	0.5% (0.4%, 0.7%)	2.8% (0.6%, 5.8%)
Madagascar 2009	6.7% (6.3%, 7.1%)	4.5% (4.1%, 4.9%)	0.5% (0.4%, 0.6%)	6.0% (3.7%, 8.9%)
Tanzania 2016	6.0% (5.5%, 6.4%)	4.1% (3.7%, 4.5%)	0.4% (0.3%, 0.5%)	0.3% (0.0%, 1.3%)
Bolivia 2008	6.1% (5.6%, 6.6%)	4.1% (3.6%, 4.5%)	0.5% (0.4%, 0.6%)	11.2% (7.6%, 15.4%)
India 2006	5.9% (5.7%, 6.1%)	4.3% (4.2%, 4.5%)	0.3% (0.2%, 0.3%)	22.7% (19.8%, 25.9%)
Malawi 2016	5.8% (5.5%, 6.2%)	4.2% (3.9%, 4.5%)	0.3% (0.2%, 0.4%)	3.4% (1.6%, 5.7%)
Rwanda 2015	5.3% (4.8%, 5.8%)	3.5% (3.1%, 4.0%)	0.4% (0.3%, 0.5%)	3.0% (0.9%, 6.0%)
Benin 2012	6.6% (6.2%, 7.0%)	3.6% (3.2%, 3.9%)	0.8% (0.6%, 0.9%)	2.1% (1.1%, 3.4%)
Gabon 2012	5.5% (4.9%, 6.1%)	2.7% (2.3%, 3.2%)	0.7% (0.6%, 0.9%)	2.3% (0.7%, 4.5%)
Bangladesh 2014	4.4% (4.1%, 4.7%)	3.2% (2.9%, 3.5%)	0.2% (0.2%, 0.3%)	6.4% (3.4%, 9.8%)
Brazil 1996	5.6% (5.1%, 6.1%)	2.7% (2.2%, 3.1%)	0.8% (0.6%, 1.0%)	9.9% (6.6%, 13.6%)
Sao Tome and Principe 2009	6.9% (6.0%, 8.0%)	1.9% (1.3%, 2.6%)	1.9% (1.4%, 2.3%)	0.2% (0.0%, 1.2%)
Azerbaijan 2006	5.0% (4.3%, 5.8%)	2.0% (1.5%, 2.7%)	0.9% (0.6%, 1.1%)	0.8% (0.0%, 2.4%)
Morocco 2004	4.6% (4.1%, 5.1%)	2.4% (2.0%, 2.8%)	0.5% (0.4%, 0.6%)	6.0% (3.0%, 9.5%)
South Africa 1998	4.4% (3.9%, 4.9%)	2.1% (1.7%, 2.5%)	0.5% (0.4%, 0.7%)	7.9% (4.7%, 11.8%)
Kenya 2014	4.0% (3.7%, 4.2%)	2.6% (2.4%, 2.8%)	0.2% (0.2%, 0.2%)	0.1% (0.0%, 0.5%)
Kazakhstan 1999	4.5% (3.8%, 5.3%)	1.8% (1.3%, 2.3%)	0.8% (0.5%, 1.0%)	1.7% (0.2%, 4.0%)
Namibia 2013	4.5% (4.0%, 5.0%)	2.0% (1.6%, 2.4%)	0.7% (0.5%, 0.9%)	1.8% (0.5%, 3.8%)

(Continued)

Table 2. (Continued)

