Evaluating the Effects of Large Scale Health Interventions in Developing Countries:

The Zambian Malaria Initiative

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Introduction

Following the Roll Back Malaria Initiative in 2001, the government of Zambia committed to malaria control, leading to massive and rapid scale-up of anti-malarial efforts which peaked in 2006 and 2007. The National Malaria Control Program (NMCP) of Zambia is one of Africa's largest malaria prevention and treatment initiatives, setting a goal of a 75% reduction in malaria incidence - and a 20% decrease in under-five mortality - in five years through a combination of insecticide treated nets, indoor residual spraying, and deployment of rapid diagnostic tests and front-line combination therapy drugs. The total 2008 malaria prevention and control budget, including in-kind contributions, was estimated at US$59,816,211[1], including significant aid from the Global Fund to Fight HIV/AIDS, Tuberculosis and Malaria, the United States Agency for International Development (USAID), the World Bank, the World Health Organization (WHO), and the Bill and Melinda Gates Foundation (through the Malaria Control and Evaluation Partnership in Africa—MACEPA).

Figure 1 tells the story of the program's success according to data in Zambia's national health statistics system, the HMIS (we discuss the data used in detail in the next section). The overall number of malaria deaths in the country decreased by at least half over the period 2000-2008, during which population rose by 30%, implying a reduction in the death rate of over 60%. As will be seen below, the number of inpatient visits for malaria declined by a nearly similar magnitude, implying a reduction in morbidity as well as mortality.

Evidence from the 2001 and 2007 waves of the Demographic and Health Survey confirms the picture painted by the HMIS. The percentage of children under five reported with a fever over the two weeks preceding the interview dropped from 44.6% in 2001 to 17.9% in 2007, a reduction of close to 60%. (As a comparison, the fraction of children suffering from diarrhea fell by only a quarter, from 41.9% to 31.8%, over the same time period.) The progress made in child mortality between the two surveys is remarkable: The under-five mortality rate fell from 168 per thousand live births in 2001 to 119 in 2007. As discussed below, the latter figure may not even reflect the full mortality reduction to date. This decline was not solely the result of the malaria initiative, however, since other health campaigns were taking place at the same time.

There are different ways to quantify the magnitude of Zambia's recent success in health improvement. The reduction in under-five mortality represents approximately 25,000 children's lives saved per year. To compare the mortality improvement with more "economic" outcomes, we can do a back of the envelope calculation using the Human Development Index (HDI), which weighs economic and non-economic characteristics into an overall measure of quality of life. Using the formula for the HDI, one can calculate the amount of income growth that would be

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[1] Government of Zambia, Ministry of Health. *2008 National Malaria Control Action Plan: Actions for Scale-up for Impact on Malaria in Zambia.* Lusaka.

equivalent to a particular rise in life expectancy at birth. A conservative estimate, using just the data on under-five mortality, is that life expectancy at birth in Zambia rose by 2.25 years over the period 2000-2007.[2] Plugging this into the HDI formula shows that an equivalent rise in HDI would be achieved if income per capita grew by 25%.[3]

In the research program of which this paper is a part, we study the Zambian malaria initiative with three broad goals. First, we want to systematize and improve the quality of available data on both inputs to malaria control in Zambia and the outcomes of the malaria control program. As will be seen below, much of the available data were not easily interpretable before we began our efforts and this task has consumed most of our efforts thus far. The second goal of the project is to use the available data from Zambia to examine the causal relationship between inputs into malaria control and health outcomes. Much of the monitoring of the campaign's progress has focused solely on the inputs side, for example on the number of bed nets distributed or houses sprayed. Jointly analyzing data on inputs and health outcomes will allow for some measurement of how well the program is doing in achieving its stated goal, and possibly even for a calculation of which intervention methodologies produce the biggest "bang for the buck". Finally, our third goal (which we do not advance in the current paper) is to use the experience of the current malaria campaign in Zambia to understand the economic effects of malaria and of its control.

