

Factors contributing to child mortality reductions in 142 low- and middle-income countries between 1990 and 2010

Running Head: Factors contributing to lower U5MR

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Author Contributions

DB designed the study and set up the statistical platform. DB, RC, and NA ran the statistical analysis. All authors participated in interpreting the findings and drafting the report.

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Competing Interests

None of the authors have competing interests.

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Abstract (299 words)

Background

Since 1990, child mortality has declined by 41% worldwide, with Millennium Development Goal (MDG) 4 requiring a 75% reduction overall by 2015. This paper compares two possible sources of progress: improvements in levels of health interventions, social and environmental determinants (health determinants) versus improvements in their efficacy.

Methods

Using the Oaxaca Blinder method, an econometric method used to compare the effects of different contributing characteristics, this paper decomposes the progress made by 142 low- and middle- income countries (LMICs) as $\Delta U5MR = C + \Delta\beta X + \beta\Delta X$. X is a vector of health determinants and β is a vector of coefficients. We estimate $\Delta\beta X$ and $\beta\Delta X$ for each LMIC for 1990 to 2010 to account for the share of $\Delta U5MR$ of each component. We interpret $\Delta\beta X$ as improvement in the efficacy of health determinants and $\beta\Delta X$ as improvement in the levels across countries.

Findings

Reductions in U5MR since 1990 were due primarily to changes in levels of health determinants, more than changes in their efficacy or impact. The relative share of overall improvement attributable to any single factor varies by country and by model specification, but in all cases improvements across different sectors each contributed significantly to overall progress. Furthermore, regardless of the statistical model, all countries consistently showed that improvements in the factor levels accounted for more than 80% of progress and improvements in the efficacy or strength of coefficients less than 20%.

Conclusions

Overall, countries improved child health from 1990 to 2010 through improvements in the levels of a broad array of health system, social, economic and environmental determinants of child health. These findings align with the post-2015 development agenda that builds on the lessons from the MDGs and highlights the importance of promoting health and sustainable development in a more integrated manner across sectors.

Background (535 words)

Millennium Development Goal (MDG) 4 is to reduce child mortality by two thirds by 2015. Child mortality has decreased by 41% worldwide since 1990, but the pace of reduction has varied across countries and 6.6 million children continue to die every year from preventable causes. Many papers have been devoted to measuring progress[1-5], which is not correlated with the absolute level of U5MR burden. Rather, countries with similar geography, wealth and U5MR levels have shown wide differences in child health progress over the last 40 years, likely due to differing policies and sociocultural context[6]. Several studies have been devoted to systematically accounting for past progress [7-10]. The relationship of child health improvements to the alleviation of poverty has long been recognized [11]. Other key social determinants of health include better schooling [10], good governance [8], clean water [12], and less inequality [13].

The impact of health interventions and social and environmental determinants (health determinants) of child health has been known to vary over time [14]. Because progress in lowering child mortality has been paralleled by progress in schooling, poverty reduction, and progress in health technology it is difficult to attribute the observed patterns of progress to specific factors. Nevertheless, there are two possible general explanations for the decline in child mortality. Firstly, the impact of existing levels of health determinants may have increased since 1990. For example, if improved vaccines are introduced, existing immunization coverage rates will have a higher yield than before. Secondly, progress in mortality reduction can simply reflect improvements in the absolute levels of the determinants of health without invoking technological improvements in their basic efficacy.

By examining country performance in child health over the past twenty years we can assess some of the major factors responsible for progress in child health. Our goal in this paper is to assess how much of the world's progress on MDG 4 has been due to increased levels of well-known determinants of child health and how much progress has been due to changes in the impact of these determinants over the last twenty years. We decompose the magnitude of the observed improvement due to each of these possible explanations.

Methods (1068)

We examined the under-5 mortality rate (U5MR) as the outcome variable since it is used by the UN to monitor progress towards MDG 4. U5MR is the probability per 1,000 live births that a newborn baby will die before reaching age five, if subjected to current age-specific mortality rates.[15] We did our analysis on both the Inter-agency Group for Child Mortality Estimation (IGME) and the Institute for Health Metrics and Evaluation (IHME) Global Burden of Disease Study data.[16,17] The correlation between IHME and IGME U5MR values is .98 and the decomposition findings are the same for both sources (see results). Results shown are based on IHME's U5MR estimates.