Country	Mean	Median	Variance	R^2 (Wealth)
Cambodia 2014	4.5% (4.1%, 5.0%)	2.3% (2.0%, 2.6%)	0.5% (0.4%, 0.6%)	8.3% (5.5%, 11.6%)
Nicaragua 2001	3.6% (3.2%, 3.9%)	2.1% (1.8%, 2.4%)	0.2% (0.2%, 0.3%)	4.2% (1.9%, 7.4%)
Indonesia 2012	4.0% (3.7%, 4.3%)	2.2% (1.9%, 2.4%)	0.3% (0.2%, 0.4%)	13.7% (10.5%, 16.9%)
Paraguay 1990	4.1% (3.6%, 4.6%)	1.8% (1.5%, 2.2%)	0.5% (0.4%, 0.7%)	2.0% (0.5%, 4.2%)
Turkey 2004	4.5% (4.0%, 5.1%)	1.9% (1.5%, 2.3%)	0.6% (0.5%, 0.8%)	6.1% (3.3%, 9.7%)
Comoros 2012	4.1% (3.5%, 4.7%)	1.1% (0.8%, 1.5%)	0.8% (0.6%, 1.0%)	0.1% (0.0%, 0.6%)
Uzbekistan 1996	4.4% (3.7%, 5.1%)	1.3% (0.9%, 1.7%)	0.9% (0.7%, 1.2%)	0.1% (0.0%, 0.6%)
Guatemala 2015	2.9% (2.6%, 3.2%)	1.7% (1.5%, 1.9%)	0.2% (0.1%, 0.2%)	4.7% (2.4%, 7.5%)
Dominican Republic 2013	3.2% (2.8%, 3.7%)	1.3% (1.0%, 1.6%)	0.4% (0.3%, 0.6%)	2.5% (0.8%, 4.9%)
Kyrgyzstan 2012	2.8% (2.4%, 3.3%)	0.9% (0.6%, 1.3%)	0.5% (0.3%, 0.6%)	0.1% (0.0%, 0.6%)
Vietnam 2002	3.0% (2.5%, 3.4%)	1.0% (0.8%, 1.4%)	0.4% (0.3%, 0.5%)	2.1% (0.4%, 4.6%)
Peru 2012	2.3% (2.1%, 2.4%)	1.5% (1.4%, 1.6%)	0.1% (0.1%, 0.1%)	10.5% (7.4%, 14.3%)
Colombia 2005	2.2% (2.0%, 2.4%)	1.2% (1.0%, 1.4%)	0.1% (0.1%, 0.2%)	4.1% (2.1%, 6.6%)
Egypt 2014	2.5% (2.3%, 2.7%)	1.3% (1.1%, 1.5%)	0.2% (0.2%, 0.3%)	3.5% (1.8%, 5.7%)
Honduras 2012	2.2% (2.0%, 2.5%)	1.1% (0.9%, 1.3%)	0.2% (0.1%, 0.3%)	1.3% (0.3%, 2.8%)
Philippines 2013	2.5% (2.2%, 2.8%)	0.9% (0.7%, 1.2%)	0.3% (0.2%, 0.4%)	3.8% (2.0%, 5.7%)
Guyana 2009	3.1% (2.5%, 3.7%)	0.4% (0.1%, 0.7%)	0.9% (0.7%, 1.3%)	0.8% (0.1%, 1.9%)
Jordan 2012	1.7% (1.5%, 1.9%)	0.7% (0.5%, 0.8%)	0.2% (0.1%, 0.2%)	0.5% (0.0%, 1.5%)
Albania 2009	2.4% (1.9%, 2.9%)	0.1% (0.0%, 0.2%)	0.9% (0.6%, 1.2%)	1.0% (0.2%, 2.3%)
Armenia 2010	2.4% (1.9%, 3.1%)	0.1% (0.0%, 0.3%)	1.0% (0.7%, 1.3%)	0.5% (0.0%, 1.6%)
Moldova 2005	2.9% (2.3%, 3.6%)	0.0% (0.0%, 0.2%)	1.2% (0.7%, 1.7%)	0.3% (0.0%, 1.1%)
Ukraine 2007	1.8% (1.3%, 2.4%)	0.0% (0.0%, 0.2%)	0.7% (0.3%, 1.1%)	0.1% (0.0%, 0.6%)

https://doi.org/10.1371/journal.pone.0238847.t002

mothers from the low risk group. There is also often a statistical, but not substantive difference in birth order.

The most substantial differences between the higher and lower risk groups are for residency (urban/rural), wealth, and previous death of a sibling. High risk births are substantively poorer than the remaining 80% of the population. In Cambodia, high risk births average at the poorest 32nd percentile of wealth while the low risk births average around the 53rd percentile of wealth. We find similar results for other countries: Bolivia: 32% against 52%; Brazil: 31% against 53%; Peru: 30% against 53%; Nigeria: 32% against 53%.

