Infant Mortality, Fertility, and Malaria: The Effect of Mosquito Net Distribution in Sub-Saharan Africa*

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Abstract

Over the last decade, there has been a large international effort to distribute insecticide treated bed nets (ITNs) to reduce the incidence of malaria in Sub-Saharan Africa. At the same time, infant mortality and fertility in Sub-Saharan has declined substantially over this period. In this paper, we ask to what extent the declines in infant mortality and fertility can be attributed to the introduction of bed nets. Using the rapid increase in the distribution of ITNs in the mid-2000s, we use a difference-in-differences estimation strategy to identify the causal effect of bed nets on infant mortality and fertility. We show that increases in mosquito net usage alone have had a significant impact on infant mortality. For example, 50% of the reduction in infant mortality from malaria in Nigeria from 2003 to 2010, and 10% of the overall reduction, can be attributed solely to the introduction of bed nets.

Keywords: Malaria, Infant Mortality, Fertility, Sub-Saharan Africa, Bed Nets

JEL Codes: I15, J13, O10

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1 Introduction

Over the last decade, infant and child mortality in Sub-Saharan has declined substantially. According to the United Nations, the infant mortality per 1000 births in Sub-Saharan Africa fell from 102 in 1995-2000 to 79 in 2005-2010, a reduction of 22.5%. One major source of infant and child mortality in Africa is malaria. According to the World Malaria Report 2012, there were 219 million episodes of malaria leading to 660,000 deaths in 2010 (WHO 2012). About 90% of these deaths occurred in Africa where 16% of all death among children aged less than five are due to malaria (WHO 2012). Malaria is particularly dangerous for children under five who have not yet developed partial immunity from the disease, and for pregnant women and their unborn children. Using available technologies, malaria can be prevented, diagnosed, and cured – making the large burden of disease from malaria particularly tragic.

In light of the preventable nature of malaria, within the past 20 years there has been renewed emphasis to coordinate the global efforts against the disease. The Roll Back Malaria Partnership (RBM) was created in 1998 to identify and implement preventive measures that had been shown to be effective in reducing the risk of contracting malaria. Examples of such measures include the use of insecticide-treated mosquito nets (ITNs), indoor residual spraying (IRS), and intermittent preventive treatment during pregnancy (IPTp). Indeed, a main goal of RBM is to achieve full coverage of all people at risk of malaria in areas targeted for malaria prevention. This full coverage includes universal usage of ITNs and IPTs for vulnerable groups like pregnant women and children. To achieve these goals a large amount of resources have been spent to reduce mortality due to malaria. For example, international disbursements for malaria control rose from less than US$ 100 million in 2000 to US$ 1.71 billion in 2010 (WHO 2012). A good fraction of these resources have been used to disseminate ITNs, as they are considered to be an effective and cheap way to prevent contact from the mosquitoes which carry the disease. The percentage of households owning at least one ITN in Sub-Saharan Africa is rose from 3% in 2000 to 53% in 2011 (WHO 2012). According to the WHO, approximately 90% of persons with access to an ITN within the household actually use it (WHO 2012).

Given the emphasis placed on ITNs within the campaigns to reduce malaria, a natural question is how much of the reduction in infant mortality in Sub-Saharan African can be attributed to the usage of mosquito nets. Estimating the direct effect of mosquito nets is not trivial. At the same time as the introduction of bed nets, non-malarial mortality was also falling due to improvements in sanitation, nutrition, and from other health interventions. Given these improvements, it is likely that malarial mortality would have fallen even in the absence of a concerted international effect to reduce malaria deaths. As a result, it is incorrect to fully attribute the full decline in infant mortality due to malaria in Sub-Saharan African to bed nets alone. Given the large interest in these bed net distribution programs, and in order to get a better sense of their cost effectiveness, a well identified estimate of the effect of bed nets on malarial mortality would be highly beneficial.

In this paper, we take advantage of the rapid increase in the usage of ITNs across Sub-Saharan African in the mid 2000s to identify the decline in infant mortality which can be attributed to the use of mosquito nets. Our identification strategy uses a difference-in-differences approach which exploits the fact that the pre-intervention burden of malaria was not constant across Africa, or even within countries within Sub-Saharan Africa, and that the regional rollout of bed nets in many countries was independent of the natural malarial ecology within each sub-country region. As a result, we can estimate the effect of bed nets on mortality by testing whether regions with climatic conditions more suitable for malaria had faster reductions in infant mortality once the intervention took place. Our identification strategy is similar to recent work by Acemoglu and Johnson (2007), Bleakley (2007), Fortson (2011), and Lucas (2010), among others.

In addition, there are many theoretical reasons to believe that the introduction of bed nets could also have a fertility effect. First, a decline in mortality could cause a decline in fertility by eliminating the need for replacement children or precautionary childbearing. On the other hand, the introduction of bed nets likely reduced the cost of child-bearing (by reducing the probability of death of the mother from malaria during pregnancy) which may lead to an increase in fertility. Bed nets may also reduce the in-utero exposure to malaria,

leading to improved child heath and potentially higher educational attainment, which may change child quality and induce a change in fertility whose direction is ambiguous.

We construct a unique panel that merges average mosquito net usage, infant mortality outcomes, fertility outcomes, and an exogenous measure of malaria ecology based on rain and temperature at the region-year level. This panel is created using birth histories and mosquito net usage from the Demographic and Health Surveys, Malaria Indicator Surveys, and Multiple Indicator Cluster Surveys. The exogenous measure of Malaria ecology was created using malaria prevalence from the Malaria Atlas Project and rain and temperature data from the Climatic Research Unit at the University of East Anglia. Overall our sample has 220,806 births for 22 countries and 269 regions from 1999 to 2012.

Our preliminary results show that increases in mosquito net usage reduce child mortality faster in areas with climatic conditions more conducive to malaria. For example, 50% of the reduction in mortality from malaria in Nigeria from 2003 to 2010 can be attributed solely to the introduction of bed nets. This corresponds to 10% of the overall reduction of mortality in Nigeria over this time period. Since other interventions to reduce malaria directly such as IRS or IPTp have surely had an additional effect, this implies that less than half of the reduction in mortality during this period is due to improvements in the general health environment, giving weight to the argument that these interventions are both effective and important to continue supporting with international donations.

We also find that the introduction of bed nets reduced fertility rates, perhaps due to a decreased need for replacement children. We calculated that the introduction of bed nets reduced the total fertility rate in Nigeria by 0.42, or approximately 7%. We then calculate the elasticity of fertility to mortality, and find it to be slightly greater than 1, which we believe is a plausible value given the demand for replacement and precautionary children.