An important advantage of using U5MR is that it is the same outcome that is being used to measure progress on the MDGs by each country. However, because many countries do not have complete vital registration data the value of U5MR for some countries is not actually measured by counting deaths. IHME and IGME use models to derive U5MR estimates for many countries and therefore U5MR is not a random variable. This means that in a regression of $U5MR=C+\beta X+\varepsilon$, any conventional test of statistical significance for β is not valid. For more details about how IHME estimates are fit see the appendix methods. Throughout this paper we recognize this limitation and we do not attempt to make claims that any single regression coefficient in analysis of U5MR measures or signifies causal connection to U5MR. The imputed observations in data on U5MR will disallow us from claiming that the coefficient for one independent variable is meaningfully larger than the coefficient on another independent variable or is

meaningfully larger than zero. Constructed data like the modeled U5MR series simply cannot be used this way and we do not try to. However, statistical significance of coefficients is not relevant to our effort in accounting for change from factor growth vs factor impact. In this analysis, the statistical significance of various determinants of health is not the question. We will be studying health determinants of health that have already been linked to population health in other studies. The central question in our decomposition analysis rests mostly on how much the levels of the health determinants themselves have changed over time. We refer to regression models to assess how much all of the beta coefficients in models of U5MR have changed between over 20 years instead of finding out the size of a particular coefficient.

An alternative approach to support our decomposition would have been to base the study of U5MR determinants on the overlapping years of discordant raw survey estimates of child death underlying the IHME and UN Interagency Group's models. This approach was rejected because it would require drawing inferences about child health measures that are of less interest to policy makers. The survey based reports of annual mortality have not been accepted as the official measure for tracking progress in child health. Given that the official measure for tracking MDG 4 is drawn from a model-based estimate, we need to analyze the behavior of this estimate in order to inform policymakers.

Analysis included all countries classified as low- or middle-income in 2000 (GDP per capita > \$9,266). We examined the decline in U5MR in these countries over two time periods: 1990-2010 and 2000-2010. We scanned many different sources to collect data for over 250 health determinants to potentially use in this analysis. Our final baseline model for both 1990-2010 and 2000-2010 included the following variables, all of which have theoretical and empirical support: GDP per capita, percent of the population with access to clean water,[18-21] percent of children under 2 who received the measles vaccine, [19,22-24] percent of girls enrolled in primary school lagged by 10 years,[9,25,26] total fertility rate,[18,19,27,28] percent of births attended by a skilled birth attendant,[19,22,29], Gini coefficient, and percent of national parliament seats held by women. For details about selection criteria for independent variables see the appendix methods. Completeness of the dataset varied by indicator, see Table 1. All GDP figures are in constant 2000 USD. For those independent variables lacking complete data, simple regression imputation was used to fill in missing data, using ordinary least squares regression (OLS) to predict the missing independent variables against log GDP per capita, year, UN subregion, urbanization, total fertility rate (TFR), log population, and ethnic fractionalization.[30] More details are in Appendix A.

Procedures

The conceptual model is that U5MR decline occurs as a result of A) Changes in the levels of factors that contribute to U5MR decline; B) Changes in the impact of these factors making them more or less important over time; and C) The interaction of changes in both levels and their impact. We apply Oaxaca-Blinder (OB) decomposition to decompose the changes in U5MR between 1990 and 2010, and between 2000 and 2010, into the sum of each of these three components [31,32]. The interaction term was usually small, but for this analysis was considered to be a component of impact. The OB method works for linear models of outcomes that have a normal distribution, but the distribution of U5MR values is non-negative and skewed to have a long right tail. In order to apply the method the log of U5MR was used in all models. The analysis was done in Stata 12 using the add-in `oaxaca.ado` commands [33]. For details about how the Oaxaca-Blinder decomposition method avoids potential problems caused by the nonrandom U5MR dependent variable see the appendix methods.

Sensitivity Analysis

In sensitivity analysis alternative models were estimated that did not transform U5MR, but did decomposition based on zero truncated Poisson models using `nldecompose.ado` [33]. The analysis uses population weighting and also tests weighting by the number of births. Both weighting schemes generate roughly similar conclusions (Appendix B Table 3).