High risk births are disproportionately born to mothers that have already experienced a prior death of another child. The odds ratio is 18.8 (13.1, 26.7) in Benin; 16.3 (10.9, 24.1) in Mali; and 15.4 (11.9, 19.9) in Nigeria. Even for relatively wealthier countries, the odds ratio for another death is high for mothers that have experienced a prior death. The only countries in which a prior death is not a significant risk factor for a subsequent birth are Moldova and Vietnam. Ukraine seems an exception, but the fractions of the births with a prior death are small, and this makes the odds ratio for Ukraine not very meaningful.

4 Discussion

In this study we have investigated inequality in under-5 mortality within and between socioeconomic groups for a large pool of LMIC. We have made three related contributions to the existing research. First, we show that for all 67 countries in our sample, most of the variability in mortality risk exists within socioeconomic groups, not between groups. Second, we show that within countries the average mortality risk—which is closely related to national averages

Table 3. Efficiency gains by targeting 20% highest risk as estimated from our model versus targeting the poorest 20%. The first column gives the country and year. The second column gives sample size per survey. The third column is under 5 mortality rate in the 20% poorest. The fourth column is the mortality rate in the 20% identified as having the highest mortality risk for each sample with 95% posterior intervals. Efficiency Gain is defined as (HRDeaths—PoorDeaths)/PoorDeaths. CAR is Central African Republic.

Country Year	Sample Size	Mortality Poor	Mortality High Risk	Efficiency Gains
Albania 2009	2,481	32%	86% (74%, 94%)	168% (132%, 195%)
Armenia 2000	2,602	22%	53% (47%, 59%)	144% (116%, 175%)
Armenia 2010	1,545	23%	77% (63%, 91%)	230% (170%, 290%)
Angola 2011	5,812	24%	44% (41%, 46%)	80% (69%, 89%)
Azerbaijan 2006	2,739	27%	49% (42%, 55%)	83% (59%, 107%)
Bangladesh 2000	9,061	26%	39% (36%, 40%)	50% (42%, 57%)
Bangladesh 2004	7,261	24%	38% (35%, 40%)	55% (44%, 65%)
Bangladesh 2007	6,929	25%	43% (40%, 45%)	69% (58%, 79%)
Bangladesh 2014	14,512	27%	40% (37%, 42%)	47% (39%, 56%)
Burkina Faso 1993	5,514	19%	31% (29%, 33%)	61% (51%, 70%)
Burkina Faso 1999	5,702	21%	30% (28%, 31%)	39% (32%, 46%)
Burkina Faso 2003	12,060	20%	33% (32%, 34%)	69% (62%, 74%)
Burkina Faso 2010	16,759	23%	35% (33%, 36%)	52% (47%, 57%)
Benin 1996	5,386	22%	32% (31%, 34%)	47% (39%, 55%)
Benin 2001	5,691	26%	34% (32%, 36%)	33% (26%, 41%)
Benin 2006	16,984	22%	35% (34%, 36%)	57% (52%, 63%)
Benin 2012	12,904	21%	51% (49%, 53%)	139% (129%, 148%)
Bolivia 1998	9,334	29%	42% (40%, 45%)	48% (40%, 55%)
Bolivia 2004	10,546	25%	42% (40%, 44%)	67% (58%, 75%)
Bolivia 2008	10,048	29%	42% (40%, 45%)	46% (37%, 55%)
Brazil 1996	6,023	34%	51% (47%, 55%)	50% (40%, 62%)
Burundi 2011	6,016	25%	38% (35%, 40%)	54% (45%, 64%)
Cambodia 2000	12,071	27%	39% (38%, 41%)	47% (42%, 53%)
Cambodia 2011	7,258	28%	47% (43%, 49%)	64% (53%, 74%)
Cambodia 2014	8,272	31%	51% (48%, 54%)	67% (56%, 77%)
CAR 1995	4,429	25%	36% (34%, 39%)	46% (35%, 54%)
Chad 1997	6,941	15%	34% (33%, 36%)	133% (123%, 143%)
Chad 2004	6,260	18%	34% (33%, 36%)	93% (83%, 102%)
Chad 2015	18,985	22%	39% (38%, 40%)	77% (72%, 82%)
Congo 2005	4,419	23%	40% (38%, 42%)	74% (63%, 85%)
Congo 2012	7,597	22%	39% (36%, 41%)	74% (63%, 84%)
Côte d'Ivoire 1999	2,757	25%	42% (39%, 45%)	73% (60%, 84%)
Côte d'Ivoire 2005	3,812	22%	38% (35%, 41%)	70% (56%, 83%)
Côte d'Ivoire 2012	7,224	21%	40% (38%, 42%)	94% (85%, 104%)
Cameroon 1991	3,140	26%	41% (39%, 44%)	57% (46%, 67%)
Cameroon 1998	4,080	30%	43% (40%, 45%)	43% (34%, 51%)
Cameroon 2004	7,535	26%	40% (38%, 41%)	52% (46%, 58%)
Cameroon 2011	10,812	29%	39% (38%, 41%)	35% (30%, 41%)
Colombia 1990	4,087	34%	63% (56%, 70%)	86% (65%, 105%)
Colombia 1995	5,041	30%	56% (49%, 62%)	90% (66%, 112%)
Colombia 2005	15,630	32%	51% (46%, 57%)	58% (43%, 76%)
Comoros 1996	2,208	22%	42% (38%, 46%)	93% (75%, 111%)
Comoros 2012	3,390	18%	57% (51%, 62%)	223% (190%, 253%)
DRC 2007	7,971	24%	40% (39%, 42%)	70% (64%, 76%)
DRC 2014	15,132	22%	39% (37%, 40%)	74% (68%, 81%)