The rest of the paper is organized as follows: Section 2 presents background information on the recent increase in bed nets in Africa, Section 3 outlines our methodology, and Section 4 describes the data. Section 5 presents the results and discusses them. Section 6 concludes.

2 Background on Malaria and ITN Rollout

Malaria has historically been a major cause of mortality worldwide. Malaria, or diseases very similar to malaria, have been recorded across the globe since 3000 B.C. The malaria parasite was discovered in the late 19th century, and in the early 20th century programs to control malaria began to be developed. During the 1930s and early 1940s, great strides were made in malaria control, including the invention of anti-malarial drugs such as chloroquine, and the discovery of vector-controlling chemicals such as DDT. Immediately following WWII, several national malaria eradication programs began and had great success, especially in the United States, India, and Sri Lanka. In the United States, the National Malaria Eradication Program was launched in July of 1947, and had succeeded in completely eradicating malaria in the American South by 1951.

In 1955, the World Health Organization (WHO) launched the Global Malaria Eradication Campaign. Mostly through the use of insecticide spraying, malaria was eradicated from 37 countries by 1973 when the campaign was terminated. However, by the mid-1980s the prevalence of malaria began to rise again. This led to a renewed interest in malaria and the creation of the Roll Back Malaria Partnership in 1998. Malaria control then became an important component of the Millennium Development Goals of the United Nations.

In Africa, most cases of malaria are caused by the bite of a female anopheline mosquito that is infected with protozoan parasites. Although there are several species of the parasite, the Plasmodium falciparum strain is the most common in Africa (responsible for 98% of infections) and it is also the deadliest (RBM, 2012). In this study we refer to "malaria episodes" and "malaria prevalence" as those caused by the P. falciparum parasite.

The P. falciparum parasite needs a human host to complete its cycle and only 40 out of the 430 known species of anopheline mosquito can carry the parasite (Crawley and Nahlen, 2004). Following the bite by an infected mosquito, the parasites leave the skin and migrate to the liver. After release, the parasites penetrate red blood cells where they multiply, causing an infection. An infected individual with no previous immunity is almost certain to develop severe flu-like symptoms that may lead to death depending on

the age and general health of the individual.

Since children between 6-months and 3 years have not yet developed immunity, they are the most vulnerable population (Crawley and Nahlen, 2004). By age 10, most infected individuals will suffer at worst mild complications (febrile episodes) and by 15 most individuals have asymptomatic infections or very low levels of the parasite, and the risk of developing even mild complications is very low.

Malaria infections can be controlled using several preventive interventions: sleeping under an insecticide-treated mosquito net (ITN), indoor residual spraying (IRS), intermittent preventive treatment during pregnancy (IPTp), use of mosquito repellents, cleaning drains, and treatment of standing water with larvicidal chemicals. These interventions work by reducing the number of mosquitoes and/or by preventing bites. Anophelene mosquitoes tend to rest in walls and curtains inside a house and they are inclined to bite at night. This makes sleeping under an insecticide-treated mosquito net highly effective to prevent malaria transmission (RBM, 2012). Indeed, sleeping under an ITN is considered the most cost-effective intervention to prevent malaria since the mosquito dies immediately when it comes into contact with the ITN (Lengeler, 2004). This not only prevents infection but also reduces the mosquito population.

Because of the effectiveness of ITNs, the Global Malaria Action Plan (GMAP), endorsed in the 2008 Millennium Development Goals Malaria Summit of the United Nations, set a target of achieving universal coverage with ITNs for all endemic areas in Africa by 2010 (RBM 2012). In order to meet this goal the Roll Back Malaria Partnership helped individual governments in Africa to secure funding to scale-up their anti-malaria programs.

Before the creation of the Roll Back Malaria Partnership the use of mosquito nets including ITNs was very limited. Even in the early stages of the campaign, the distribution of nets was slow and not uniform across countries. The earliest scale up in the distribution of nets did not start until 2006 (RBM, 2012).

Although the Roll Back Malaria Partnership is in charge of secure funding and helps individual countries with technical advice, the actual distribution of nets is most often

done by the individual countries' National Malaria Control Programs. In the early stages, bed net distribution was usually done by giving pregnant women a net during the first visit to an antenatal care facility. Once the scale-up phase started, each household received a voucher for every two members which could be redeemed for a net later. In a personal correspondence with Dr. Mea Antoine Tanoh, the director of Côte d'Ivoire's National Malaria Control Program, we established that, in general, once a national malaria control program decided that the whole country should have universal coverage with ITNs, they did not emphasize particular regions based on malaria incidence.

3 Methodology

To estimate the causal effect of bed nets on infant mortality and fertility, we use a classic difference in differences model to exploit the geographic and time variation in the rollout of bed nets. This estimation strategy is commonly used in the literature. Our methodology has been used by Fortson (2009, 2011) to find the effect of HIV on fertility and schooling, and Lucas (2010) and Bleakley (2007) which look at malaria and educational attainment. Specifically, we run the following regressions to estimate the effect of bed nets on mortality and fertility respectively:

$$M_{irt} = \alpha_r^m + \psi_r^m t + \gamma_1^m \mathrm{Net}_{rt} + \gamma_2^m \left(\mathrm{ME}_r - \overline{\mathrm{ME}}\right) \cdot \mathrm{Net}_{rt} + \gamma_3^m \mathrm{Risk}_{irt} + \Pi^m X_{irt} + \epsilon_{irt}^m, \quad (1)$$

and

$$TFR_{rt} = \alpha_r^f + \psi_r^f t + \gamma_1^f \mathrm{Net}_{rt} + \gamma_2^f \left(\mathrm{ME}_r - \overline{\mathrm{ME}}\right) \cdot \mathrm{Net}_{rt} + \epsilon_{rt}^f, \quad (2)$$

where i references the individual, r is the region, and t is the year of interview.

M_{irt} is our child mortality variable, which is an indicator which takes the value of 1 if the child is dead at the time of the interview, and 0 if the child is still alive. Following Fortson (2009), TFR_{rt} is the total fertility rate, an estimate of the number a children a women will have over her lifetime if current age-specific fertility rates remain constant.

Specifically, the total fertility rate is calculated as:

$$TFR_{rt} = 5 \sum_{i=3}^{7} \frac{\text{births}_{r,t,5i,5i+4}}{\text{exposure}_{r,t,5i.5i+4}}$$

where $\text{births}_{r,t,5i,5i+4}$ are the number of births to women in the $5i$ to $5i + 4$ age group in region r in year t, and $\text{exposure}_{r,t,5i.5i+4}$ is the collective number of years spent in the respective age group by women in region r.[1] This TFR is calculated using detailed birth histories in the DHS dataset, described in more detail in the Data section of the paper.

