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Impact of Malaria Interventions on Reductions in Neonatal Mortality in Malawi, Rwanda, and Mainland Tanzania

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Abstract

Between 2000 and 2010 sub-Saharan Africa's impressive gains in under-five mortality have been accompanied by a more modest reduction in neonatal mortality. As a result, neonatal mortality now accounts for about a third of all under-five deaths in the region. This study selected three countries in SSA with significant reductions in NMR during this period, in an attempt to identify factors that contributed to the observed reductions in NMR and with special interest in the relative importance of scale-up of interventions to protect women against malaria during pregnancy. Multivariate decomposition procedures were used to examine the extent to which the scale-up of malaria interventions contributed to the observed neonatal mortality reductions. Results show that in all three countries—Malawi, Rwanda, and mainland Tanzania—the rapid increase in mosquito net ownership was associated with the observed reductions in neonatal mortality. In Malawi—where information on mothers' use of IPTp was available—the study did not find evidence that the scale-up of IPTp was associated with the reduction in NMR. In conclusion, the findings reinforce the importance of consistent and universal mosquito net use in areas with high prevalence of malaria. While malaria interventions are most often geared towards saving the lives of children at older ages (6 months to 5 years), the study findings contribute to a growing body of evidence pointing to the importance of malaria interventions to neonatal survival.

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Background

While sub-Saharan Africa made impressive gains in under-five mortality between 2000 and 2010 with rates dropping 32 percent, neonatal mortality improved at a far slower pace showing only a 19 percent reduction[1]. As a result, neonatal mortality now accounts for about a third of all under-five deaths in the region (Liu et al. 2012). Despite the recent and substantial declines, as of 2012 sub-Saharan Africa still has the highest neonatal mortality rates of any region at 32 deaths per 1,000 live births and over a million total neonatal deaths (UNICEF 2013). Of 12 USAID high-priority countries for maternal and newborn health in sub-Saharan Africa with available Demographic and Health Survey (DHS) data, only four show a significant improvement in NMR between 2000 and 2010. Notably, these declines have occurred in malaria-endemic countries in which malaria control interventions were significantly scaled-up over the decade.

The primary causes of neonatal death in sub-Saharan Africa are prematurity (33%), intrapartum-related complications (asphyxia) (20%), and sepsis and meningitis (10%). These remain the leading causes even as neonatal mortality has declined; the greatest declines have been in infectious causes, including tetanus, diarrhea, and pneumonia (Liu et al. 2012). Low birth weight, which encompasses both preterm birth and intrauterine growth retardation (IUGR), is a major indirect cause of neonatal death (Lawn, Cousens, and Zupan 2005). In many countries in sub-Saharan Africa, malaria during pregnancy is an important cause of low birthweight and is thus a major cause of neonatal morbidity and mortality (Guyatt and Snow 2001).

Recent efforts to promote newborn survival have focused on packages of interventions directed at women and infants along the continuum of care from preconception to infancy (Darmstadt et al. 2005; Liu et al. 2012; The Partnership for Maternal Newborn & Child Health 2011). These include 1) health promotion, education and reproductive health services for girls and women before they become pregnant; 2) focused antenatal care; 3) skilled attendance at birth, including emergency obstetric and newborn care; 4) post natal care for early identification and referral of illness and provision of preventive care; 5) integrated management of childhood illness, including emergency newborn care and kangaroo mother care for low birthweight infants. In addition to these packages, several cross cutting programs have been emphasized for their impact on maternal and child health: nutrition and breastfeeding promotion, prevention of mother to child transmission of HIV, malaria prevention and immunization. Together it has been estimated that these interventions could prevent 38-67% of the 1.2 million newborn deaths in sub-Saharan Africa (Darmstadt et al. 2008).

The recommended interventions to address malaria in pregnancy are sleeping under insecticide treated nets (ITN) and— in high and medium transmission countries in SSA—intermittent presumptive treatment (IPTp) with sulfadoxine-pyrimethamine (SP). Both ITN and IPTp have been found to be very effective in reducing malaria-attributable neonatal death. One randomized, placebo-controlled clinical trial in

[1] Calculation of data from IGME child mortality estimates: http://www.childinfo.org/mortality_ufmrcountrydata.php

Mozambique found that IPTp reduced neonatal mortality by 61% (Menéndez et al. 2010). A meta-analysis by Eisele and colleagues found that coverage with either IPTp or ITN was associated with an 18% reduction in neonatal mortality and a 21% reduction in low birthweight among women in their first or second pregnancies (Eisele et al. 2012). A widely accepted estimate is that between 10-30% of neonatal deaths could be averted with 90% coverage of IPTp (Darmstadt et al. 2005). Researchers have found no additive effect of ITN and IPTp on neonatal mortality (Eisele et al. 2012). Current recommendations are for pregnant women in endemic countries of Africa to receive a dose of SP at each ANC visit, at least one month apart, starting in the second trimester of pregnancy (WHO 2012) .

ITNs have been shown to reduce maternal anemia, increase mean birthweight and decrease fetal loss, though the effects were strongest in women in their first and second pregnancy. One meta-analysis found a 23% reduction in low birthweight in women who used ITNs in their first and second pregnancy (Gamble, Ekwaru, and ter Kuile 2006). The World Health Organization recommends universal coverage with ITNs for people living in or visiting a malaria-endemic region. This means that each household should own enough ITNs such that every household member could sleep under an ITN assuming that each ITN can be used by two persons. Pregnant women are particularly susceptible to malaria and thus use of ITNs is particularly important for women of reproductive age.

A better understanding of the factors contributing to declines in neonatal mortality rates will be crucial to the attainment of global mortality reduction goals such as those outlined in the Millennium Development Goals. Relying on DHS survey data from three malaria-endemic countries in sub-Saharan Africa, this study seeks to identify factors that have contributed to observed improvements in neonatal mortality rates. In particular, this study examines the extent to which the expansion of interventions to protect mothers and newborns against malaria has contributed to the observed declines in NMR. Much of the recent work has focused on lives saved during the post-neonatal period attributable to IPTp and ITN. This work will put into context the relative contribution of these interventions to the decline in NMR over the past decade as compared to other maternal and child health interventions.

Methods

Data and variables

The data for the study draw from Demographic and Health Surveys from three malarious countries in sub-Saharan Africa: Malawi (2000 and 2010 surveys), Rwanda (2000 and 2010 surveys), and mainland Tanzania[2] (1999 and 2010 surveys). These are nationally representative, population-based household surveys that monitor demographic trends; reproductive health behaviors, attitudes, and outcomes; and socio-demographic characteristics of women and men of reproductive age. All surveys include a full birth history for live births of interviewed women. All data are collected in face-to-face household interviews, and a standard core questionnaire is included in each survey, enabling comparisons across countries and over time.