The rest of this paper is structured as follows. In Section 2, we discuss our data sources regarding both health outcomes and inputs into malaria control. A good deal of our effort in this project has gone into improving the quality of the data in the Zambian Health Management Information System (HMIS), an administrative record system that has the potential to yield richly detailed data, but is also subject to a number of problems. We discuss the HMIS data, how we have tried to improve it, and the picture of changing malaria impact painted in this improved data. Section 3 describes the background to and scope of the current malaria initiative. Section 4 presents data on how the different components of the initiative has been rolled out, focusing in variation among different regions. In Section 5, we attempt to assess the link between data on the rollout – that is, inputs to reduced malaria – and data on improvements in malaria mortality and morbidity, using both the HMIS and the Zambian Demographic and Health Surveys (DHS). Section 6 concludes by discussing avenues for future research and also the challenge of sustaining the progress made in Zambia thus far.

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[2] This is based on multiplying a one in twenty reduction in under five mortality by 2000 life expectancy at birth, with was approximately 45 years.

[3] The HDI is the sum of three terms, two of which are $\frac{e_0 - 25}{60}$ and $\frac{\ln(y)}{\ln(40,000) - \ln(100)}$, where e_0 is life expectancy at birth and y is real GDP per capita. The change in income that has the same impact on HDI as a particular change in life expectancy is given by the equation $\Delta \ln(y) = \frac{\ln(40,000) - \ln(100)}{60} \times \Delta e_0$.

2. Data on Malaria and Other Health Outcomes

In this paper we rely on two data sources: first, the 2001 and 2007 waves of the Demographic and Health Survey (DHS), and second, the Zambian Health Management Information System (HMIS).[4]

2.1 DHS data

Our first source of data is quite standard: the 2001 and 2007 waves of the Zambian Demographic and Health Survey (DHS). We use the children recode files, which contain detailed information on all children under age 5 at the date of the interview as well as a complete list of household and respondent characteristics. We have 13,219 observations, 6,877 from 2001, and 6,342 from 2007.

To link the DHS households to the NMCC's rollout data, we used ArcGIS to map DHS cluster locations into the respective districts. All 72 districts were covered in the 2001 survey; 70 out of 72 were covered in 2007.

2.2 HMIS data

The national Health Management Information System (HMIS) captures an impressive amount of routine health data. The database was first introduced in 1995 to collect disease data, service delivery information, and clinic operations reports. It provides data on health outcomes in the facilities that are formally part of the Ministry of Health. These range in size from hospitals (located in 60 or the 72 districts in Zambia) to small health posts which would be staffed by a single nurse or Community Health Worker.[5]

The database has recently been subject to major technical revisions, resulting in a completely revised system involving a monthly reporting structure and new management software that captures additional indicators, including separate measures for confirmed and unconfirmed malaria cases. Officially the new HMIS became the primary reporting system

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[4] A third potential source of data is the Malaria Indicators Survey (MIS) conducted in 2006 and 2008. The MIS collects data on household uptake of anti malarial measures (such as use of bednets and IRS) and health outcomes such as child sickness. However, this data was not available for our use at the time of this writing.

[5] Lusaka's referral hospitals are not included in the HMIS in order to prevent redundancy; theoretically, every person seen in such a hospital should have already been recorded at another hospital or health center.

beginning January 2009. Most districts transitioned into the new system by reporting in both formats for some part of 2008. Using historical data however, the NBER team worked with files from the old HMIS. The following description relates to this original system.

Traditionally, data was passed from health facilities up to the level of the district, and from there to the provincial levels (9 in Zambia). The facilities kept both hard copy patient logs and tally sheets that track clinic functions. At the end of each quarter, facilities reported their summary data to District Medical Offices. District Health Information Officers were charged with collecting the reports from each health facility and compiling district reports. They were responsible for ensuring all health facilities have reported, as well as cleaning each facility's data.

Provincial Data Management Specialists collected data from the districts and compile a provincial data set disaggregated at the facility level. Before forwarding the data on to the national level, the provincial officer once again cleaned the data and verified it for completeness. Each of the provincial data sets were compiled into a unified national data set at the Ministry of Health in Lusaka. This data set remained disaggregated at the facility level.