To test whether governance and per capita GDP growth were highly collinear with other determinants of health, we employed ordinary least squares regression. We used the absolute increase in the factor level as the dependent variable and four independent variables: average annual GDP per capita growth since 1990, starting GDP per capita in 1990 (or the earliest year available), improvement in government effectiveness from 1996-2010 (the only available years), and starting government effectiveness index in 1996. We ran these regressions using all countries in the dataset, as well as the subset of Countdown to 2015[1] countries.

For the Oaxaca-Blinder analysis, we estimated 32 models for 1990-2010 and 37 models for 2000-2010. Indicators within a given policy area were iteratively exchanged one at a time for another in the given policy area, and the OB decomposition was recalculated. For details see Appendix C.

RESULTS (912)

There were 142 countries with 2000 GDP per capita < \$9,266 and reported values of U5MR in the analysis. The population weighted average U5MR for this group of countries was 78 (Min 13-Max 297) in 1990 and 46 (Min 4-Max 180) in 2010. Thus there was a population-weighted drop of 32 deaths per 1000 in U5MR in 20 years.

The relationship between income and health is well-documented and intuitive. Figure 1 shows an apparently tight relationship between Log GDP per capita and Log U5MR. Every country in the world except perhaps Equatorial Guinea (GNQ) and Serbia (SRB) falls along a linear relationship, with a correlation coefficient of -0.79. The slope of the curve stayed roughly the same but shifted downward from 1990-2010, likely due to improved leveraging of existing resources over time.

The social factors associated with reductions in child mortality showed large improvements from 1990 to 2010 (Table 1). The most significant changes were increases in health service delivery with a 111% increase in the log odds of skilled birth attendance, and a 92% increase in the log odds of children receiving measles vaccine. Indeed, the level of a wide variety of known child health determinants have improved significantly since 1990, and have increased faster in countries which have shown greater child health improvements (Appendix C Figure 1).

Table 2 suggests that the strength of the association between U5MR and its health determinants is not shifting substantially. Although the magnitude of the impact of the various factors changed slightly, only the change in the impact of skilled birth attendance was statistically significant.

In answer to the central question of our study, Table 3 shows that the levels of factors were mostly responsible for the improvement in U5MR. If all of the factors changed their impact by the amounts shown in Table 3 and the levels of factors did not change between 1990 and 2010 it would have led to only 20% of the U5MR improvement actually observed. Most of this improvement was due simply to the passage of time, as countries experienced social and economic development. Correspondingly, if the impact per unit of the factors remained fixed at 1990 levels, the true increases in the factors alone would have reduced U5MR by 80% of the total observed improvement. In comparison to IGME's U5MR data, U5MR would have reduced by 76% and no single factor dominates either analysis. The slight

difference in results is attributed to the differences between UN IGME and IHME estimates for U5MR.[34] For a table comparing IGME and IHME results see appendix results.

Figure 2 shows one of the many specifications attributing the observed U5MR decline to the contribution of various factors. This figure must be interpreted with caution. Different specifications produce slight shifts in the proportion of decline accounted for by each variable. Subject to these limitations, we note that in the presence of other health determinants, that growth in GDP per capita accounts for just 11% of factor-level-related gains in child health since 1990. Meanwhile, declines in fertility rates, the rise in access to clean water and the rise in measles immunization each accounted for about 15%, and access to skilled birth attendance accounted for 33%. The effect of girls' education, measured by the 10-year lag in girls' primary school enrollment, accounted for 8%, while women's representation in parliament accounted for 4%. The contribution of a slightly increased Gini coefficient was negligible.

While these were the variables included in the model, each was highly correlated with other variables from the same policy area. For example, replacing measles immunization with immunization against DPT3, Polio, or BCG would result in a similar contribution (Appendix C Figure 2). It would be inappropriate to conclude that it was only these variables that contributed to mortality declines. It would be better to consider that advances in the social system underlie a country's ability to register all sorts of improvements in a linked set of health determinants. Advances in broad processes of social function are the more likely the determinant of mortality decline.