[2] Zanzibar is excluded from the analysis, as the context of malaria prevalence and program coverage is distinct from mainland Tanzania.

For several key maternal and delivery care indicators, the standard DHS survey only collects information for women's most recent birth in the five years preceding the survey. For this reason, the study population was restricted to women's most recent live birth that occurred during the five years preceding each survey (1-59 months preceding the month of interview)[3].

The key outcome, neonatal death, is defined as a death that occurred in the first month of life (days 0-29). The study examines the impact of scale-up of two key malaria interventions—household ownership of a mosquito net and, where available and relevant, the mother's use of IPTp—on improvements in neonatal survival between 2000 and 2010. The indictor of household mosquito net ownership identifies households that own at least one mosquito net of any type at the time of interview. Although long-lasting insecticide-treated nets (LLINs) are now the standard mosquito net commodity purchased and distributed by National Malaria Control Programs, this was not the case in 2000. For comparability across surveys the analyses are restricted to looking at the potential protective effects of any nets, whether treated with insecticides or not. Furthermore, while we are interested in the mother's mosquito net use during pregnancy—when it would be helpful to prevent malaria-associated neonatal death—this information is not available; instead, we use ownership of a mosquito net at the time of interview as a proxy for ownership and use during the pregnancy. For Malawi, the mother's exposure to IPTp is defined as her use of two doses of SP during her most recent pregnancy ending in a live birth. Information about IPTp is not available in the 1999 Tanzania survey. Since Rwanda discontinued its IPTp policy in 2008 and the information was not collected in the 2010 survey, we do not examine this indicator in Rwanda.

The study examines the scale-up of malaria interventions within the broader context of known determinants of neonatal mortality, including sociodemographic factors and mother's use of other essential maternal and delivery services, as per the literature. At the level of the household, variables were created for place of residence (rural/urban) and for comparative household wealth (bottom third/top two thirds)[4]. Indicator variables were created to identify the following characteristics of the mother: mother's age at child's birth (under age 18/18-34 years/35 years or older), marital status (currently married or in union/not currently married or in union), and educational attainment (none/primary/secondary or higher). To adjust for any maternal and household characteristics that cannot be measured, including genetic risk, an indicator was created to identify mothers who have lost another child under age five (yes/no). Indicator variables were also constructed to identify several characteristics of the child: sex (male/female), preceding birth interval (less than 24 months/24-35 months/36 months or greater/first births), birth order (first or second/third/fourth or higher), and whether the child was a multiple birth (yes/no). The multivariate analysis did not adjust for child's size at birth, because low birth weight is a key pathway through which we expect mother's protection against malaria to result in lower levels of neonatal

[3] Neonatal mortality levels have been observed to be lower among most recent births, compared to all births (Winter et al. 2013). This difference is likely due to a selection bias in the most recent birth sample. The selection tends to omit closely spaced births, and close spacing between births is associated with higher mortality risk. However, while NMR levels are lower among most recent births, underlying relationships and trends are not expected to be different.

[4] Like the original DHS wealth index, the recently developed comparative wealth index (CWI) was constructed by DHS based on household-level data on assets, services, and amenities, and ranks households according to their level of wealth. However, the CWI uses a fixed reference point, the 2002 Vietnam DHS, enabling comparisons across time and country (Rutstein and Staveteig 2014). Trends are presented in Table 2 for all three wealth terciles (thirds), but the upper two thirds were combined for the regression analysis due to a small number of deaths in the wealthiest third.

mortality, rather than a potential confounder. Mother's nutritional status was examined (BMI and short stature) but results are not shown, as anthropometry was collected only in a subsample of respondents in several surveys, and not at all in the Tanzania 1999 DHS.

Indicator variables were constructed to identify women's use of three key maternal care and delivery services. We identify mothers who made at least four ANC visits (yes/no) and mothers who received tetanus injections during the pregnancy with the most recent child (2 or more/one/none). In addition to being a direct measure of the mother's protection against tetanus, we interpret this indicator as a proxy for the quality of antenatal care. Lastly, we identify children who were delivered in a health facility (any facility/home birth).

Several other indicators of maternal and neonatal care were considered for inclusion, but are not shown in final models. These include early initiation of breastfeeding, delivery by a health professional, and a post natal care visit for the child within two days. Because of its high association with place of delivery, delivery by a health professional is not included in the analysis. Because information about whether the *child* had a post natal visit is not available for both surveys in any single country, it is not included. Despite a strong association with neonatal mortality, early initiation of breastfeeding is not included because of issues with reverse causality. Since newborns with life threatening conditions may not be put to the breast or may be unable to breastfeed, the observed association is difficult to interpret.

Analysis

First, overall trends in neonatal mortality among women's most recent children born in the five years preceding each survey—that is, in months 1 to 59 before each woman's month of interview—were calculated. Log probability models were used to estimate the probability of dying in the first month of life, and a two-tailed z-test was used to test the significance of the reduction in neonatal mortality observed between the two surveys in each country.[5] In order to examine the extent to which the scale-up of malaria interventions contributed to the observed neonatal mortality reductions, multivariate decomposition procedures were used.

Multivariate decomposition provides a way to analyze differences in the outcome between two groups or, as in this case, between two points of time. In Equation 1, this difference is represented by $Y_A - Y_B$. This study used the mvdcmp procedure in Stata, which is comparable to the Oaxaca-Binder Method but provides flexibility to use non-linear models. The decomposition procedure divides the total decline in neonatal mortality into two portions: the portion that can be attributed to the change in the prevalence of a set of indicators (referred to as the *endowments* portion, and represented by X_A and X_B in Equation 1), and the portion that can be attributed to the change in the effect of these indicators (referred to as the *coefficients* portion, and represented by β_A and β_B in Equation 1) (Powers, Yoshioka, and Yun 2011).

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[5] The model agrees exactly with the CSPRO software normally used to calculate neonatal mortality rates, along with all the other standard under-five mortality rates, and follows the standard DHS mortality estimation protocol (Rutstein and Rojas 2006), but has several advantages. Because it falls within the framework of generalized linear models (with binomial error and log link), it can easily incorporate information on sample weights, survey stratification, and clustering of households, and it easily produces standard errors, confidence intervals, and test statistics. This model was first applied to DHS data in a study of child mortality in West Africa (Balk et al. 2004).