Mean mosquito net usage in a region-year is given by Net_{rt}. Since our dataset contains birth histories for all children under the age of one, and since the precise age in months of children differs at the time of the interview, different children will be exposed to malaria for different amounts of time. As a result, we must control for the age of the child in months at the time of the interview to control for the length of time exposed to malaria. This is the variable Risk_{irt} in equation (1). In equation (2), since the woman could have become pregnant at any time during the previous year, the risk exposure is equal to twelve for all women, and therefore its effect becomes part of the constant. In some of the mortality regression specifications, we control for other variables known to be correlated with infant mortality, such as birth interval, mother's age at birth, birth order, and the child's gender, which are contained in X_{irt}. We also include region fixed effects and country-specific time trends.

ME_r is our malaria endemicity measure. We do not use actual malaria prevalence in each year, since mortality and malaria prevalence are necessarily endogenous to the introduction of bed nets. Instead, we create a measure of underlying malarial ecology based on rain and temperature patterns at the region level as a proxy for the pre-rollout malaria endemicity. This measure of malarial ecology is constructed as the linear prediction of a regression of malaria prevalence on regional rain and temperature data. Since climate is a good predictor of malaria prevalence, but is exogenous to the timing of the rollout of bed nets within a country, we can identify the parameter γ_2^m which tells us how much more

[1] Note that the fraction inside the summation is merely the annual age-specific fertility rate for women in each 5 year age group. We multiply by 5 in order to convert annual fertility rates in to 5 year fertility rates, then sum over all 5 year age groups.

effective bed nets are in areas where malaria prevalence was higher pre-rollout. If bed nets are effective in reducing malaria, then we expect γ_2^m to be negative. As mentioned before, the direction γ_2^f could be either positive or negative, depending on whether mortality has a negative effect on fertility via a reduction in replacement fertility, precautionary childbearing, or a movement along the quality-quantity frontier; or a positive effect on fertility due to a reduction in the costs and increase in the benefits of childbearing after the introduction of bed nets.

4 Data

Our data on children and households come from the Demographic and Health Surveys (DHS), the Multiple Indicator Cluster Surveys (MICS), and the Malaria Indicator Surveys (MIS) that have been carried out in Sub-Saharan Africa since 1999. The DHS provides birth histories for all children born to women in the sample, and is the main source of our individual level data. We also have data on children from MICS, a set of nationally representative surveys of households, children and women. Unlike MICS, the DHS provides data on the exact date of death of the child. Most of the MICS surveys ask whether a child is dead at the time of the survey, but does not tell us when, meaning it is more difficult to determine whether the child died before the age of one. As a result, we omit all cases where the child was born over one year before the interview.

A subset of both DHS and MICS surveys ask whether or not the child slept under a bed net, from which we calculate bed net usage by region-year. In addition, we can also use data from the MIS to calculate bed net usage by region-year. Our sample is necessarily restricted to the set of countries and years for which we have both data on child mortality from the DHS or MICS, and data on bed net usage. Table 1 details the years and countries which appear in our sample. Overall, the dataset includes 74 surveys from 22 countries and 274 regions. Building the dataset was a tedious task: for many countries, surveys and waves, we had to figure out how to merge the recode files. Some variables from the DHS and MICS are not directly comparable. For instance, the regions of a specific country are not the same across waves and surveys in the original data sets,

and we thus used maps of the countries to define a new region variable that was consistent.

[Insert Table 1 here]

Ideally, we would use the pre-intervention levels of malaria in each region as our measure of malaria prevalence in equation (1). However, such measures at the region level are difficult, if not impossible, to find. As a result, we needed to create a measure of malaria prevalence which was exogenous to the subsequent provision of bed nets. Since malaria prevalence is highly dependent on climatic conditions, our measure of malaria endemicity is created using rain and temperature data. We use the climatic variables to predict the malaria endemicity in a region based on the exogenous climatic factors, and then use the coefficients from that regression to create the exogenous predicted suitability of a given region for malaria.

Specifically, we begin by taking the average temperature for each region in each month from 2000-2010 from the Climatic Research Unit at the University of East Anglia climate dataset. We then take the average over all months to get the average temperature for a region. We then find the average max temperature – we find the month with the highest average temperature in the region for each year, and then average over all the years. The maximum temperature month always occurs during the rainy season, and allows us to capture a richer picture of what happens with the climate over the year and the non-linear effects temperature seasonality may have on malarial ecology. We then find the average minimum temperature using the same method as we did to find the average maximum.

We then repeat the exact same process to find the average, minimum, and maximum levels of precipitation for each region. We then take the squares, cubes, and quartics of each of the six climate variables in our model, leaving us with 24 climate variables to use to explain malaria prevalence at the region level in a very rich, highly non-linear fashion. We then take malaria prevalence as given by the Malaria Atlas Project in 2010 as our dependent variable, and regress that on our 24 climate variables. The fit of the resulting prediction – an R^2 of 0.68, is very good (See Appendix A).

Figures 1 and 2 show the relationship between average temperature and rainfall respec-

tively and our predicted malaria prevalence measure (malaria ecology). Temperature and malaria are positively correlated at more mild temperatures, but the relationship becomes flat as temperatures exceed 25 degrees Celsius. The relationship between malaria and precipitation is even more non-linear, being approximately an inverted U-shape. Even so, there is a large amount of variation in our prediction even at similar temperatures or precipitation levels because of the non-linearities we allow in the model, which demonstrates how rich our predictive model is.

[Insert Figures 1 and 2 here]

Table 2 provides summary statistics for the most important variables in our basic regression model. The fraction of children under one who had died by the time of the interview was 5.2%. While this number may seem low for Sub-Saharan Africa, it should be noted that some children who were alive at the time of interview will also eventually die before they turn one, since different children were interviewed at different times during their first year. Table 2 shows that mean risk exposure, or age at the time of interview, is 6 months – implying that overall infant mortality rates should be closer to 10%, which is in line with standard estimates of child mortality in Sub-Saharan Africa over this period. The mean total fertility rate across all regions and years in our sample is 5.076 children per woman.

[Insert Table 2 here]

PfPR measures actual malaria prevalence in 2010 from an age-standardized estimate of Plasmodium falciparum prevalence rate measured using parasite rate surveys and a geo-statistical modeling framework. It averages 34.6% of the total population for regions in our sample, which is similar to our exogenous malaria prevalence measure, which shows a 33.8% prevalence rate. There is large variation in the level of malaria prevalence across regions of our sample ranging from 0 to over 70%. The average mother's age is around 26 years old, 50% of birth are boys, and 20% of women had a birth within 24 months.