A similar pattern holds when decomposing the decline in child mortality since 2000 (Appendix C Figure 3). The relative contributions of the factors changes only slightly compared to 1990. In 2000 the contribution of governance, corruption, and political stability was also assessed, and found to be less than 1%.

For a sensitivity analysis, different policy variables from the same "policy area" were exchanged for variables in the baseline model for both 1990 and 2000. For all the 1990-2010 (Appendix C Figure 2) decompositions, the contribution of the factor level changes was greater than 75% in 29 of 32 models tested (mean 82%, range 58%-94%), and the impact of switching one variable for another did not alter the conclusions (Appendix C Figure 3). Economic growth accounted for an average of 12% of total gains across all models tested (range -5% to 37%).

At this point, one might still reasonably object that while improved levels of determinants appear to be the drivers of health, such gains may still depend primarily on improved governance and GDP growth. However, OLS regressions of factor improvements against governance and growth show that in fact economic growth and governance account for only 1-22% of the observed level of factor improvements, and less than 10% for TFR and measles immunization coverage (Appendix C Table 4).

In summary, no single health input dominated as the cause of mortality decline. Rather, the summation of improvements in many different policy areas is what saved lives. Economic growth and good governance, while valuable ends in themselves, were only minor predictors of U5MR improvements or of the levels of factors that drove improved child health.

DISCUSSION (809)

This analysis has decomposed improvements in U5MR to determine how much of the recent improvements can be attributed to higher impact/efficiency of various determinants of U5MR reduction

and how much is attributable to improved levels or coverage of these determinants. The analysis shows that improved levels of determinants of health are the major explanation. Improvements in factors from diverse sectors as the environment, education, the health system, fertility, and women's empowerment all correlate significantly to mortality reductions. These findings on the importance of a multi-sector approach to improving child health align with the findings of country case studies, qualitative analysis, and literature review from the larger MDGs 4 and 5 Success Factors Study.[35]

Why some countries were able to achieve more multisectoral progress than others remains unclear, but we did address the reasonable concern that such progress was largely the result of only economic growth and improved governance. We find that these two factors were only minor predictors of either gains in child health or in the other factor levels that drove child health. The OB decomposition showed that economic growth accounted for an average of 12% of child health gains across all models tested, while governance contributed less than 1% of the overall improvements. These findings were further supported by OLS analysis of factor level improvements.

Indeed, there are several countries that showed meager economic growth and limited improvements in governance since 1990, but have still made major improvements in their children's health and are on track to meet MDG 4 despite these and other major obstacles. Figure 3 shows the trajectory since 1990 for Algeria, Honduras, Liberia, Malawi, and Nepal, each on track to meet MDG 4. All had economic growth below the world average since 1990, and only Liberia showed any significant improvement in governance, so it must have been their performance in other factors that led to their gains. Each does well in many of the policy areas in this analysis. Furthermore, each country had its own unique formula for success, and retains opportunities to still improve further. For example, Malawi significantly outperformed the rest of the world in improving access to clean water and girls' education, but continues to lag in fertility reduction. Algeria, on the other hand, can attribute a large portion of its success to fertility reduction, but has had a decline in clean water access, and could likely improve if it reversed that trend. Honduras, Nepal, and Liberia performed well across multiple policy areas. These examples suggest that there are likely many different avenues to improved child health, and successful countries likely employed strategies tailored to their unique challenges and context.

The limitations of our study require that the findings are interpreted with care. Variables within and even between policy areas are highly correlated, and interchanging one for another (Appendix C) usually did not alter significantly the contribution of that policy area. Thus, readers should not examine the results to find support for any single particular factor as being able to deliver health gains. The main conclusion that can be drawn from this analysis is that it is the improved levels in a combination of proven child health inputs that contributed to child health.

Furthermore, this analysis should not be taken to discount the importance of improvements in specific health conditions. Our analytical approach used U5MR as a summary indicator and this made it inappropriate to regress mortality on other health indicators so we excluded undernutrition or HIV from the model. Progress on these specific health conditions obviously matters substantially for U5MR.