Equation 1:

$$
\begin{aligned}
Y_A - Y_B &= F(X_A\beta_A) - F(X_B\beta_B) \\
&= \underbrace{F(X_A\beta_A) - F(X_B\beta_A)}_{\textbf{Endowments}} + \underbrace{F(X_B\beta_A) - F(X_B\beta_B)}_{\textbf{Coefficients}}
\end{aligned}
$$

The decomposition procedure relies on two key pieces of information: the prevalence of all selected indicators at both points in time (presented in Table 2), and the coefficients derived from multivariate regression models predicting neonatal death run separately at each time point (presented in Table 3)[6]. The mvdcmp procedure assumes additivity of the components for composition and effect (Powers et al. 2011). Three decompositions were performed, to examine the decline in neonatal mortality between 1999/2000 and 2010 separately in each country.

Results

Reductions in neonatal mortality

In all three study countries, there has been a statistically significant reduction in neonatal mortality between the two surveys (see Table 1). In Malawi, the neonatal mortality rate among women's most recent children born fell from 26 deaths per 1,000 live births in the five years preceding the 2000 DHS to 20 deaths per 1,000 live births in the five years preceding the 2010 DHS. In Rwanda, the NMR declined from 29 to 14 deaths per 1,000 live births, and in mainland Tanzania from 32 to 18 deaths per 1,000 live births in the five years preceding the 1999 and 2010 surveys.

[6] Table 3 presents results from a multivariate version of the log probability model used to calculate the neonatal mortality rates presented in Table 1. The decomposition procedure includes the same set of variables but, due to constraints of the mvdcmp procedure, uses a Poisson model that closely approximates the log probability model.

Table 1. Neonatal mortality rate (NMR) (five-year rate) and the difference in NMR between surveys among women's most recent children born in the five years preceding the survey, Malawi, Rwanda, and mainland Tanzania

Malawi								Rwanda								Tanzania (Mainland)							
2000 MDHS			2010 MDHS			Difference		2000 RDHS			2010 RDHS			Difference		1999 TDHS			2010 TDHS			Difference	
NMR	LB	UB	NMR	LB	UB			NMR	LB	UB	NMR	LB	UB			NMR	LB	UB	NMR	LB	UB		
25.9	22.2	30.3	20	16.9	23.7	5.9	*	29.40	24.70	35.10	14.10	11.40	17.50	15.30	***	31.5	23.5	42.1	17.7	14	22.3	13.8	**

Note: * indicates p<.05; ** indicates p<.01;*** indicates p<.001.

Trends in sociodemographic characteristics

Table 2 presents trends in sociodemographic characteristics of the household, mother, and child, as well as trends in coverage of malaria interventions and other key maternal and delivery care interventions, among most-recent children born in the five years preceding each survey in Malawi, Rwanda, and mainland Tanzania.

Household-level socioeconomic status and urban residence are expected to be positively associated with neonatal survival. Between the 2000 and 2010 surveys, the percentage of most-recent children born into urban households as compared to rural households did not increase substantially in Malawi, Rwanda, or mainland Tanzania. However, the comparative wealth index shows that in all three countries there has been improvement in absolute wealth across the decade. The percentage of children born into the poorest third of households[7] declined from 94% to 80% in Malawi, from 91% to 80% in Rwanda, and from 83% to 73% in mainland Tanzania between the 1999/2000 and 2010 surveys. The percentage of most-recent children born into households in the wealthiest third increased from 2% to 9% during this period in Malawi, from 5% to 7% in Rwanda, and from 6% to 13% in mainland Tanzania.

Several characteristics of the mother, including her age at the child's birth, her educational attainment, and her marital status, have been found to be associated with neonatal survival of her child. The percentage of children born to mothers in the lowest-risk age range, 18-34, increased in Rwanda, from 69% in 2000 to 75% in 2010, with a corresponding decline in the percentage of children born to mothers age 35 or older, from 30% in 2000 to 24% in 2010. The percentage of children born to young mothers (under age 18) remained low in Rwanda, at 1% in 2010. In Tanzania, there has been a slight increase in the percentage of children born to mothers age 35 or older, from 18% in 1999 to 21% in 2010. In Malawi, the maternal age distribution remained relatively unchanged between the 2000 and 2010 surveys; in 2010 78% of children were born to mothers in the lowest risk age range, while 6% were born to young mothers (under age 18) and 16% were born to mothers age 35 or older.

There have been noteworthy improvements in mothers' educational attainment in both Malawi and Rwanda. In Rwanda the percentage of mothers with primary education increased from 55% in 2000 to 71% in 2010, while the percentage with no education fell from 35% to 19%. In Malawi the percentage of mothers with secondary education increased from 8% to 16%, while the percentage with no education fell from 31% to 17%. In contrast, in Tanzania the educational attainment of mothers remained unchanged between the 1999 and 2010 surveys; in 2010 24% of mothers had no education, 70% had a primary education, and 7% had secondary education or higher.

According to the 2010 survey in each country, the great majority of children (over 80%) were born to mothers either married or in union, and this percentage was similar in the earlier surveys.

Several characteristics of the child affect the risk of neonatal death; male children, multiple births, first-born, and high-order births, children born after a short interval or after a long interval, and children with low birth weight have an increased risk of neonatal mortality (Rutstein and Winter 2014). The prevalence of these risk factors among children has remained little changed across the two surveys in each country. About half of children are male, and between 1.5% and 2.5% are multiple births in each country. The

[7] Recall that this is relative to the 2002 Vietnam DHS survey.

percentage of children who were first births increased in Rwanda, from 17% in 2000 to 22% in 2010, while the percentage of children of fourth or higher order decreased, from 50% in 2000 to 43% in 2010. The percentage of children born after a short (<24 months) or a long (3+ years) preceding birth interval remained relatively unchanged in both Rwanda and mainland Tanzania; in Malawi there was a slight decrease in the percentage of children born after a short interval, from 16% in 2000 to 14% in 2010, but an increase in the percentage of children born after a long interval, from 47% in 2000 to 54% in 2010.

In order to control for potential unidentified genetic or household level risk factors, a measure of whether the child's mother lost another child under five is included in the analysis. In all countries, there has been a roughly ten percentage point reduction in the percentage of children whose mother lost another child under age five. This reduction reflects the gains in child survival during the decade.