Average net usage in our sample is 26.1% and ownership is 42.9%. However, these numbers masks a large amount of variation over time and across countries and regions – the precise variation we use to identify the effectiveness of bed nets. Ideally, we would have a balanced panel of net usage (ownership) and mortality data at the region level to estimate our model. In reality, we have waves of the DHS, MIS, and MICS, which do not occur for every country every year. Table 3 gives us a richer picture of how bed net use has changed for each country over time given the data we do have. Early in the sample, bed net usage rates are low. For example, in the year 2000 for the 11 countries for which we have reliable data, the average bed net usage rate is just 11%.[2] Compare that to 2010, where the average bed net usage rate among a different set of 11 countries is 40.8%.

[Insert Table 3 here]

In many countries, the precise years of the scale-up can be identified even with this spotty data. In Cameroon, bed net usage started at 13.5% in 2000 and stayed low at 11.4% in 2004, but then jumped to 27.9% in 2006. By 2011, at 29.1% bed net usage was virtually unchanged from the 2006 level, but ownership increase from 32.2% to 51.1%. We can infer that sometime between late 2004 and early 2006 there was large scale-up of the distribution of bed nets in Cameroon. In Senegal, bed net usage remained around 17.5% until 2006, when it jumped to 30.4% and then continued rising to 36.5% in 2008 and 46.3% in 2010. The timing of the scale up was different for different countries – some were slow and gradual, while others were rapid. Some countries experienced an early scale-up, while others have yet to begin (see Swaziland, for example). Such variation in timing and intensity, along with the variation in malaria prevalence before the distribution of bed nets, is ideal for our identification strategy.

Figure 3 shows that in our sample mortality has steady declined during the study period and at the same time the percentage of children under 5 sleeping under a net have sharply increased starting in 2004. Need to add fertility to this figure. In the following

[2] We omit Madagascar from this calculation, since an 88.9% bed net usage rate is a result of poor data quality in the MICS survey for that year.

section, we will study whether net usage can explain the decline in mortality and fertility.

5 Results

5.1 The Effect of Bed Nets on Mortality

Table 4 reports our estimates of the effect of bed nets usage on infant mortality. In specifications 3 and 4, the coefficient of interest is on the interaction of our malaria ecology and net usage. The coefficient on net usage gives us the average partial effect of net usage on mortality for all four specifications. Using our baseline specification (column 1), we find that a 10% increase in net usage in the region is associated with a decline of 2.3 deaths per 1000 infants out of an overall mortality of 53 deaths per 1000 infants. We find this effect controlling for the level of malaria ecology in the region and individual characteristics. However, when we control for region fixed effects the effect of net usage becomes insignificant.

[Insert Table 4 here]

Column 4 gives us our preferred estimates where we control for country time trends. The coefficient on the interaction between malaria ecology and net usage is negative and significant at the 10% level, while the average partial effect of net usage is close to zero and insignificant. To quantify the magnitude of this interaction effect, note that if malaria prevalence was at 100% before the introduction of bed nets, then increasing bed net usage from 0% to 100% would result in a decline in infant mortality of 49 deaths per 1000 infants. However, this is an unrealistically extreme case – malaria prevalence before the scale-up in bed net use was approximately 33% for the entire Sub-Saharan region, and net usage over this period only increased to less than 50% coverage.

To realistically show the effect bed nets had on mortality, we use the case of Nigeria as an example. Nigeria had one of the highest malaria prevalence rates before the introduction of bed nets, and a decently large increase in bed net usage over our sample

(5.5% in 2003 to 31.9% in 2010, with most of the scale up occurring in the time period 2008-2010). Our predicted malaria prevalence measure is 50.7% for Nigeria, making its climate the most conducive for malaria to be endemic in our sample. Using these figures, the increase in the interaction term between 2003 and 2010 was (0.319 - 0.055)*0.507 = 0.125. Multiplying this with our estimate of -0.049 yields -0.00613, or a reduction in child mortality of 6.13 deaths per 1000 children. According to our DHS data, child mortality fell from 115 to 56 per 1000 in Nigeria between 2003 and 2010, a decrease of 59 per 1000. So 6.13 / 59 = 10.4 % of the decline in overall mortality in Nigeria was solely due to the introduction of bed nets from 2003 to 2010.

Another interesting question is what fraction of the decline in malaria-specific infant mortality was due to the introduction of bed nets. Malaria mortality could fall even without any sort of malaria specific intervention; as mentioned before, general health improvements such as better water, sanitation, or nutrition could also have an effect. However, annual cause-specific infant mortality rates in Africa are not available. Some good estimates come from the Global Burden of Disease published by the WHO, but they are not for all years and never break out the mortality data specifically for infants. However, using a few admittedly crude statistics, we can back out a rough estimate of the decline just to get a sense of its magnitude.

Estimates of the fraction of total infant mortality in Nigeria due to malaria deaths range from 25% to 50%. Taking an intermediate value of 1/3, if infant mortality was 114 per 1000 in 2003, then approximately 38 per 1000 were due to malaria. The World Malaria Report 2011 reports that malaria-specific mortality had fallen by 33% percent since 2000 in the WHO African region. Using this number for the decline in malaria specific mortality in Nigeria from 2003 to 2010, malaria mortality in 2010 would be 25 per 1000, or a decline of 13 per 1000. Since we estimated the introduction of bed nets reduced child mortality by approximately 6.13 per 1000, this implies that a little under half (47.2%) of the decline in malaria was solely due to the introduction of bed nets.

The estimates on our additional controls are expected. In our baseline regression, we find that net usage is higher in regions where there is more malaria, and the cumulative

probability of death is larger for children who were older at the time of the survey. In our regression with added controls, having a birth interval of less than 24 months, and being male were all positively associated with infant mortality.

Table 5 presents the results for the effect of mosquito net ownership on mortality. Unlike bed net usage, we find no effect of bed net ownership on infant mortality.

[Insert Table 5 here]

5.2 The Effect of Mortality on Fertility

Table 6 reports our estimates of the effect of bed nets on the total fertility rate. Just as with our results for mortality, our coefficient of interest is on the interaction term between bed nets and malarial ecology, found in specifications (3) and (4). Our preferred specification is found in column (4), which includes country-specific time trends. The coefficient on the interaction between bed net usage and our malarial ecology measure is negative and significant at the 5% level. A coefficient of -3.382 means that, in a region where malaria prevalence was 100%, increasing the usage of bed nets from 0% to 100% would reduce fertility by 3.382 children per women. To interpret this coefficient in a more realistic setting, we again take the case of Nigeria between 2003 and 2010. As calculated in the previous section on the mortality results, we find that this interaction term rose by 0.125 in Nigeria over this period. Multiply that with the coefficient of -3.382, and we find that the increase of bed net usage in Nigeria between 2003 and 2010 reduced TFR by 0.42 children per woman.