(*Continued*)

Table 3. (Continued)

Country Year	Sample Size	Mortality Poor	Mortality High Risk	Efficiency Gains
DR 1999	3,250	26%	50% (46%, 55%)	97% (78%, 116%)
DR 2002	12,941	32%	49% (45%, 52%)	50% (40%, 61%)
DR 2007	13,945	26%	46% (42%, 50%)	77% (61%, 93%)
DR 2013	4,782	30%	51% (45%, 56%)	67% (48%, 85%)
Egypt 1996	12,791	30%	41% (40%, 43%)	40% (35%, 46%)
Egypt 2003	11,850	30%	49% (46%, 52%)	64% (54%, 72%)
Egypt 2008	11,394	32%	51% (46%, 55%)	59% (46%, 72%)
Egypt 2014	14,486	29%	52% (48%, 56%)	78% (64%, 91%)
Eswatini 2007	2,421	22%	47% (42%, 51%)	111% (91%, 129%)
Ethiopia 1997	12,984	18%	38% (36%, 39%)	109% (101%, 116%)
Ethiopia 2003	13,218	22%	38% (37%, 40%)	79% (71%, 86%)
Gabon 2001	3,783	20%	43% (39%, 47%)	111% (93%, 129%)
Gabon 2012	5,149	26%	48% (44%, 52%)	84% (70%, 98%)
Ghana 1994	3,281	24%	42% (40%, 46%)	77% (65%, 90%)
Ghana 1999	3,226	23%	42% (39%, 45%)	84% (69%, 98%)
Ghana 2003	4,134	25%	41% (38%, 44%)	63% (52%, 75%)
Ghana 2008	3,258	25%	44% (40%, 49%)	81% (64%, 99%)
Ghana 2014	6,370	27%	41% (37%, 44%)	53% (40%, 64%)
Guinea 1999	6,867	24%	32% (30%, 34%)	32% (26%, 39%)
Guinea 2005	7,807	22%	33% (31%, 34%)	48% (42%, 54%)
Guinea 2012	8,010	26%	37% (35%, 39%)	45% (38%, 52%)
Guatemala 1999	7,083	23%	42% (38%, 45%)	81% (68%, 95%)
Guatemala 2015	11,719	28%	46% (43%, 49%)	66% (54%, 79%)
Guyana 2005	1,268	14%	86% (76%, 93%)	525% (450%, 575%)
Guyana 2009	2,464	10%	68% (59%, 77%)	578% (489%, 667%)
Honduras 2006	12,380	23%	43% (39%, 46%)	88% (72%, 102%)
Honduras 2012	10,065	26%	50% (44%, 55%)	93% (71%, 113%)
Haiti 1995	3,020	24%	40% (37%, 43%)	65% (53%, 75%)
Haiti 2000	7,063	23%	36% (34%, 38%)	56% (48%, 64%)
Haiti 2006	5,907	26%	41% (39%, 44%)	60% (49%, 70%)
Haiti 2012	6,944	20%	40% (37%, 43%)	102% (88%, 116%)
India 1993	65,681	29%	41% (41%, 42%)	45% (42%, 47%)
India 2000	53,079	30%	39% (38%, 39%)	31% (29%, 33%)
India 2006	59,240	32%	43% (42%, 44%)	35% (32%, 38%)
Indonesia 1997	23,155	26%	46% (45%, 48%)	79% (73%, 85%)
Indonesia 2003	16,049	31%	51% (48%, 53%)	65% (57%, 73%)
Indonesia 2007	20,592	34%	49% (48%, 51%)	44% (39%, 49%)
Indonesia 2012	19,788	35%	52% (49%, 54%)	46% (39%, 53%)
Jordan 1990	9,308	28%	47% (44%, 51%)	67% (55%, 79%)
Jordan 1997	6,408	27%	54% (50%, 59%)	100% (84%, 119%)
Jordan 2002	7,098	23%	48% (43%, 53%)	108% (88%, 130%)
Jordan 2009	13,691	23%	52% (47%, 56%)	123% (104%, 141%)
Jordan 2012	11,205	26%	54% (48%, 59%)	106% (84%, 128%)
Kenya 1993	6,514	29%	45% (42%, 48%)	55% (46%, 65%)
Kenya 1998	5,789	28%	51% (48%, 53%)	83% (73%, 93%)
Kenya 2009	5,412	20%	48% (45%, 51%)	136% (120%, 150%)
Kenya 2014	23,924	16%	44% (42%, 46%)	179% (166%, 192%)