There were opportunities for error at every stage of this process. The quality of health facility data was very dependent on staff and their commitment to record keeping. Some health facilities had been meticulous about their record keeping, plotting their health outcomes manually, and discuss them with their staff. Others had not been able to keep records in conjunction with patient visits, or delegated reporting requirements to semi-literate staff. Some health facility staff members admitted to only updating tally sheets on a monthly basis, or simply estimating figures when time for reporting is limited.

The transfer from health facility paper records to electronic district summaries was also error-prone. The original HMIS database had no built-in consistency checks for disease data, and data was entered only once. In data verification exercises, data entry mistakes were one of the most frequent causes of error. Further, while data officers at all levels of the health system were responsible for cleaning and verifying health facility data, these checks were not systematic and in many cases are completely non-existent.

The quarterly updates were transferred from district to province and from province to the Ministry via disks, flash drives, and occasional e-mail, resulting in a national data set that lagged behind current developments, sometimes by over half a year. When data sets were processed in Lusaka, only the most recent quarter received from the provinces were appended to previous data. However, even after initial submission deadlines, data staff at sub-national levels continued to work on assembling missing data and auditing reports. As a result, changes subsequently made at the district or province level were lost in the national data set. To compound the problem, when data was cleaned at the district and provincial levels, revised data sets were passed upwards towards Lusaka, but not returned to the original sources of the data.

Consequently, significant inconsistencies existed between the data sets at different levels of the health system, and there was no single authoritative data set to rely upon. Further, a significant number of health facilities simply failed to report their HMIS figures or have provided their data to districts too late to be captured in aggregated reporting to the national level.

2.2.1   Improvement of the HMIS

Ultimately, the HMIS provides the only source of consistent, national health data. Selected surveys (especially the Demographic and Health Surveys and the Malaria Indicator Survey) provide more accurate snapshots of malaria levels in select districts at given times, but only the HMIS allows for detailed, localized analysis of malaria levels over time. With this in mind, a major goal of this project was to clean the HMIS. In order to validate the entire HMIS, data efforts have focused on re-collecting data from each of the more than 1000 health facilities in Zambia, using data sets from each of the 72 districts.

To facilitate this data collection, the project organized a series of malaria data workshops in each province. Prior to these workshops, HMIS data was systematically scanned for outliers and suspicious data points (duplicate figures, significant variance between quarters or years, reporting inconsistencies). District health officials were asked to find missing reports and justify all irregular data ahead of the workshops. This data audit served as one of the final updates of health data from 2000 to 2008, ahead of its transition into the new HMIS system.

The workshops also provided an opportunity to bring together disparate data reflecting malaria prevention and treatment campaigns at the district level. Districts were asked to visit each health facility in an attempt to capture all malaria interventions within the facility's catchment area by government and non-government partners. District pharmacists provided their data on treatment drugs (COARTEM) and diagnostic test distribution (RDTs) to each health facility, while the environmental health technician provided data on IRS activities. During the workshop, this data was pooled with health outcomes, presented, and discussed by the districts. Subsequently, it could be used by the project team to plausibility-check the national data sets. While the workshops helped to build a data set of unprecedented detail, they also built local capacity through several days of training to on how to compile and analyze integrated health databases.

In total, the nine provincial workshops were conducted at a total cost of approximately $200,000. Funding was provided by the NGOs Malaria Consortium and MACEPA, as well as the National Malaria Control Centre with support from a World Bank Grant. The workshops brought together a diverse array of district health personnel, including district information officers, malaria focal point persons, and district directors of health. Provincial and national health officers also attended each workshop. In total, over 250 attendees were trained in various aspects of data

collection, cleaning, and analysis.[6]   Finally, the workshops disseminated the most recent version of the HMIS database to national, provincial, and district levels, thereby ensuring that the most updated versions were available both to local and to central decision-making.