To compare these results with the results from fertility, note that according to the World Bank Development Indicators, the TFR for Nigeria in 2003 was 5.77. A fall in TFR of 0.42 therefore represents a decrease of 7.32% from its 2003 level. In comparison, infant mortality was 115 deaths per 1000 children aged 0-1 in 2003. We calculated that the increase in bed net usage over this period reduced infant mortality by 6.13 deaths per 1000, a decrease of 5.33%. Therefore, the elasticity of fertility to infant mortality is the ratio of these two percentages, or $7.32/5.33 = 1.37$.

We believe 1.37 to be a plausible value. An elasticity of 1 implies that parents simply are replacing the children they have lost before the age of 1 – for example, if 10% of your kids die, you increase the number of kids you have by 10% to replace them. However, if the elasticity is more than one, that implies that a reduction in mortality has a disproportionately larger effect on fertility. There are several reasons why this is likely to be the case. First is precautionary childbearing. In a high mortality environment, a risk averse individual who depends on children for old age support is likely to have more children than they otherwise would want in order to assure that they achieve the minimum number of surviving adult children. For example, assume that a child born has only a 50% chance of living to adulthood, and that an individual wants at least one child to survive to support them in old age. If the individual were risk neutral, she would simply bear the number of children which would give her one adult child, or two children. However, assuming the deaths of her children are independent random events, having only two children leaves her with a 25% chance of having no surviving children. If she is risk averse, she may prefer to have more children to reduce the chance that she is childless in her old age. As a result, an improvement in the mortality environment may cause her to reduce her fertility more than one for one with the reduction in mortality – she will reduce her replacement children one for one, but also reduce the number of "precautionary" children as well since the probability of her children dying is lower.

Another reason we think it is plausible that this elasticity is greater than one is that we are only measuring infant mortality. Just as bed nets will reduce the mortality of children under the age of one, it will also likely reduce the mortality of children over the age of one as well. Inasmuch as deaths of children over the age of one are also likely to be replaced, we are only measuring a subset of the "replaced" children with our measure of infant mortality. As a result, we may estimate an elasticity greater than one, even if the entire reduction in fertility is due purely to replacement fertility.

Table 7 is very similar to Table 6, except that we measure the effect of bed net ownership, not bednet usage. We find very similar results on the effect of bed nets on fertility in our preferred specification, a coefficient of -3.743 vs. -3.382. The effect on bed

net ownership is significant at the one percent level.

6 Conclusion

Over the past decade, there has been a large international emphasis on malaria eradication in Sub-Saharan Africa. According to the World Malaria Report 2012, just under $2 billion was spent on malaria eradication efforts in 2011 alone. Most of the effort to reduce malaria has come through the distribution of insecticide-treated bed nets, as they are seen as the most cost-effective malaria control intervention.

However, measuring the effectiveness of these bed nets is difficult. Mortality has been falling in Sub-Saharan Africa before the rapid introduction of the bed nets, mainly due to general improvements in the health environment. If we observe mortality falling in Sub-Saharan Africa as bed nets are distributed, it is unclear to what extent we can attribute the decline in mortality specifically to the bed nets. Using a large data set of DHS and MICS birth histories, along with data on bed net usage from DHS, MICS, and MIS, we estimated the effect of the rapid increase in bed net usage in Sub-Saharan Africa on infant mortality and fertility. We found that bed nets have been effective in their goal of reducing infant mortality – for our example of Nigeria, 10% of the reduction in all-cause infant mortality and 50% of the reduction in malaria-specific mortality was due solely to the introduction of bed nets.

We also found that the introduction of bed nets reduced fertility rates, perhaps due to a decreased need for replacement children. We calculated that the total fertility rate in Nigeria fell by approximately 7% due to the introduction of bed nets. The elasticity of fertility to mortality was calculated at 1.37, a plausible value given the demand for replacement and precautionary children. We believe this estimate may be overestimated since we would be picking up the effect of all child mortality in the reduced fertility measure, but underestimating child mortality since we only look at infant mortality.

Although our paper explores the reduced-form effect of bed net usage and mortality, and bed net usage and fertility, we cannot causally determine the effect of the reduction on child mortality itself on fertility directly. This relationship forms an integral part of

many theories of fertility decline, especially within the demographic transition framework which has been very influential among demographers and economists alike. However, in contrast to the somewhat convincing evidence supporting a negative effect of fertility on infant mortality, conclusive evidence on the effect of infant mortality on fertility has not been forthcoming, with different studies producing quite different results.

The fertility effects we find, at least partially, are driven by the change in infant mortality we uncover. However, we cannot disentangle the pure effect of mortality on fertility from the effect of the cost of childbearing which changes with the introduction of bed nets. Neither can we disentangle the effect of movements along the quality-quantity frontier which come from improved child health and educational outcomes on fertility. Given the important theoretical relationship between mortality and fertility in theories of fertility transitions, we hope that this paper may spur further interest in research on this question.

Our findings strengthen the arguments made by the WHO for an increase in funding for disbursements for malaria control. After rising from $100 million in 2000 to $1.71 billion n 2010, international donations have stagnated over the past three years. There is a sense that donor fatigue may threaten the funding for the continued distribution of malaria control commodities. According to the World Malaria Report 2012, an estimated US$ 5.1 billion is needed every year between to achieve universal coverage of malaria interventions including ITNs. However, only $2.3 billion is available, less than half of what would be needed to achieve universal coverage.

Our findings support the contention that erosion of international funding for malaria control, specifically of ITNs, could not only cause an increase in infant mortality due to malaria, but also reinforce higher fertility. Inasmuch as higher fertility is associated with lower education achievement, higher maternal mortality, and lower income per capita, this reduction in funding could be especially detrimental – not only for the children who die, but also for the families which are left behind.

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Table 1. List of Surveys by Country

Country	# of surveys	# of regions	Survey sources
Angola	3	17	MICS01, MIS06, MIS11
Burkina Faso	3	13	DHS03, MICS06, DHS10
Burundi	4	17	MICS00, MICS05, DHS10, MIS12
Cameroon	4	12	MICS00, DHS04, MICS06, DHS11
Dem Rep Congo	3	11	MICS01, DHS07, MICS10
Côte d'Ivoire	3	11	MICS00, AIS05, DHS11-12
Ghana	3	10	DHS03, MICS06, DHS08
Kenya	3	8	MICS00, DHS03, DHS08
Liberia	2	15	MIS09, MIS11
Madagascar	4	6	MICS00, DHS08, MIS11, MIS13
Malawi	5	26	DHS00, DHS04, MICS06, DHS10, MIS12
Mozambique	2	10	MICS08, DHS11
Niger	2	8	MICS00, DHS06
Nigeria	4	36	DHS03, MICS07, DHS08, MIS10
Rwanda	5	12	MICS00, DHS00, DHS05, DHS(I)07, DHS10
Senegal	5	10	MICS00, DHS05, MIS06, MIS08, DHS10
Sierra Leone	3	4	MICS00, MICS05, DHS08
Swaziland	3	4	MICS00, DHS06, MICS10
Tanzania	4	21	DHS04, AIS07, DHS10, AIS11
Uganda	3	4	DHS06, MIS09, DHS11
Zambia	3	9	MICS99, DHS01, DHS07
Zimbabwe	3	10	DHS05, MICS06, DHS10

Notes. DHS(I) stands for Interim DHS.