Trends in coverage of malaria and other maternal and delivery care interventions

In Malawi, Rwanda, and mainland Tanzania, the first local ITN campaigns began targeting specific districts or regions in the 1990s. In Malawi, ITNs first became available nationwide commercially and at health facilities in 2003, in mainland Tanzania in 2004, and in Rwanda, in 2005. All three countries have had dramatic increases in mosquito net coverage between the 2000 and 2010 surveys, from 14% to 77% in Malawi, from 8% to 93% in Rwanda, and from 29% to 89% in mainland Tanzania.

Malawi was one of the first countries in sub-Saharan Africa to adopt the policy of giving all pregnant women sulfadoxine-pyrimethamine (SP) IPT in 1993. Tanzania and Rwanda adopted the policy in 2001 and 2005 respectively (Eisele et al. 2012). However, in 2008 Rwanda discontinued the program due to increased resistance to SP (President's Malaria Initiative 2013). Both Malawi and Tanzania have achieved widespread implementation of the policy. In Malawi, there was a greater than twofold increase in the coverage of IPTp between the 2000 and 2010 surveys; the percentage of women who received at least two doses of SP during pregnancy increased from 19% to 53%. In Tanzania, we can assume that in the 1999 survey no mothers had received two doses of preventative SP during ANC visits for their most recent birth; by 2010 this percentage increased to 28%.

In each country, there were also important changes in the coverage of essential birth-related care indicators between the 2000 and 2010 surveys. Antenatal care is an essential gateway into maternal care services, and provides an opportunity to identify and treat pregnancy-related problems so that avoidable complications and deaths can be averted. The percentage of women in Malawi, Rwanda and mainland Tanzania who had at least one antenatal care check-up from a health professional for their most recent birth was already over 90% in the earlier survey, and increased to at least 95% in each country in the 2010 survey (data not shown). The percentage of women who had at least four antenatal care visits as recommended by the World Health Organization (from any provider) for their most recent birth is much lower. In Rwanda the percentage increased threefold from 2000 to 2010, from 11% to 36%. By contrast, in Malawi and mainland Tanzania there was a decline in the percentage of women with at least four ANC visits, from 57% to 46% in Malawi, and from 71% to 43% in mainland Tanzania. These declines could reflect changes in antenatal care policies and goals during this period. Both Malawi and Tanzania adopted the World Health Organization's recommended Focused Antenatal Care (FANC) framework, which reduces the number of recommended visits to four and promotes focused rather than routine visits for women with low-risk pregnancies (WHO 2002).

The provision of neonatal tetanus toxoid (TT) injections is a particularly important component of antenatal care. Providing women with two doses of TT during pregnancy can prevent neonatal tetanus, which is nearly always fatal. If a woman has been previously vaccinated, one dose of TT is sufficient, and if she has already had five or more vaccinations, she will have acquired lifetime protection. According to the 2010 Rwanda DHS, 34% of mothers received at least two TT vaccinations for their most recent birth, up slightly from 31% in 2000. In Malawi, there was a small improvement in the percentage of mothers who received at least two TT vaccinations for their most recent birth, from 62% to 69%, but in Tanzania the percentage declined from 62% to 48%[8].

Delivery in a health facility is considered essential to promoting maternal and newborn survival. All three countries have made impressive gains in facility births between 2000 and 2010. In Rwanda, the percentage of children delivered in a health facility increased from 26% to 72% between 2000 and 2010. In Malawi and mainland Tanzania, the percentage of children delivered in a health facility increased from 56%% to 76%, and from 46% to 54%, respectively, during this period.

Table 2: Trend in sociodemographic characteristics of the household, mother, and child, and in coverage of malaria interventions and other recommended maternal and delivery care, among women's most recent children born in the five years preceding the survey, Malawi, Rwanda, and mainland Tanzania

	Malawi		**Rwanda**		**Tanzania (Mainland)**	
	2000 DHS	2010 DHS	2000 DHS	2010 DHS	1999 DHS	2010 DHS
	%	%	%	%	%	%
Characteristics of the household, mother, and child						
Place of residence						
Urban	13.4	15.4	14.7	12.8	22.9	22.8
Rural	86.6	84.6	85.3	87.2	77.1	77.2
Comparative wealth index[1]						
Bottom third	93.9	80.1	91.3	79.9	82.6	72.9
Middle third	4.2	11.4	4.3	13.3	11.0	13.9
Top third	2.0	8.5	4.5	6.8	6.4	13.2
Mother's age at child's birth						
<18 years	6.7	6.0	1.6	1.3	6.7	5.6
18-34 years	75.5	77.8	68.7	74.7	75.8	73.4
35+ years	17.9	16.2	29.7	24.0	17.5	21.0

[8] The preferred indicator, "full tetanus protection," takes into account whether a woman was fully vaccinated against tetanus prior to the most recent pregnancy and did not need two additional doses. However, because this indicator could not be calculated in the earlier surveys, we rely on this less precise measure. A higher percentage of women were fully covered, in our study population, according to the 2010 survey data: 89% in Malawi, 78% in Rwanda, and 89% in mainland Tanzania.

(Table 2 Continued)

	Malawi		Rwanda		Tanzania (Mainland)	
	2000 DHS	2010 DHS	2000 DHS	2010 DHS	1999 DHS	2010 DHS
	%	%	%	%	%	%
Mother's marital status						
Currently in union	87.0	85.5	78.5	82.8	83.5	81.9
Not currently in union	13.0	14.5	21.5	17.2	16.5	18.1
Mother's educational attainment						
None	30.7	16.6	34.7	18.9	26.6	23.7
Primary	61.7	67.0	55.2	71.4	70.0	69.7
Secondary or higher	7.6	16.4	10.2	9.7	3.4	6.6
Previous child to mother died under age five years						
No	60.7	70.8	62.3	73.8	66.7	75.6
Yes	39.3	29.2	37.7	26.2	33.3	24.4
Sex of child						
Female	50.3	50.1	49.4	48.4	50.0	49.7
Male	49.7	49.9	50.6	51.6	50.0	50.3
Multiple birth						
Single Birth	97.5	97.6	98.6	98.5	98.6	98.4
Multiple Birth	2.5	2.4	1.4	1.5	1.4	1.6
Birth order						
First	21.2	18.3	17.1	22.4	22.9	19.2
Second	18.6	19.0	17.6	19.0	18.0	19.3
Third	15.8	17.3	15.5	15.1	15.1	16.6
Fourth or higher	44.4	45.4	49.8	43.4	44.0	45.0
Preceding birth interval[2]						
<2 years	16.2	13.7	20.3	18.2	13.8	12.8
2 years	36.7	32.9	36.0	37.8	38.9	37.4
3+ years	47.1	53.5	43.6	44.0	47.3	49.8