(*Continued*)

Table 3. (Continued)

Country Year	Sample Size	Mortality Poor	Mortality High Risk	Efficiency Gains
Kazakhstan 1999	2,651	25%	50% (43%, 56%)	103% (76%, 127%)
Kyrgyzstan 1997	2,400	27%	52% (46%, 57%)	92% (71%, 110%)
Kyrgyzstan 2012	3,705	19%	53% (45%, 60%)	184% (141%, 223%)
Liberia 2009	6,871	22%	36% (35%, 38%)	65% (57%, 73%)
Liberia 2013	8,220	24%	37% (36%, 39%)	59% (51%, 66%)
Lesotho 2005	3,115	23%	46% (42%, 51%)	103% (85%, 123%)
Lesotho 2010	3,107	17%	45% (41%, 50%)	160% (134%, 185%)
Lesotho 2014	3,250	17%	44% (39%, 48%)	158% (133%, 184%)
Morocco 1992	5,422	27%	39% (36%, 42%)	46% (35%, 57%)
Morocco 2004	6,493	30%	49% (45%, 53%)	63% (50%, 76%)
Moldova 2005	1,744	21%	88% (72%, 96%)	317% (244%, 358%)
Madagascar 1997	5,960	19%	36% (34%, 38%)	93% (83%, 103%)
Madagascar 2004	5,268	30%	45% (42%, 48%)	50% (40%, 59%)
Madagascar 2009	12,686	25%	43% (41%, 45%)	73% (64%, 81%)
Mali 1996	9,960	24%	30% (29%, 31%)	26% (22%, 30%)
Mali 2001	13,031	21%	32% (31%, 33%)	56% (52%, 59%)
Mali 2006	15,201	23%	33% (32%, 34%)	45% (41%, 49%)
Mali 2013	9,249	21%	47% (45%, 48%)	122% (113%, 131%)
Malawi 1992	4,746	21%	34% (33%, 36%)	62% (54%, 69%)
Malawi 2005	9,663	24%	34% (32%, 35%)	42% (35%, 48%)
Malawi 2010	20,677	22%	34% (33%, 35%)	53% (47%, 58%)
Malawi 2016	16,793	24%	41% (39%, 43%)	70% (61%, 77%)
Mozambique 1997	6,834	23%	39% (38%, 41%)	72% (65%, 78%)
Mozambique 2004	8,942	19%	36% (34%, 37%)	91% (83%, 99%)
Mozambique 2011	10,379	24%	42% (40%, 44%)	77% (69%, 85%)
Nicaragua 1998	8,665	20%	46% (43%, 49%)	131% (115%, 147%)
Nicaragua 2001	9,008	23%	43% (40%, 47%)	87% (72%, 103%)
Nigeria 1990	8,696	25%	43% (42%, 45%)	70% (65%, 75%)
Nigeria 2003	5,848	22%	36% (34%, 37%)	61% (54%, 67%)
Nigeria 2008	30,182	24%	37% (36%, 37%)	55% (52%, 58%)
Nigeria 2013	34,186	26%	40% (39%, 41%)	56% (53%, 58%)
Niger 1998	7,644	18%	32% (31%, 33%)	81% (75%, 86%)
Niger 2006	9,820	17%	35% (33%, 36%)	106% (98%, 114%)
Niger 2012	13,573	20%	37% (36%, 39%)	84% (77%, 89%)
Namibia 1992	3,692	22%	46% (43%, 49%)	104% (91%, 118%)
Namibia 2000	4,354	23%	55% (50%, 59%)	138% (119%, 157%)
Namibia 2007	4,668	29%	50% (46%, 54%)	73% (59%, 87%)
Namibia 2013	4,691	22%	51% (46%, 56%)	130% (108%, 152%)
Pakistan 1991	8,356	20%	46% (45%, 48%)	129% (120%, 138%)
Pakistan 2007	9,531	26%	47% (44%, 49%)	78% (69%, 87%)
Pakistan 2013	11,854	26%	42% (40%, 44%)	64% (56%, 71%)
Peru 1992	9,085	27%	44% (42%, 46%)	66% (58%, 74%)
Peru 1996	19,554	28%	42% (40%, 44%)	51% (45%, 58%)
Peru 2000	17,334	29%	42% (40%, 44%)	48% (41%, 54%)
Peru 2008	13,739	30%	45% (41%, 49%)	48% (35%, 60%)
Peru 2012	31,443	32%	44% (41%, 46%)	35% (27%, 42%)