Table 2. Descriptive Statistics

Variable	Mean	S.d.	n
Mortality	0.052	0.223	190 531
Fertility	5.076	1.741	882
Net Usage (in region)	0.261	0,211	190 531
Net Ownership	0.429	0.269	171 457
PfPR 2010	0,3388	0.1937	190 531
Malaria Ecology	0,3462	0.1654	190 531
Risk Exposure	6.035	3.698	190 531
Mom Age at Birth/10	2.631	0.686	190 531
Birth interval under 24	0.190	0.392	190 531
Male	0.507	0.499	190 531
Trend	7.679	3.493	190 531

Table 3. Evolution of Mosquito Net Usage and Ownership by Country and Year

Country									Year							
		1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Angola	Usage			10.2					22.5					26.6		
	Ownership								35,1					36,2		
Burkina Faso	Usage					17,8			16,3				54,7			
	Ownership					38,4			49,4				67,6			
Burundi	Usage		2,7					17,8					48,1		54,8	
	Ownership							17,6					54,9		64	
Cameroon	Usage		13,5				11,4		27,9					29,1		
	Ownership						19,5		32,2					51,1		
Congo (Dem. Rep)	Usage			13,7						22			38,7			
	Ownership									30,9			52,8			
Cote d'Ivoire	Usage		9,3					7,9	17,5					39,9		
	Ownership							21	28,4					72,4		
Ghana	Usage					15,8			36,6		42,7					
	Ownership					19,9			33,5		48					
Kenya	Usage		15,7			17,6					54					
	Ownership					24,9					64,4					
Liberia	Usage										30,7			38,4		
	Ownership								30,9		55,5			53,5		
Madagascar	Usage		88,9			39,9						50,8		77,2		65,2
	Ownership					41,6						64,9		81,6		72
Malawi	Usage		3,6				20,8		30,6				46,6		59,5	
	Ownership		17,8				43,4		51,4				67,7		60,2	
Mozambique	Usage					11,5					41,4			37,4		
	Ownership					19					54			57,2		
Niger	Usage		21,6						19,1							
	Ownership								72,5							
Nigeria	Usage					5,5				4,3	12,3		31,9	18,6		
	Ownership					10,6				4,9	18,3		45,3	40,1		
Rwanda	Usage		9,7					16,4		60,8			69,8			
	Ownership		9,2					19,8		60			82,6			
Senegal	Usage		17,2					17,6	30,4		36,5		46,3			
	Ownership							45,8	62,6		76		82			
Sierra Leone	Usage		14,9					20,5			28,9					
	Ownership							20,2			40,6					
Swaziland	Usage		0.0						0,01				1,8			
	Ownership								6,7				11,1			
Tanzania	Usage						30,6			41,8		68,9		74,1		
	Ownership						46,2			61,8		76,7		93,4		
Uganda	Usage		12,7						20,3			40,7		52,3		
	Ownership		15,3						33,7			59,2		74,4		
Zambia	Usage	7,8		15,7						34,4						
	Ownership			27,2						66,7						
Zimbabwe	Usage	2,7						6,3				22,3	13,6			
	Ownership	9,6						20,5					40,8			

Table 4. The Effects of Mosquito Net Usage on Infant Mortality in Sub-Saharan Africa

	One year mortality			
	(1)	(2)	(3)	(4)
Net usage (in region)	-0,0230	-0,0036	-0,0034	0,0049
	(0,0062)	(0,0049)	(0,0049)	(0,0059)
MalEco*Net usage			0,0069	-0,0499
			(0,0215)	(0,0280)
Malaria ecology	0,0314			
	(0,0059)			
Risk exposure	0,0028	0,0028	0,0028	0,0028
	(0,0002)	(0,0001)	(0,0001)	(0,0001)
Mom age at birth/10	-0,0001	-0,0001	-0,0001	-0,0002
	(0,0009)	(0,0008)	(0,0008)	(0,0008)
Birth interval under 24	0,0317	0,0313	0,0313	0,0313
	(0,0023)	(0,0013)	(0,0013)	(0,0013)
Male	0,0102	0,0102	0,0102	0,0102
	(0,0009)	(0,0010)	(0,0010)	(0,0010)
Trend	-0,0019	-0,0023	-0,0023	-0,0024
	(0,0003)	(0,0002)	(0,0002)	(0,0009)
Constant	0,0348	0,0434	0,0434	0,0442
	(0,0038)	(0,0026)	(0,0026)	(0,0028)
Region fixed effects	no	yes	yes	yes
Country time trend	no	no	no	yes
R^2	0,009	0,013	0,013	0,014
N	190 531	190 531	190 531	190 531

Table 5. The Effects of Mosquito Net Ownership on Infant Mortality in Sub-Saharan Africa

	One year mortality			
	(1)	(2)	(3)	(4)
Net ownership (in region)	-0,0175	-0,0005	0,0013	-0,0015
	(0,0051)	(0,0049)	(0,0050)	(0,0056)
MalEco*Net ownership			0,0318	-0,0078
			(0,0178)	(0,0246)
Malaria ecology	0,0267			
	(0,0058)			
Risk exposure	0,0025	0,0026	0,0026	0,0026
	(0,0002)	(0,0001)	(0,0001)	(0,0001)
Mom age at birth/10	0,0001	0,0005	0,0005	0,0000
	(0,0001)	(0,0008)	(0,0008)	(0,0001)
Birth interval under 24	0,0305	0,0302	0,0302	0,0303
	(0,0025)	(0,0014)	(0,0014)	(0,0014)
Male	0,0104	0,0103	0,0103	0,0103
	(0,0010)	(0,0011)	(0,0011)	(0,0011)
Trend	-0,0021	-0,0024	-0,0024	0,0053
	(0,0003)	(0,0003)	(0,0003)	(0,0033)
Constant	0,0392	0,0428	0,0424	0,0365
	(0,0041)	(0,0028)	(0,0028)	(0,0038)
Region fixed effects	no	yes	yes	yes
Country time trend	no	no	no	yes
R^2	0,008	0,013	0,013	0,013
N	171 457	171 457	171 457	171 457