(Table 2 Continued)

	Malawi		Rwanda		Tanzania (Mainland)	
	2000 DHS	2010 DHS	2000 DHS	2010 DHS	1999 DHS	2010 DHS
	%	%	%	%	%	%
Maternal and delivery care						
Attended 4 or more ANC Visits						
Yes	56.6	45.9	10.4	35.5	71.0	43.1
No	43.4	54.1	89.6	64.5	29.0	56.9
Number of tetanus injections during pregnancy						
2+	61.6	69.4	30.7	34.4	62.0	48.3
1	20.4	18.5	34.7	42.6	21.4	24.7
0	18.0	12.2	34.6	23.0	16.7	27.0
Delivered in a health facility						
Yes	56.1	76.2	25.8	71.8	45.7	54.3
No	43.9	23.8	74.2	28.2	54.3	45.7
Mother received two doses of SP during pregnancy[3]						
Yes	29.3	52.9	n/a	n/a	0.0	28.4
No	70.7	47.1			100.0	71.6
Household owns a mosquito net						
Net	13.9	77.4	8.1	93.2	29.3	89.1
No net	86.1	22.6	91.9	6.8	70.7	10.9
Total N	**7,943**	**13,497**	**5,062**	**6,355**	**2,101**	**5,303**

[1] The DHS-constructed comparative wealth index uses a fixed baseline (the 2002 Vietnam DHS) enabling measurement of improvements in wealth over time and comparison of absolute wealth across country.

[2] First births are excluded from the percentages.

[3] For mainland Tanzania, we assume 0% coverage of IPTp in 1999, as the intervention was not introduced until 2001.

Results of multivariate analysis

The factors identified in Table 2 with improved coverage between 2000 and 2010 could only have contributed to the observed declines in neonatal mortality if they are associated with the probability of neonatal death. Log probability models were used to examine the probability of dying during the first month of life, separately in each survey.

After adjusting for sociodemographic factors and the mother's use of antenatal care, receipt of tetanus toxoid vaccinations, and place of the child's delivery, household ownership of a mosquito net remains significantly associated with neonatal mortality in the 2010 survey—but not the earlier survey—in all three countries. According to the 2010 Malawi survey, children born into a household without a mosquito net were 1.7 times more likely to die during the neonatal period compared with children born into a household with a mosquito net; according to the 2010 Rwanda and Tanzania surveys, children born into a household without a mosquito net were more than three times more likely to die during the neonatal period.

In Malawi—where we were able to identify the number of doses of SP the mother was given during her most recent pregnancy—we did not find evidence that women's exposure to IPTp was associated with lower risk of neonatal mortality after adjusting for sociodemographic factors and use of other maternal and neonatal care services.

As expected, several sociodemographic characteristics of the household, mother, and child remained significant predictors of neonatal mortality in the full model. Children whose mother was at least 35 years at the time of his or her birth had roughly twice the adjusted risk of dying in the neonatal period compared with children whose mother was in the lowest risk age range (18-34 years), according to each country's 2010 survey. The length of the preceding birth interval was an important predictor of neonatal mortality in Malawi and Rwanda, such that children born after a short interval had 2.9 and 3.9 times the adjusted risk of neonatal death compared with children born after a two-year interval, according to the 2010 surveys in Malawi and Rwanda, respectively. In Tanzania, the child's birth order was a significant determinant of neonatal mortality, such that according to the 2010 survey, third-order births had a 66% lower risk of neonatal death compared with first and second order births. Male children had between 1.5 and two times the adjusted risk of dying in the neonatal period compared with female children, in the 2010 survey for each country, and being a multiple birth conferred substantial excess risk in Rwanda and Malawi.

According to the 2010 Malawi survey, children whose mother had lost another child under age five were 1.6 times more likely to die during the neonatal mortality compared with mothers who had not lost another child under five. Contrary to our expectation, we found no evidence that the child's place of residence, household wealth, or the mother's educational attainment were associated with neonatal survival in adjusted models.

Table 3. Adjusted relative risk of dying during the neonatal period, among women's most recent children born in the five years preceding the surveys, Malawi, Rwanda, and mainland Tanzania

	Malawi								Rwanda								Tanzania (Mainland)							
	2000 DHS				**2010 DHS**				**2000 DHS**				**2010 DHS**				**1999 DHS**				**2010 DHS**			
	aRR	**LB**	**UB**		**aRR**	**LB**	**UB**		**aRR**	**LB**	**UB**		**aRR**	**LB**	**UB**		**aRR**	**LB**	**UB**		**aRR**	**LB**	**UB**	
Place of residence																								
Urban	1.00				1.00				1.00				1.00				1.00				1.00			
Rural	1.25	0.63	2.47		0.89	0.55	1.45		2.57	0.99	6.70		0.65	0.33	1.29		0.56	0.22	1.42		0.67	0.35	1.26	
Comparative wealth index[1]																								
Bottom third	0.99	0.37	2.66		0.90	0.57	1.41		0.52	0.15	1.83		1.78	0.74	4.27		1.40	0.32	6.12		0.78	0.42	1.42	
Top two thirds	1.00				1.00				1.00				1.00				1.00				1.00			
Mother's age at child's birth																								
<18	1.28	0.77	2.13		0.60	0.31	1.19		1.46	0.52	4.11		1.32	0.17	10.39		1.89	0.71	4.98		0.83	0.29	2.39	
18-34	1.00				1.00				1.00				1.00				1.00				1.00			
35+	1.51	0.93	2.47		2.29	1.49	3.52	***	1.35	0.86	2.12		1.93	1.11	3.35	*	6.96	2.06	23.46	**	2.03	1.01	4.10	*
Mother's marital status																								
Currently in Union	1.00				1.00				1.00				1.00				1.00				1.00			
Not Currently in Union	1.13	0.75	1.72		0.81	0.53	1.24		0.97	0.63	1.50		0.76	0.39	1.48		1.58	0.64	3.93		2.04	1.15	3.60	*
Mother's educational attainment																								
None	1.06	0.44	2.53		0.92	0.47	1.80		2.28	0.75	6.94		0.94	0.30	2.91		0.56	0.09	3.51		0.87	0.28	2.66	
Primary	1.38	0.62	3.07		1.23	0.71	2.13		1.53	0.54	4.32		1.10	0.41	2.96		0.80	0.15	4.17		1.31	0.51	3.38	
Secondary or higher	1.00				1.00				1.00				1.00				1.00				1.00			

(Table 3 Continued)