Changes resulting from our Correction

The workshops resulted in a more complete, correct, and consistent HMIS database for the years 2000 through 2008. In terms of completeness, the initial, raw HMIS that we received had 2,957 health center quarterly reports and 361 hospital reports marked as missing, for a total of 3,318 records (out of a total of approximately 45,000 facility quarterly reports that should have been present). This came directly from the HMIS through their "Reporting Completeness" indicator, which notes whether a health center was expected to provide a report in a given quarter (was it operational) and whether the report was received.   Reportedly missing records were not always due to missing data; in many cases the HMIS erroneously stated that a health center was operational during a particular quarter or the health center had a unique reporting practice (like reporting jointly with another center) that wasn't accounted for in the computer. Part of the goal of the workshops was to revise the system to eliminate these issues. Over the course of our work, the number of missing quarterly reports was reduced by 63% and data was added on 28 facilities (1.9% of the total) that had been missing all together in the HMIS.[7]

Ahead of the workshops, apparent data entry errors could be identified and listed, which allowed district staff to review them ahead of the workshops. These resulting changes often had major implications for national level trends. For instance, in the uncorrected HMIS, under-five malaria deaths rose 3,342 in 2006 to 3,783 in 2007 – a worrying trend to observe in the middle of a massive anti-malaria campaign. These figures had been reported in the 2008 *World Malaria Report*, among other places. The workshops showed that the reported increase was due to three districts with erroneous figures. In the fully corrected HMIS, under-five malaria deaths fell from

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[6] Improving the HMIS data was only one aspect, and in the end not the major thrust, of the workshops. Rather, analytical capacity building and giving people the idea of "what can be done with their data" were the focus. The workshops frequently created lively debates between districts as participants challenged each other and displayed the impacts of best and worst practices. In many cases, these workshops provided the first opportunity for district medical officers to use data to consider the effects of interventions they had implemented and create strategic plans for future interventions. The notion that data analysis capabilities empower district staff and generate increased interest in accurate and complete data was considered a promising approach by the Ministry of Health and its partners. Follow-up workshops have been initiated in several provinces.

[7] This did not reflect the impact of our work alone. Data completeness and accuracy could have increased without us because districts had the chance to revisit things on their own, and because national level data is updated with a time lag.

3,235 in 2006 to 2,680 in 2007. Table 1 lists the total number of corrections of different types of data.

2.2.2 Remaining Issues in the HMIS Data

Diagnosis and Access to Health Facilities

The number of malaria cases that are reported in HMIS is potentially biased by factors that cannot be readily observed in the data.

One issue is the inconsistency in diagnostic practices over time. The HMIS is supposed to report all outpatient and inpatient visits, broken down by diagnosis. A difficulty in using this data is that the way in which malaria is diagnosed has changed over the period we examine. Mis-diagnosis of malaria is thought to have been very common. Because of both lack of diagnostic technology and enforced treatment guidelines, health workers often classified a large fraction of fevers as malaria. As discussed below, part of the anti-malaria initiative has included the deployment of Rapid Diagnostic Tests (RDTs) in health centers, in order to both economize on malaria treatment and properly treat non-malaria fevers. The deployment of RDTs should have lead to a reduction in diagnosed cases of malaria even if there was no true change in disease prevalence. Similarly, it is thought that introduction of RDTs led to increased diagnosis of other conditions, particularly pneumonia and respiratory tract infections. However, data on the use of RDTs is not available in HMIS.

Another bias from diagnosis concern HIV/AIDS. In the field, we were told that a lot of HIV deaths were officially diagnosed as malaria for reasons of stigma, especially for young to middle-age men. This may inflate malaria deaths and also cause a false indication of declining malaria deaths as HIV treatment improves. Further, because only primary cause of death is listed in the HMIS, AIDS patients who die of malaria may be classified as malaria deaths.

Another issue is that the accessibility of the health system changed over time. This is most dramatically shown in outpatient data for adults in rural facilities. A large increase in this variable is recorded in 2006. Likely, it can be explained by the abolishment of user fees in rural health clinics that took place that year. Prior to 2006, all public-sector patients were expected to pay nominal fees for consultations, diagnostic tests and some drugs supplied in government clinics. In 2006, all consultation and diagnostic fees were removed for patients living in designated rural areas (additionally, some drugs like antimalarials have been provided free of charge with support from international organizations). Again, without a true change in disease prevalence; it is likely that prior to the abolishment of user fees, many would-be outpatients had resorted to self-treatment.