(*Continued*)

Table 3. (Continued)

Country Year	Sample Size	Mortality Poor	Mortality High Risk	Efficiency Gains
Paraguay 1990	4,375	22%	48% (43%, 53%)	118% (96%, 139%)
Philippines 1993	9,340	27%	48% (46%, 51%)	78% (68%, 87%)
Philippines 1998	8,361	27%	50% (46%, 53%)	84% (72%, 97%)
Philippines 2003	7,863	33%	53% (49%, 58%)	63% (50%, 77%)
Philippines 2008	7,480	29%	54% (50%, 58%)	83% (70%, 97%)
Philippines 2013	8,159	32%	56% (51%, 61%)	77% (62%, 92%)
Rwanda 1992	6,071	18%	37% (35%, 38%)	99% (90%, 109%)
Rwanda 2005	9,139	22%	34% (32%, 35%)	52% (46%, 58%)
Rwanda 2008	4,865	18%	43% (41%, 45%)	143% (130%, 156%)
Rwanda 2015	8,096	24%	41% (38%, 45%)	74% (60%, 88%)
Sierra Leone 2008	6,413	23%	40% (38%, 42%)	71% (63%, 78%)
Sierra Leone 2013	13,981	22%	36% (35%, 37%)	64% (59%, 69%)
Senegal 1997	7,311	24%	34% (32%, 36%)	41% (33%, 49%)
Senegal 2005	10,284	26%	36% (34%, 37%)	36% (30%, 42%)
Senegal 2009	13,229	24%	36% (34%, 37%)	49% (43%, 55%)
Senegal 2015	12,606	27%	38% (36%, 40%)	45% (37%, 52%)
Sao Tome and Principe 2009	1,685	19%	54% (48%, 60%)	181% (150%, 212%)
Togo 1998	7,211	22%	33% (32%, 35%)	51% (43%, 58%)
Togo 2014	6,901	24%	40% (38%, 43%)	70% (60%, 80%)
Timor-Leste 2010	9,499	22%	42% (39%, 44%)	87% (76%, 97%)
Turkey 1993	4,998	33%	49% (45%, 52%)	47% (38%, 56%)
Turkey 1998	4,162	31%	51% (46%, 56%)	64% (48%, 78%)
Turkey 2004	4,765	30%	51% (47%, 55%)	68% (54%, 81%)
Tanzania 1999	6,715	20%	36% (33%, 37%)	81% (70%, 90%)
Tanzania 2005	7,200	23%	36% (34%, 38%)	55% (46%, 63%)
Tanzania 2010	11,262	25%	38% (36%, 40%)	54% (47%, 61%)
Tanzania 2016	8,745	21%	40% (37%, 42%)	86% (73%, 99%)
Ukraine 2007	1,494	19%	87% (65%, 100%)	350% (233%, 417%)
Uganda 1995	6,244	25%	35% (33%, 37%)	43% (35%, 51%)
Uganda 2001	5,933	25%	36% (34%, 38%)	46% (37%, 55%)
Uganda 2010	5,912	24%	36% (34%, 38%)	47% (38%, 56%)
Uganda 2011	7,852	24%	37% (35%, 39%)	57% (47%, 65%)
Uzbekistan 1996	2,656	24%	55% (50%, 60%)	129% (109%, 153%)
Vietnam 2002	4,060	29%	54% (47%, 59%)	83% (61%, 102%)
South Africa 1998	5,564	33%	48% (44%, 53%)	45% (31%, 58%)
Zambia 1997	5,614	23%	35% (34%, 37%)	52% (45%, 61%)
Zambia 2002	6,027	24%	35% (33%, 37%)	46% (39%, 55%)
Zambia 2007	5,808	16%	36% (34%, 38%)	122% (108%, 135%)
Zambia 2014	12,324	26%	42% (39%, 44%)	61% (51%, 69%)
Zimbabwe 1994	4,622	21%	47% (43%, 50%)	122% (103%, 141%)
Zimbabwe 1999	3,713	21%	50% (46%, 54%)	135% (115%, 153%)
Zimbabwe 2006	4,357	19%	46% (41%, 50%)	137% (112%, 162%)
Zimbabwe 2011	4,374	20%	49% (45%, 54%)	146% (124%, 168%)
Zimbabwe 2015	5,726	25%	44% (41%, 46%)	72% (61%, 82%)