	Malawi								Rwanda								Tanzania (Mainland)							
	2000 DHS				**2010 DHS**				**2000 DHS**				**2010 DHS**				**1999 DHS**				**2010 DHS**			
Previous child to mother died under age five years																								
No	1.00				1.00				1.00				1.00				1.00				1.00			
Yes	1.78	1.15	2.74	**	1.64	1.14	2.36	**	1.09	0.74	1.61		1.54	0.97	2.47		2.03	0.69	5.96		0.96	0.49	1.88	
Sex of child																								
Female	1.00				1.00				1.00				1.00				1.00				1.00			
Male	1.61	1.17	2.20	**	1.63	1.19	2.23	**	1.78	1.22	2.58	**	1.46	0.90	2.36		1.71	0.78	3.74		1.79	1.07	2.98	*
Preceding birth interval																								
<2 years	1.47	0.87	2.49		2.89	1.67	5.02	***	1.62	0.96	2.74		3.93	2.03	7.64	***	0.72	0.17	2.98		1.64	0.63	4.32	
2 years	1.00				1.00				1.00				1.00				1.00				1.00			
3+ years	0.90	0.56	1.44		2.11	1.32	3.35	**	0.98	0.63	1.52		1.35	0.70	2.61		1.13	0.35	3.72		1.43	0.73	2.80	
First birth	2.55	1.39	4.67	**	5.02	2.65	9.52	***	1.22	0.65	2.29		2.37	0.94	5.97		1.34	0.37	4.94		1.11	0.51	2.40	
Birth order																								
First or second	1.00				1.00				1.00				1.00				1.00				1.00			
Third	1.03	0.56	1.88		0.83	0.42	1.64		0.57	0.28	1.17		0.88	0.36	2.12		1.09	0.24	4.98		0.33	0.12	0.91	*
Fourth or Higher	0.69	0.38	1.25		0.64	0.38	1.09		0.63	0.37	1.07		1.08	0.46	2.53		0.14	0.03	0.72	*	0.45	0.18	1.08	
Multiple birth[2]																								
Single Birth	1.00				1.00				1.00				1.00								1.00			
Multiple Birth	6.07	3.58	10.31	***	6.48	3.98	10.57	***	10.47	5.95	18.44	***	4.68	1.88	11.68	***					3.25	0.99	10.69	

(Table 3 Continued)

	Malawi								Rwanda								Tanzania (Mainland)							
	2000 DHS				**2010 DHS**				**2000 DHS**				**2010 DHS**				**1999 DHS**				**2010 DHS**			
Attended 4+ ANC Visits																								
Yes	1.00				1.00				1.00				1.00				1.00				1.00			
No	1.21	0.89	1.65		1.64	1.17	2.31	**	1.38	0.69	2.77		1.42	0.87	2.30		2.31	1.12	4.76	*	1.45	0.92	2.30	
Number of tetanus injections during pregnancy																								
2+	1.00				1.00				1.00				1.00				1.00				1.00			
1	1.32	0.87	2.00		1.24	0.85	1.81		1.27	0.83	1.93		0.84	0.45	1.56		0.98	0.33	2.94		1.00	0.52	1.91	
0	2.80	2.02	3.87	***	1.21	0.78	1.89		1.45	0.93	2.27		1.19	0.62	2.28		1.38	0.71	2.68		1.53	0.83	2.82	
Delivered in a health facility																								
Yes	1.00				1.00				1.00				1.00				1.00				1.00			
No	1.13	0.82	1.57		0.91	0.60	1.36		0.77	0.50	1.18		0.78	0.47	1.28		0.75	0.35	1.60		0.63	0.35	1.13	
Household owns a mosquito net																								
Net	1.00				1.00				1.00				1.00				1.00				1.00			
No Net	0.72	0.47	1.12		1.69	1.17	2.45	**	3.43	0.80	14.65		3.28	1.91	5.65	***	0.91	0.34	2.42		3.21	1.90	5.40	***
Mother received two doses of SP during pregnancy																								
Yes	1.00				1.00				n/a				n/a				n/a				n/a			
No	1.18	0.78	1.77		1.16	0.86	1.57																	

Note: * indicates p<.05; ** indicates p<.01;*** indicates p<.001. The table presents adjusted relative risk (aRR) estimates, which compare the probability of dying in one group relative to the probability of dying in the reference group, after adjusting for all other variables in the model.

[1] The DHS-constructed comparative wealth index uses a fixed baseline (the 2002 Vietnam DHS) enabling measurement of improvements in wealth over time and comparison of absolute wealth across country. The upper two thirds were combined for use in the regression analysis due to a small number of deaths in the wealthiest third.

[2] Due to the small number of cases of multiple births in the Tanzania 1999 sample, results are suppressed.

Decomposition results

While Table 3 describes associations between key indicators and neonatal mortality within individual surveys, Table 4 identifies factors that are associated with the reduction in the NMR between the 1999/2000 and 2010 surveys in Malawi, Rwanda, and mainland Tanzania. To address this question, the change in neonatal mortality across surveys was divided into two parts, one representing changes in the distribution of sociodemographic characteristics and coverage of interventions ("endowments," summarized in Table 2), and the other representing the strength of effect of those characteristics or interventions ("coefficients," summarized in Table 3). Within the population of most recent births in the five years preceding each survey for which complete information on key indicators was available, the decline in the NMR was 5 points between the 2000 and 2010 Malawi surveys, 16 points between the 2000 and 2010 Rwanda surveys, and 14 points between the 1999 and 2010 Tanzania surveys[9].

Each decomposition tested whether malaria control interventions—household ownership of a mosquito net in all countries and in the case of Malawi, also mother's use of IPTp—are associated with the observed decline in neonatal mortality. Each decomposition model included the same set of sociodemographic characteristics (place of residence, comparative household wealth, mother's age at the child's birth, marital status, education, loss of a previous child under age five, child's sex, preceding birth interval, birth order, multiple birth) and maternal and delivery care indicators (use of four or more ANC visits, number of tetanus injections during the pregnancy, and whether delivery was in a health facility) that were included in the multivariate log probability models presented in Table 3.

[9] Reductions in NMR do not exactly match those presented in Table 1, as the decomposition is restricted to children with complete data on all variables included in the model.

In both Malawi and Rwanda, the total change in "endowments" (i.e., coverage) in the covariates explained a significant portion of the observed reduction in NMR, while the change in "coefficients" (i.e. effect) of these covariates was not significant (see Table 4), and the effect of the change in "coefficients" was in the opposite direction and served to reduce or dampen the effect of changes in "endowments". Since only the "endowments" portion of the results was significantly associated with the reduction in NMR in Malawi and Rwanda, we focus on these results.