To minimize the bias from such contextual factors, we focus on severe cases – specifically, inpatient malaria cases, reported malaria deaths, and reported total deaths. In the HMIS, diagnostic codes for inpatients are entered only at the time of discharge. We think that even prior to the abolishment of user fees or the advent of RDTs, severe cases would have received inpatient treatment and would have been correctly diagnosed most of the time (prior to the advent of RDTs, malaria diagnoses could be confirmed using microscopy at many clinics and hospitals treating severe malaria).

Extent of HMIS Coverage

A potential worry about the HMIS is that it only measures cases that enter the government's health system. To the extent that this is a small fraction of total cases, one would worry both that it is non-representative and, more seriously, that the fraction of cases captured by the HMIS varies over time. In the latter case, the use of the HMIS to measure trends in disease prevalence would be seriously compromised.

One way to measure to fraction of cases that the HMIS captures is to focus on deaths, because in this case there is the possibility to use other data sources as a benchmark. Figure 2 shows the under-five death rate (annual deaths of children under five in the HMIS per 1,000 children; population data are estimates from Ministry of Health). The data for the full sample show a relatively steady decline from 8.63 in 2001 to 5.08 in 2007, followed by a precipitous decline to 3.25 in 2008. This last figure may represent incomplete reporting for 2008. In the high quality sample (discussed below), the trend from 2001-2007 is roughly similar, but the decline in 2008 is greatly diminished. We thus do not use the full sample figure for 2008.

We can compare the count of deaths in the HMIS to both the DHS and to other mortality estimates. Most estimates of child mortality are expressed in terms of deaths before age five per 1,000 live births. To convert the HMIS data to this metric, we simply multiply by five (this is a slight over-estimate because the number of children declines with age due to population growth and mortality.) Thus in the HMIS data, the child mortality rate was approximately 42.9 per 1,000 live births in 2000, and 25.4 in 2007. Deaths declined by 41%. In the DHS deaths per thousand live births were calculated at 168 in 2001-2 and 119 in 2007, implying a decline of 29%.[8] Other published estimates of child mortality show numbers similar to the DHS for 2000, but do not show the same decline as observed in the HMIS and DHS. For example, WHO *World Health Statistics 2009* lists under five mortality rate for Zambia as 178 in 2000 and 170 in 2007. It is not clear what the source for these numbers is, although other WHO publications rely on the DHS estimate for the year 2000. We suspect that the lack of decline in these published figures reflects non-availability of data, rather than information from an alternative source.

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[8] Zambia DHS Final Report, March 2009, http://www.measuredhs.com/pubs/pdf/FR211/FR211[revised-05-12-2009].pdf

Using either the DHS or WHO number for 2000 as a benchmark implies that the HMIS in that year is capturing between a fifth and a quarter of deaths under age five. In terms of the change between 2000 and 2007, the HMIS shows a larger decline than the DHS, although in both cases the magnitude is impressive. Further, it is important to note that the DHS measures under-five mortality by looking at the experience of all children born in the last five years. Thus the number from the 2007 DHS includes children born in 2003, whose early life (when mortality is highest) was not impacted by the malaria initiative. Thus it is expected that the decline in the HMIS would be larger. If instead of using the HMIS death rate in 2007, we use the average death rate from 2003-2007, then the decline in under five mortality in the HMIS is 29%, exactly matching the DHS.

The low representation of total deaths in the HMIS suggests several possible biases. Presumably the fraction of disease episodes and deaths that reach a clinic or hospital is higher in urban regions than in remote, rural areas.[9] Since malaria is higher in rural regions, this suggests that malaria deaths are understated in the HMIS data. Regarding the change in malaria prevalence as a result of the anti-malaria initiative, sorting out the bias is more difficult. On the one hand, the intensity of the program was probably highest in the same areas (places with health facilities nearby) that are overrepresented in the HMIS. This might suggest that the HMIS data would overstate the impact of the program. On the other hand, areas that were near clinics, especially cities, were likely relatively better served and had lower malaria impact prior to the initiative. Thus the HMIS data may be underweighting places where the largest scope for impacting malaria incidence.