The analysis is also limited because the U5MR indicator data that forms the basis for so much country concern is intrinsically not a random variable and does not lend itself to statistical hypothesis testing, as discussed above and in the appendix. Readers should avoid over-interpretation of the relative magnitude of the relative contribution of each factor.

Looking ahead to a post-2015 agenda for Millennium Development Goals these results indicate that progress on the health of children will depend on multiple underlying determinants improving at the same time. Countries and donors must invest in a multi-faceted approach across multiple policy areas to improve child health. They can neither rely on economic growth, governance, or technical progress to bring them about, nor can they use their absence as an excuse to achieve progress. Of particular note is the long-known observation that GDP growth effects on health are weakening every year due to countries' progress on the Preston curve. The post-2015 development agenda with an emerging emphasis on multi-sector collaboration offers an unprecedented opportunity to build on the lessons from the MDGs and to promote health and sustainable development in a more integrated manner.

FIGURES

Figure 1. Relationship between Log (U5M) and Log (GDP per capita). The well-known Preston relationship is clearly visible, with a correlation coefficient of -0.79. A loess curve is added showing a similar slope for both years.



Figure 2. Contribution of changes in the levels of determinates of health (health interventions, social and environmental determinants) to reductions in U5MR, 1990-2010. There was a decline in 41% decline in population-weighted U5MR between 1990 and 2010. The stacked bar graphs show the percent contribution from each policy area to this decline, since 1990, if the impact of the factors had been held constant at 1990 levels. The baseline models includes 8 variables: Log GDP per capita, TFR, log odds clean water access, log odds lag 10 years girls primary school enrollment, log odds skilled birth attendance, and log odds measles vaccine coverage, percent of parliament seats held by women, and gini coefficient. These areas are labeled as their respective policy area.