In Tanzania, the total change in "endowments" explained 60% of the observed reduction in NMR, and the "coefficients" portion explained the remaining 40%; however, neither portion of the decomposition was statistically significant (the p-value for the "Endowments" portion is 0.08, likely due to the small sample size of the Tanzania 1999 survey). Despite the non-significance of the endowments portion as a whole, the endowment of several individual variables in the model—the mother's age at birth and marital status, the child's birth order, and household ownership of a bed net—were significantly associated with the observed change in neonatal mortality.

Of all the indicators included in our decomposition models, the dramatic increase in household ownership of a mosquito net was responsible for the greatest portion of the decline in neonatal mortality in each country. On its own, the increase in mosquito net coverage was associated with an estimated reduction in the NMR of 8 deaths per 1,000 live births in Malawi, a reduction of 25 deaths per 1,000 live births in Rwanda, and a reduction of 12 deaths per 1,000 live births in Tanzania.

Note on interpreting Table 4:

In Table 4, each "endowments" column quantifies the amount of decline in neonatal mortality explained by the change in *coverage* in each selected indicator between the two points in time, assuming that the effect of the indicator was constant across the entire period. The "coefficients" column quantifies the amount of decline in neonatal mortality explained by the change in *effects* between the two time points, if coverage (the distribution of each variable) had been constant across the entire period. If we take Rwanda as an example, in the final row of Table 4, "-15.95" indicates that the NMR declined by 16 points in Rwanda between the 2000 and 2010 surveys. Above that number, the endowment for "Household ownership of a mosquito net" is "-24.87," the largest single number in the endowments column. If nothing in the model had changed between the 2000 and 2010 reference periods *except the level* of mosquito net ownership, as indicated by the percentage of households that own a mosquito net, the NMR would have declined by 24.9 points—substantially more than the decline actually observed, and an amount that is significantly different from zero. In the same row the number for "coefficients" is -3.5, indicating that if nothing had changed between the 2000 and 2010 reference periods *except the benefits* of mosquito net use, as indicated by the coefficient in the estimation model, then the NMR would have declined by 4 points—which is not statistically significant. The combined effect of all the changes in characteristics or coverage ("endowments") would have been to reduce the NMR by 28.3 points, virtually twice (a 177% decrease) the observed decline of 16.0 points. By contrast, the combined effect of all coefficients (improved impacts of characteristics on reducing the NMR) would actually have led to an *increase* of 12.3 points in the NMR (a 77% increase), rather than a reduction. Together, the two components sum to 100% (177% + -77% = 100%) of the total observed NMR decline.

In Malawi, we found no evidence to suggest that the increasing coverage of IPTp (i.e. the mother's being given two doses of SP during pregnancy) contributed to the reduction in the NMR. We also found no evidence that increasing coverage of other maternal and delivery care services—namely, antenatal care, tetanus injections, or delivery in a health facility—contributed to the reduction in the NMR. In Malawi, the reduction in coverage of women's having at least four ANC visits from 57% to 46% between 2000 and 2010 was associated with a 1 point increase in neonatal mortality.

The change in composition of several sociodemographic characteristics of the mother and child—including the mother's age at child's birth, marital status, and loss of another child under five, the child's sex, birth order, and multiple birth—were associated with changes in neonatal mortality in at least one country. For example, the change in composition of women's age at the child's birth—and specifically, the increasing percentage of mothers in the lowest risk 18-34 age range—was associated with a reduction of 0.1 points in Malawi and 0.9 points in Rwanda. In Tanzania, the increase in percentage of children whose mother was at least 35 years at his or her birth was associated with an increase in NMR of 0.6 points. In Malawi, the reduction between surveys in the percentage of mothers who had lost another child under five was associated with a reduction in NMR of 1.1 points, suggesting that this indicator was able to capture and control for unexplained residual household and maternal risk.

We found no evidence that changes in the composition of births by urban-rural residence, increases in wealth during this period, or increases in mother's educational attainment contributed to the decline in neonatal mortality.

In sum, the results show that within the limited set of indicators included in our decomposition model, the rapid increase in household ownership of mosquito nets stands out as a driving force behind the observed reductions in neonatal mortality. In all three countries, mosquito net ownership was significantly associated with the reduction in the NMR between the 2000 and 2010 surveys, even after adjusting for the effects of key components of maternal and delivery care and sociodemographic characteristics.

Table 4. Multivariate decomposition of sociodemographic and maternal and delivery care related differences in the NMR, showing contributions to the NMR gap attributed to differences in endowments and to differences in coefficients, Malawi, Rwanda, and mainland Tanzania

	Malawi 2000 DHS-2010 DHS			Rwanda 2000 DHS-2010 DHS			Tanzania 1999 DHS-2010 DHS		
	Endow-ments		Coeffic-ient	Endow-ments		Coeffic-ient	Endow-ments		Coeffic-ient
Place of residence	0.06		1.26	-0.22		7.99	-0.03		2.02
Comparative wealth index[1]	0.31		2.75	-1.65		43.51	0.39		21.98
Mother's age at birth	-0.14	*	0.65	-0.94	*	3.96	0.57	*	12.42
Mother's marital status	-0.07		-1.34	0.28		-1.75	0.27	*	-1.86
Mother's educational attainment	0.58		0.97	0.55		15.51	0.02		-0.18
Previous child to mother died under age five years	-1.12	**	1.26	-1.22		-7.49	0.09		-22.15
Sex of child	0.02	**	0.19	0.10		-3.84	0.03	*	-0.77
Preceding birth interval	-0.36		14.43	0.06		14.23	0.23		-4.42
Birth order	-0.17		-2.03	-0.11		13.70	-0.58		-16.50
Multiple birth	0.08	***	0.00	-0.01	**	-0.48	0.00		-8.63
Attended 4+ ANC Visits	1.23	**	3.62	-2.07		0.73	1.90		6.10
Number of tetanus injections during pregnancy	-0.36		-4.52	-0.82		-8.66	0.86		-1.06
Delivered in a health facility	0.38		-2.47	2.64		1.99	0.66		4.56
Household owns a mosquito net	-7.77	**	43.14	-24.87	**	-3.48	-12.19	*	-95.76
Mother received two doses of SP during pregnancy	-0.88		-0.02	n/a			n/a		
Constant			-55.02			-63.59			98.47
Total	-8.15	**	2.88	-28.27	*	12.32	-8.65		-5.78
Percent	154.48	**	-54.48	177.25	*	-77.25	59.94		40.06
NMR Difference (per 1,000)	-5.28		*	-15.95		***	-14.43		*

Note: * indicates p<.05; ** indicates p<.01;*** indicates p<.001. The table presents summary statistics for each variable (see Table 3 for variable categories). While we would expect all endowments to sum to the total E component and all coefficients to sum to the total C component, current totals do not. This issue will be resolved in the final manuscript.