To further investigate the bias from undercounting in the HMIS, Figure 3 compares under five mortality by province in the DHS and HMIS. The data from the DHS are the under-five mortality rate for 2007. From the HMIS, we take under five deaths in 2007, divided by an estimate of under-five population, then multiplied by five to make a figure consistent with the DHS measure. The extent to which the ratio of HMIS to DHS deaths differs among provinces is quite surprising. At the high end, in Copperbelt Province, HMIS deaths are 33% of those implied by the DHS. At the low end, in Lusaka, deaths in the HMIS are only 5% of those implied by the DHS. The explanation for the low fraction of deaths recorded in the HMIS in Lusaka is that the city's two major hospitals are not included in the HMIS. Most patients near death in Lusaka would end up in one of the referral hospitals. Theoretically, all patients are supposed to be seen at another health center prior to admission to these hospitals, and the hospital is supposed to report back to the referring center with the patient's outcome for entry into the HMIS. We suspect that the reports of death do not make it back into the referring center's HMIS records.

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[9] In 2005, 36.5% of the population lived in urban areas (though presumably a smaller fraction of the under-five population).

To check whether undercounting in the HMIS might bias conclusions regarding changes in malaria over time, Figure 4 compares across provinces the change in under-five mortality in the DHS between 2001 and 2007 with the change in deaths in the HMIS per 1,000 children under five. The fit is relatively good (correlation 0.76). This gives us confidence that changes in the HMIS reflect actual changes in malaria mortality and morbidity.

Non-reporting facilities

A final concern with the corrected HMIS is the potential confusion between health facilities that have no cases to report and cases where data are actually missing. There are 1,501 health facilities in the HMIS reporting in 36 quarters between 2000 and 2008. Each quarterly record has number of in- and outpatients under and over age five, as well as the number of death for up to 61 diseases – the total number of diseases recorded in the HMIS is 71. About 70% of health facilities deal only with outpatients. Many of the remaining facilities have incomplete reporting. To make sure our results are not affected by differences in reporting, we construct a high quality sample consisting of 78 large hospitals with at least one patient reported in each quarter between 2000 and 2008 – a sample if 2808 quarter-year observation at the hospital level. To the extent that missing entries represent true zeros (no report because there was no malaria), this sample will lead to an underestimate of the true effects, as hospital with few malaria patients might discontinue reporting malaria due to the observed declines.

Table 2 shows data on inpatient visits and deaths broken into age groups (under 5 and 5+), separately for malaria and for all non-malaria conditions. We show the data both for all facilities, and for the set of "always reporting" facilities. The table shows that, as discussed below, the decline in malaria prevalence has come at the same time as a dramatic improvement in health more generally, due primarily to massive scale up of HIV treatment and child health programs.

Another notable feature is that among the group of all facilities, there is an apparently discontinuous drop in both in-patient visits and mortality, both for malaria and other conditions, in the year 2008. Among the always-reporting facilities, there is a smaller drop in malaria cases and deaths, and no apparent drop for non-malaria conditions. It is possible that this is due to reporting problems in non-always-reporting facilities. There is a particular drop off in the number of facilities providing non-zero reports in the last two quarters of 2008. We believe this is due to both the switch over to the new HMIS and to delays in facility reports reaching Lusaka. For these reasons, we assign little credence to the all-facilities drop in mortality in 2008.

In Figure 5 we look at an alternative to the always reporting facilities. We construct a chain index by looking for every pair of adjacent years at the full set of facilities that report in both years. The overall story told in this data is not very different from the always reporting facilities. From 2000 to 2008, under-five malaria deaths fall by 42% and deaths of people aged

five and above fall by 43%. The figure also shows a spike in over-five outpatients diagnosed with malaria, a phenomenon we discuss below.

As a final, very conservative way to look at the decline in malaria, we examine the ratio of malaria deaths to non-malaria deaths in Figure 6. We do this for different age groups and for both all facilities and the always-reporting facilities. If there were no actual improvement in non-malaria health outcomes, and the decline in non-malaria mortality in the HMIS reflected only reporting problems, then this measure would nonetheless correctly measure the decline in malaria mortality. As the figure shows, the ratio of malaria to non-malaria mortality fell by between 1/3 and ½ over this period.