https://doi.org/10.1371/journal.pone.0238847.t003

of child mortality—is far from the typical (modal) mortality risk experienced by most births. Third, we show that poverty status alone, while important, is a poor proxy for being at the higher risk of an an early death than the general population. All these findings have important policy implications. In addition, we have developed new methods to analyse inequality in mortality risk which have broad applicability.

While quantifying inequality in under-5 mortality between socioeconomic groups is important it misses a larger within-group inequality. In particular, we have shown that for most countries socioeconomic group explains less than 5% of the total variability in mortality. Even in countries where socioeconomic inequality matters the most, socioeconomic group explains very little of the variation in U5MR. For example, socioeconomic status explains 11% of U5MR in Bolivia and 22% in India. This means that there is a large overlap in mortality risk among births from different socioeconomic groups and, as a consequence, there is a large a number of high risk individuals outside that poorest group. In addition, being born to a particular country does not predict your mortality risk very well, which means that between country comparisons also miss most of the variability in mortality risk.

In addition of being incomplete, between country comparisons are often done in terms of average level of child mortality. However, we show that countries' distributions of mortality risk are right skewed because some births experience substantially higher mortality risk than the national averages. These are left behind populations who are largely unnoticed when we only look at average mortality in socioeconomic groups. The typical modal mortality rate in each country is very different from the national averages of child mortality. Thus between-country comparisons using national averages are not comparing typical mortality levels between countries.

Finally, most equity based policy strategies that target births are based on a single risk factor, usually poverty status. However, efficiency gains from targeting the 20% highest risk births versus the 20% poorest are substantively important for all countries that we have data for, with efficiency gains ranging from 26% in Mali (1996), to more than 550% in Guyana (2009), likely due to the fact that it is one of the few countries with an apparent decrease in mortality risk with increasing wealth. Although the 20% highest risk births are usually the poorest and from rural areas, as might be expected, including other risk factors and their interactions considerably improves the identification of left behind individuals.

One previously overlooked characteristic is the importance of having experienced a prior death of a child. [28, 29] This is likely the case because this variable represents several unmeasured risk factors at the maternal level. However, it is an observable variable and can be the object of policy targeting. And it should be used to do so. We find that this is a particularly important characteristic for Sub-Saharan Africa countries in our sample. For these countries, just targeting mothers that have already experienced the death of a child could be an effective way to reach high risk populations.