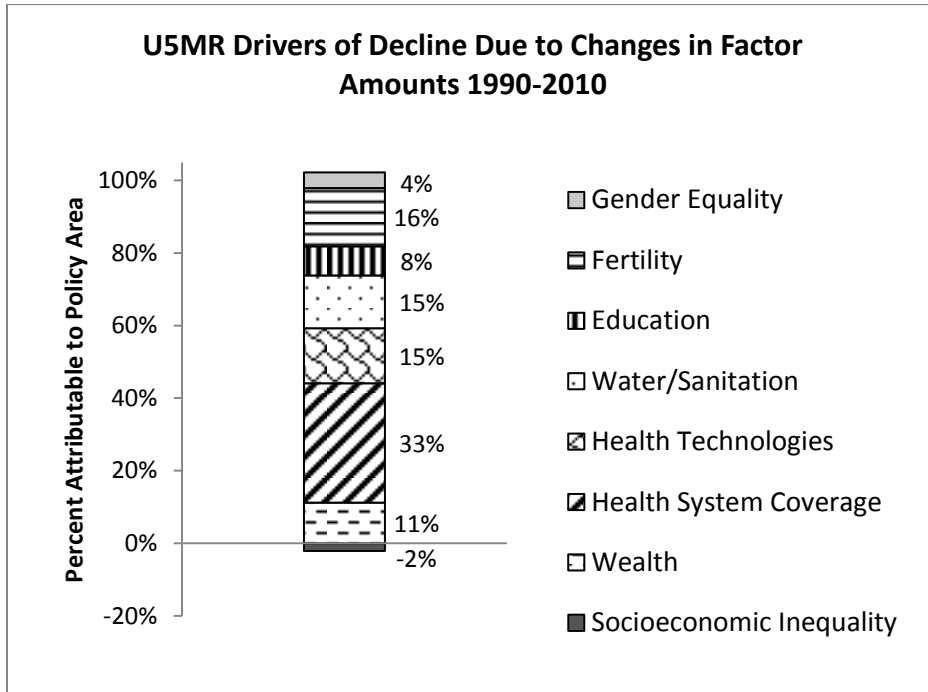
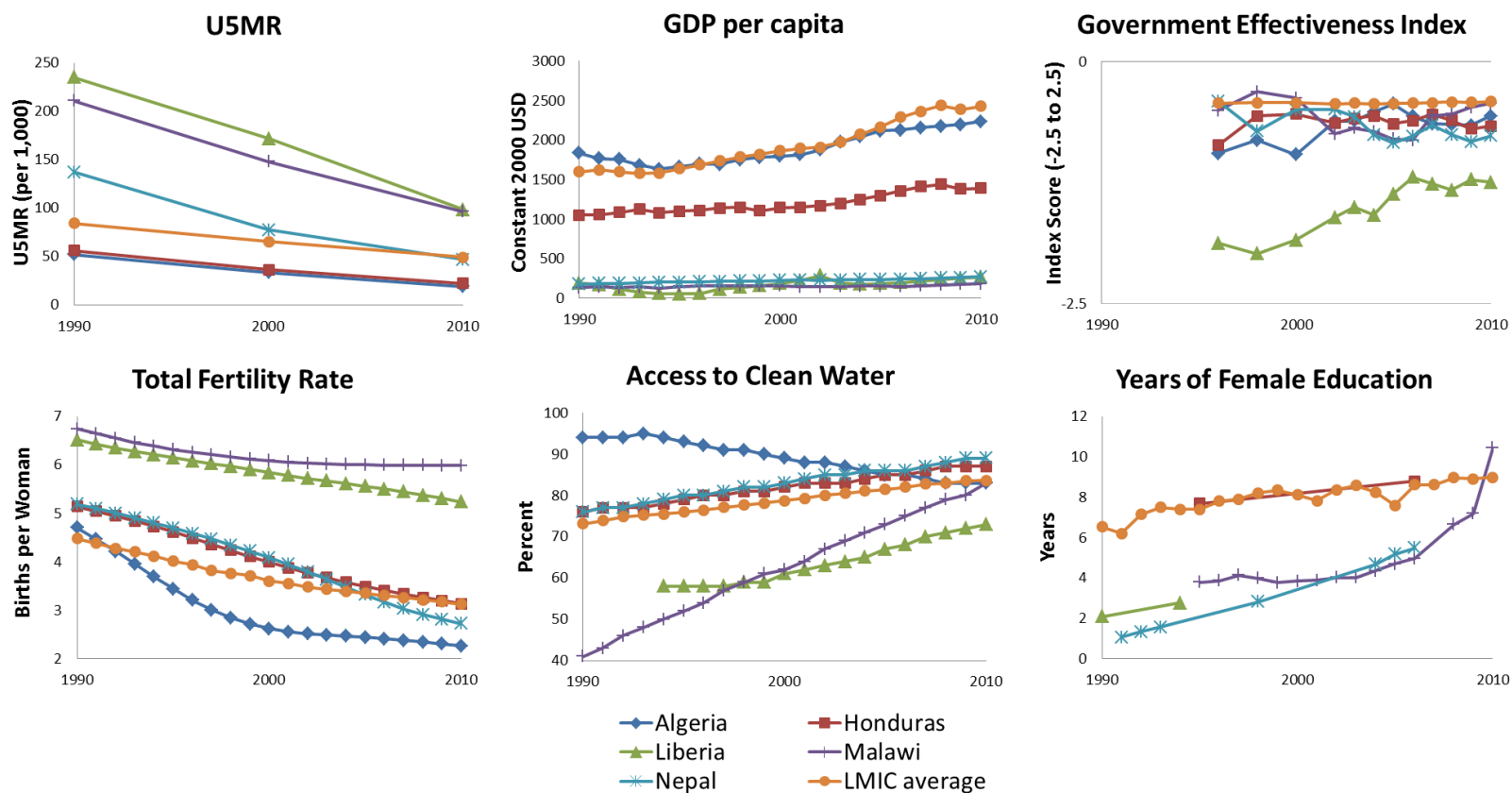


Figure 3. Selected Countries by Policy Variable. Algeria, Honduras, Liberia, Malawi, Nepal are all on track to meet MDG 4, and all have experienced meagre economic growth and governance from 1990-2010. An unweighted LMIC average is shown for comparison (circles), and is usually outperformed by these 5 countries. Lag 15 years expected girls schooling is shown in lieu of lag 10 years girls primary enrollment due to a more complete dataset.



TABLES

Table 1: Summary statistics for sample of countries showing change in U5MR and change in factors responsible for U5MR.