[1] The DHS-constructed comparative wealth index uses a fixed baseline (the 2002 Vietnam DHS) enabling measurement of improvements in wealth over time and comparison of absolute wealth across country. The upper two thirds were combined for use in the regression analysis due to a small number of deaths in the wealthiest third.

Discussion and Conclusions

Between 2000 and 2010 sub-Saharan Africa's impressive gains in under-five mortality have been accompanied by a more modest and inconsistent reduction in neonatal mortality (UNICEF 2013). This study selected three countries in SSA with significant reductions in NMR during this period, in an attempt to identify factors that contributed to the observed reductions in NMR and with special interest in the relative importance of scale-up of interventions to protect women against malaria during pregnancy. Results show that in all three countries—Malawi, Rwanda, and mainland Tanzania—the rapid increase in mosquito net ownership was associated with the observed reductions in neonatal mortality. The study did not find evidence that the scale-up of IPTp was associated with the observed reduction in NMR in Malawi.

While ownership of a mosquito net at the time of interview is an imprecise proxy for the mother's use of an ITN during pregnancy, the indicator identifies an important protective effect against neonatal mortality. The observed association is plausible, given the well-documented association between malaria during pregnancy and elevated risk of neonatal death (Eisele et al. 2012; Guyatt and Snow 2001). In a multi-country study examining the impact of protection against malaria during pregnancy on neonatal mortality and the child's birth weight in 25 malarious countries in African, Eisele and colleagues found that exposure to malaria protection during pregnancy (either through mosquito net ownership or through IPTp) was associated with lower odds of both neonatal mortality and lower odds of having a low birth weight, among women's first or second births.

In contrast to previous findings in malarious sub-Saharan African settings (Eisele et al. 2012; Menéndez et al. 2010), our study did not find a protective effect between IPTp and neonatal mortality in Malawi. The null finding could be driven by a lack of power, given the relatively low coverage of IPTp and the rarity of the event of a neonatal death. Eisele and colleagues, for example, detected an effect of IPTp exposure in a pooled analysis combining data from 25 African countries, rather than in any individual survey (Eisele et al. 2012).

Another recent multi-country study examined determinants of declines in neonatal mortality between 2000 and 2010 (Lawn et al 2012). They found that inter-country differences in declines in neonatal mortality rates can be attributed largely to the baseline NMR and two other factors: declines in national fertility rates and national socioeconomic improvements (Lawn, Cousens, and Zupan 2005). To control for these country-level factors in our individual-level analysis, two covariates were included: a measure of the child's birth order (first or second/third/fourth or higher) to adjust for the impact of declining fertility levels, and an innovative relative wealth index, to adjust for overall improvements in wealth between 2000 and 2010. The comparative wealth index compares household wealth to a fixed reference point independent of the survey itself, so that we were able to adjust for improvements in household wealth between surveys. In contrast to Lawn and colleague's findings, we did not find evidence that improvements in wealth or changes in the composition of birth order were associated with the observed declines in neonatal mortality in Malawi, Rwanda, or mainland Tanzania.

Our measure of household ownership of a mosquito net was associated with neonatal survival in the 2010 survey for each country, but not in the earlier survey. There are several potential explanations for the increase in effect size. First, recall that we use mosquito net ownership on the day of interview as a proxy for ownership (and use) during pregnancy. Given the rapid expansion of ITN ownership in each country between 2000 and 2010, we can expect that the variable is a better proxy for net ownership during pregnancy in the 2010 survey than in the 2000 survey. Second, we are looking at ownership of "any net" while ITNs are more protective than untreated nets[10], providing both barrier protection against mosquito vectors as well as direct insecticidal effects, and the composition of "any net" changed during this period, from largely untreated to majority insecticide-treated nets. For example, in Tanzania, according to the 2004/5 TDHS 49% of households that owned any mosquito net owned an ITN, while according to the 2007/8 THMIS this percentage had increased to 69%, and according to the 2009/10 THMIS the percentage had increased to 85%. Third, the increasing effect of household mosquito net ownership could be a reflection of the additional community-level benefit of ITNs once overall net coverage reaches a certain threshold (Gimnig et al. 2003; Howard et al. 2000). That is, beyond protecting the individual who sleeps underneath an ITN, once ITN coverage is high in a community, ITNs serve to suppress the vector population through direct insecticidal effects and reduce their ability to transmit malaria.

Several limitations to the study are worth noting. Most importantly, while we would like to know whether malaria interventions have actually led to a reduction in neonatal mortality, the DHS is a cross-sectional survey and thus we can only report associations; we cannot infer causation. In addition, the DHS collects information from respondents about past events, behaviors, and outcomes. Such information—for example, concerning women's receipt of maternal care services for their most recent birth—is subject to recall bias. For several indicators of interest—as mentioned above— there is an issue regarding the timing of measurement. While we are interested in assessing characteristics at the time of the mother's pregnancy and at the birth of the child, certain variables are only measured at the time of interview. For example, educational attainment, and all household characteristics are measured at the time of the interview rather than during the pregnancy. Perhaps most problematically, as discussed above, to assess the mother's mosquito net use during pregnancy, we use her mosquito net use the night before the interview as a proxy, with the understanding that the findings must be interpreted cautiously. This type of measurement error would be expected to dampen the strength of true associations. Finally, between 2000 and 2010 there were some revisions to the DHS survey questionnaires and definitions of some variables. For this reason it was not possible to include some indicators of interest, such as exposure to postnatal care for either the mother or the newborn.

While most often, malaria interventions are geared towards saving the lives of children at older ages (6 months to 5 years), the study findings contribute to a growing body of evidence pointing to the importance of malaria interventions to neonatal survival. In particular, the findings reinforce the importance of consistent and universal mosquito net use in areas with high prevalence of malaria. Future studies should look more closely at the independent and combined effects of mosquito net usage and IPTp use on maternal and neonatal health in different epidemiological contexts.

[10] We use "any net" because we cannot construct household ownership of an ITN in the earlier surveys, as questions on treatment of nets were not asked in all households.

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