Taken together these results support the view that measuring national averages of under-5 mortality is insufficient to identify left behind groups. [5, 30–34] The concerns raised by United Nations General Assembly Resolution 68/261 are real and important, and we have shown that policy makers and international agencies should routinely implement disaggregation of inequality measures by several demographic variables simultaneously. [4] However, our findings suggest that monitoring inequality between socioeconomic groups of births may not enable policy makers to accurately identify many left behind children. We recommend using nationally representative surveys or administrative data to estimate mortality risk at the individual level to identify left behind populations that can be the target of interventions. We also recommend our methods to properly quantify and monitor high risk populations.

Our findings should not be interpreted as recommending against targeting the poor. Poverty *alone* is not the best guide for equity based policies because other risk factors are also important. Poverty status needs to be combined with other available information to identify high risk births. This is important for both low and high mortality countries, because children in need are spread out across socioeconomic groups. Further, since high risk children tend to be poor and from rural areas, most interventions that work for the poorest children will probably work for the highest risk children. Thus we are not suggesting major changes in interventions targeting high risk populations. Instead, we are proposing a new methodology that combines information from multiple well known risk factors simultaneously to identify high risk births. Our approach considers interactions among risk factors that are readily available for LMIC via nationally representative health surveys, and frees researchers and policy makers from having to decide which risk factors capture most of the inequality in each country-year.

The methods developed in this paper have broader applicability and are flexible enough to be applied to a number of different scenarios. For example, some countries with good vital registration system could use their administrative data instead of surveys. When people wish to implement an intervention in a particular country, our methodology points the way to a more targeted and impactful intervention. Implementers will need to choose variables, and they may choose different predictors than we have chosen, depending on data available and political and medical considerations. This is acceptable and something we consider a necessary part of implementing our methods in practice.

Our recommendations are also related to a large body of literature in medicine and public health that develops risk scores for individuals to identify those at risk of some event. These scores have been applied to a variety of outcomes and our results suggest the possible usefulness of such scores for identification of high risk children. [35] Our approach requires representative surveys of the population, such as DHS or Multiple Indicator Cluster Surveys (MICS) so that we can rank children by mortality risk based on demographics. Policy makers could use mobile apps, which are now widely used for data collection, to collect and combine information on the children, calculate their risk, and then check whether their score is above or below a pre-determined threshold. We would not suggest a single risk score for the entire world. Rather, we would develop a score for each country, and we would update the score as new data became available.

The calculus of the efficiency gains assumes that interventions have the same costs for each birth. In reality, costs need to be adjusted according to local conditions. However, our approach provides a baseline to which any other allocation algorithm should be compared. Every comparison allocation scheme also needs to accommodate costs, not just our allocation scheme. For example, targeting the poor is likely easier in urban settings than in rural settings, and this would be a differential cost for the simple "intervene with the poor" intervention. It is possible to incorporate costs; one would multiply estimated probability of mortality times cost, then follow our same procedure to identify a combination of cheapest and most at risk to intervene with, until the budget had been spent. Instead of identifying the 20% most at risk, one would tabulate costs until the allocation funds had been spent. No matter differential costs, combining information from multiple observable risk factors better identifies high risk populations. Having identified higher risk populations, public health officials can then work to bring down costs, and best target at-risk births.

Our methodology has not explicitly included the complex sampling design from the DHS. We did this to create a more parsimonious set of methodological innovations. We treated DHS samples as a random sample. However, we have included all variables used to stratify the surveys, which implicitly incorporates some of the sample design in our analysis. Future research should explicitly incorporate survey design.

In conclusion, our results show that despite progress toward reducing national averages of under-5 mortality, we still have substantial inequality within groups of births defined by commonly used stratifiers that measure progress toward SDG's. Our results suggest that researchers and policy makers should also quantify inequality in mortality risk within groups of births in addition to between-groups comparisons. Quantifying both between and within group inequality helps us to have an accurate picture of inequality in under-5 mortality and to identify left behind populations that otherwise cannot be easily identified.

Supporting information

S1 Appendix. [36].
(PDF)

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