Population-weighted Averages for 142 LMICs Variable	Values in 1990			Values in 2010			Change	Percent Change
	Mean	Min	Max	Mean	Min	Max		
U5MR	77.7	12.7	297.0	45.8	4.0	180.1	-31.9	-41%
log U5MR	4.1	2.5	5.7	3.5	1.4	5.2	-0.6	-15%
Log odds of Measles Vaccine, imputed	1.2	-1.3	4.1	2.3	-0.8	4.18	1.1	92%
Log odds Skilled Birth Attendance, imputed	0.9	-3.1	5.3	1.9	-2.3	5.3	1.0	111%
Log odds Lag 10 yrs Fem. Pri. Sch. Enrollment, imp.	1.5	-2.0	4.3	2.0	-1.3	5.9	0.5	33%
Log odds of Having Clean Water, imputed	1.2	-1.7	5.3	2.1	-0.4	5.3	0.9	75%
Total Fertility Rate, imputed	3.4	1.6	8.3	2.7	1.16	7.2	-0.7	-21%
GDP per Capita	989	128	6,773	1,805	106	11,345	816	83%
Percent Parliament Seats held by Women, imputed	11.5	-5.7	36.9	15.8	0.0	53.8	4.3	37%
Gini Coefficient, imputed	36.9	19.5	74.3	38.6	27.2	65.8	1.7	5%

*sample size for all values was 135 in 1990, 142 in 2000, 136 in 2010.

Table 2. Estimates of Impact of U5MR Factors in 1990 and 2010. From multivariate ordinary least squares regression weighted for population.

VARIABLES	Regression Coefficients for Log(U5MR)			1990-2010 Change	1990-2010 Percent Change	p-value
	1990	2000	2010			
<i>Factors Associated with Lower Mortality</i>						
Log GDP per capita	-0.064	-0.210***	-0.088	-0.024	38%	0.78
Log odds of Having Clean Water	-0.064*	-0.062	-0.088**	-0.024	38%	0.65
Log odds Lag 10 yr Fem. Prim. Enroll	-0.079**	-0.077**	-0.080*	-0.001	1%	0.99
Log odds Skilled Birth Attendance	-0.110***	-0.097***	-0.174***	-0.064	58%	0.04
Log odds of Measles Vaccine Seats Held by Women in Nat'l Parliaments (%)	-0.133***	-0.108***	-0.075**	0.058	-44%	0.23
	-0.007*	-0.011***	-0.005	0.002	-29%	0.72
<i>Factors Associated with Higher Mortality</i>						
Total Fertility Rate	0.093***	0.051*	0.115***	0.022	24%	0.65
Gini Coefficient	0.001	0.013***	0.007	0.006	600%	0.32
Constant	4.782***	5.296***	4.465***			
Observations	135	142	140			
R-squared	0.915	0.895	0.892			

*** p<0.01, ** p<0.05, * p<0.1

Table 3. Results of Oaxaca Decomposition of the log U5MR gap between 1990 and 2010 when it was 0.66 units lower. Change in factor levels alone would have predicted a gap that was 0.528. Change in factor impact alone would have predicted a gap that was 0.128. The relative contribution to the gaps is shown in the lower panel. Positive percentages in column 1 indicate a positive contribution to a positive gap. Positive percentages in column 2 indicate that a change in the impact of that factor increased over time.

	Change in Factor Levels*	Change in Factor Impact
Total Gap in Log U5MR between 1990 and 2010	0.656	0.656
Predicted Gap if Factor Impact Fixed at 1990 Levels and Factors Changed as Observed in Data	0.528	
Predicted Gap if Factor Levels Fixed at 1990 and Impacts Changed as Estimated by Model		0.128
Ratio of Predicted to Actual Gap	0.80	0.20
Relative Contribution by Factor		
Log GDP per capita	11%	118%
Total Fertility Rate	16%	-56%
Log odds of Having Clean Water	15%	22%
Log odds Lag 10 yr Fem. Prim. Enroll	8%	2%
Log odds Skilled Birth Attendance	33%	43%
Log odds of Measles Vaccine	15%	-55%
Parliament Seats held by Women	4%	-16%
Socioeconomic Inequality	-2%	-187%
Time		232%
Total	100% of 0.528	100% of 0.128

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