Table 6. The Effects of Mosquito Net Usage on Fertility in Sub-Saharan Africa

	Total fertility rate (TFR)			
	(1)	(2)	(3)	(4)
Net usage (in region)	-0.344	0.500	0.930	0.919
	(0.284)	(0.381)	(0.651)	(0.664)
MalEco*Net usage			-1.379	-3.382**
			(1.691)	(1.655)
Malaria ecology	1.365***			
	(0.344)			
Trend	-0.169***	-0.224***	-0.224***	
	(0.0180)	(0.0196)	(0.0196)	
Constant	5.920***	5.513***	5.372***	4.775***
	(0.175)	(0.782)	(0.801)	(0.768)
Region fixed effects	no	yes	yes	yes
Country time trend	no	no	no	yes
R^2	0.163	0.612	0.613	0.788
N	832	826	826	826

Notes. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 7. The Effects of Mosquito Net Ownership on Fertility in Sub-Saharan Africa

	Total fertility rate (TFR)			
	(1)	(2)	(3)	(4)
Net ownership (in region)	-0.154	-0.126	0.758*	0.367
	(0.250)	(0.336)	(0.408)	(0.404)
MalEco*Net ownership			-4.059***	-3.743***
			(1.165)	(1.096)
Malaria ecology	1.198***	3.299*	3.466*	2.739
	(0.344)	(1.815)	(1.906)	(1.931)
Trend	-0.137***	-0.182***	-0.154***	-0.472***
	(0.0217)	(0.0230)	(0.0238)	(0.110)
Constant	5.563***	5.178***	4.884***	5.459***
	(0.197)	(0.652)	(0.698)	(0.720)
Region fixed effects	no	yes	yes	yes
Country time trend	no	no	no	yes
R^2	0.102	0.681	0.688	0.810
N	721	701	684	684

Notes. Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Figure 1: Predicted Malaria Prevalence and Rain

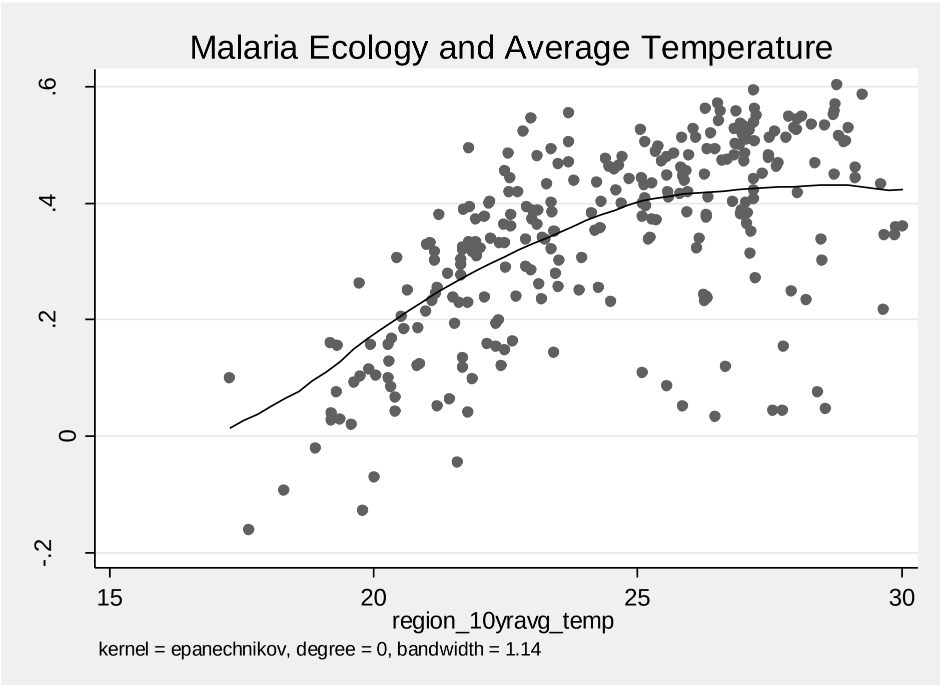


Figure 2: Predicted Malaria Prevalence and Rain

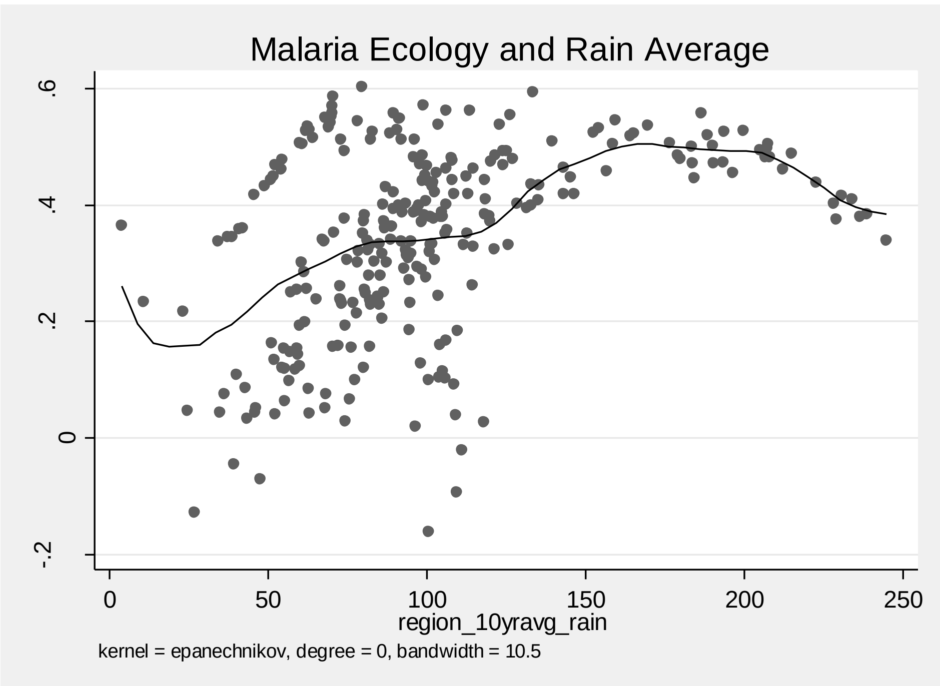
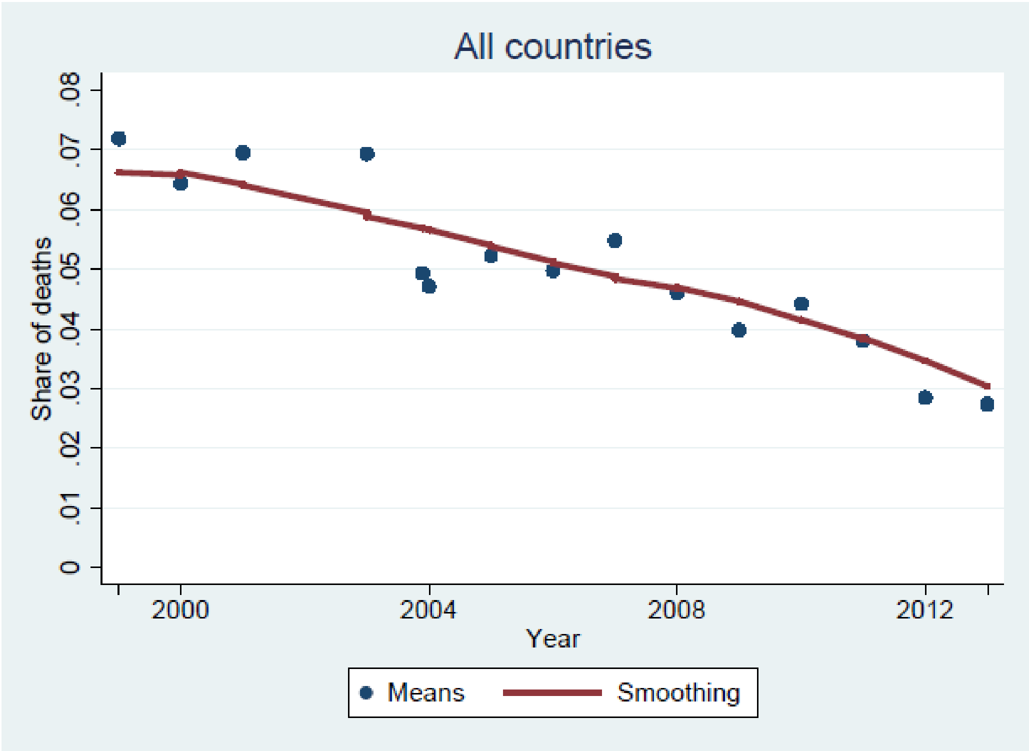
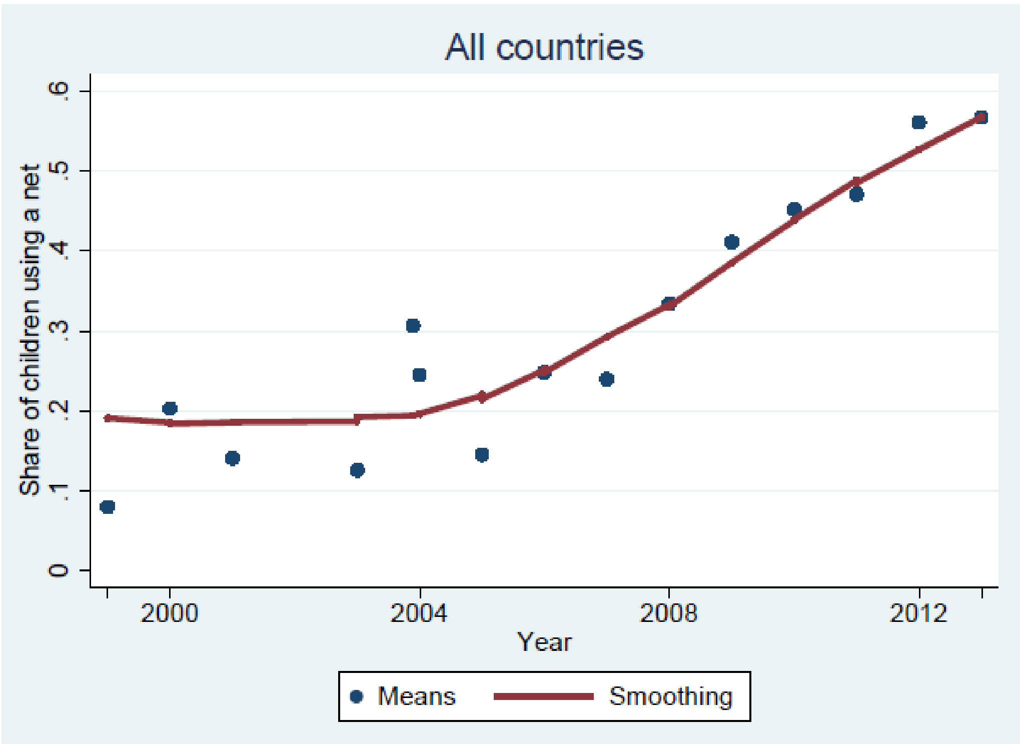


Figure 3: Evolution of mortality and bednet usage in Sub-Saharan Africa (1999-2013)





Appendix A. The Effects of Climate on Malaria Prevalence

	PfPR
Avg. rain	0.024
	(2.73)**
Avg. rain squared	-0.000
	(1.72)
Avg. rain cubed	0.000
	(1.35)
Avg. rain quartic	-0.000
	(1.23)
Avg. max. rain	-0.006
	(1.64)
Avg. max. rain squared	0.000
	(1.37)
Avg. max. rain cubed	-0.000
	(1.16)
Avg. max. rain quartic	0.000
	(0.98)
Avg. min. rain	-0.014
	(2.48)*
Avg. min. rain squared	0.001
	(1.20)
Avg. min. rain cubed	-0.000
	(0.70)
Avg. min. rain quartic	0.000
	(0.46)
Avg. temp	-33.693
	(3.62)**
Avg. temp squared	2.081
	(3.53)**
Avg. temp cubed	-0.057
	(3.43)**
Avg. temp quartic	0.001
	(3.33)**
Avg. max. temp	21.673
	(3.74)**
Avg. max. temp squared	-1.186
	(3.68)**
Avg. max. temp cubed	0.029
	(3.61)**
Avg. max. temp quartic	-0.000
	(3.53)**
Avg. min. temp	0.140
	(0.05)
Avg. min. temp squared	0.016
	(0.07)
Avg. min. temp cubed	-0.001
	(0.19)
Avg. min. temp quartic	0.000
	(0.28)
Constant	52.635
	(1.76)
R^2	0.68
N	269

Notes. * p<0.05; ** p<0.01.
Average rain and temperature are measure in millimeters and Celsius, respectively. Averages are calculated by finding the average temperature for each month from 2000-2009, and then averaging over all the months. Average maximum (minimum) rain and temperature are calculated by first finding the month with maximum (minimum) of each year 2000-2009, then averaging these averages. PMP refers to our predicted malaria prevalence measure.