2.1.3   Seasonality in the HMIS

As a check on the quality of the data in the HMIS, and also to exploit some of its richness, we look at seasonal variation in the malaria incidence. One very important aspect of the data in the HMIS, is its pronounced seasonality (which is consistent with Zambia's climate, as discussed below). Table 3 shows the results of a basic regression with quarterly under 5 mortality as dependent variable with quarter and year fixed effects.[10] As apparent from the quarter dummies, seasonal fluctuations are strong. With an average under-5 death rate of 1.75 per 1000, a negative coefficient of -0.7 in quarter three implies that the death burden in the best quarter is only about 60% of the death burden in the worst quarter (quarter 1). These seasonal fluctuations are even more pronounced for malaria. Overall, about half of the seasonal fluctuations in under-five mortality is driven by malaria.

In columns 2 and 4 of the table, we divide the sample in the middle and estimate quarter dummies separately for the two halves. What we find is that the seasonality of both has gone down. Indeed, the coefficients show that, not surprisingly, most of the decline in seasonality in total under five deaths comes for the decline in seasonality of malaria deaths.

3. Origins and Scope of the Zambia Malaria Control Program

Zambia is a land-locked country in Southern Africa with three distinct seasons: a hot, dry season from late August to October; a warm, rainy season from approximately November to April; and a cool, dry season stretching from May to early August. In the cool season temperatures can be as low as 10 degrees Celsius[11], hindering mosquito reproduction; as such,

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[10] Note that this is deaths in a quarter divided by the under five population, so its mean is one-quarter of the under-five death rate reported in Table 2/Figure 1.

[11] Data provided by the Zambian Meteorological Department.

reported cases of malaria are the lowest during the third quarter of the year. Traditionally malaria transmission is highest in the first and fourth quarters, peaking in March towards the end of the warm, rainy season. The swampy Luapula Province, in the north Zambia, remains the region's hotspot, though malaria is traditionally endemic throughout the country.

As discussed in Packard (2007), the malaria situation in Zambia prior to the current campaign represented a serious deterioration of conditions that had existed in previous decades. Annual malaria incidence rose from 121 per 1,000 in 1976 to 376 per 1,000 in 2000. Among the factors that contributed to this deterioration were Zambia's role as a front-line state in the struggle against apartheid, international constraints on the use of DDT, and the country's broader economic decline (GDP per capita at PPP rose from $954 at independence in 1964 to $1,235 in 1970 and peaked at $1,474 in 1976. It then declined, reaching a nadir of $829 in 1995 before rising to $946 in 2003.[12]) Zambia's malaria control program had relied extensively on Indoor Residual Spraying, but by 1990 spraying had ceased altogether. Resistance to chloroquine also rose as a result of improper usage.

The beginning of the current anti-malaria initiative was a result of a confluence of factors both in Zambia and elsewhere in the world. In particular, the development of new technologies and a new alignment of priorities within the development community led to a desire to undertake a demonstration case showing the possibility of rapidly scaled up malaria control. Resources would be concentrated on a single country with the goal of producing a tangible success, which would then serve a model for neighboring countries. Zambia was chosen as the test case because it was perceived as having the institutional capacity and political will to successfully undertake such a program and also because its climate made it all the more likely that success could be accomplished.

3.1 Elements of program

Zambia's integrated malaria control program is one of the world's largest national treatment and prevention plans. The program is led by the National Malaria Control Centre (NMCC), a sub-division of the Directory of Public Health and Research in Zambia's Ministry of Health. The national secretariat is responsible for overall program administration throughout the country and disburses funds to districts on a programmatic basis. The NMCC works in partnership with Medical Stores (a quasi-private national distribution program for all drugs and medical supplies in the public sector) to ensure that each district and referral hospital receives adequate supplies of drugs and diagnostic tools. 72 District Medical Offices directly implement

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[12] Penn World Tables, version 6.2. Variable *RGPCH* in year 2000 constant international dollars. GDP per capita rose a further 16 percent in total from 2003 to 2007 (World Development Indicators database), on the back of soaring copper prices. The price of copper fell by 60% in the year to February 2009, suggesting that Zambia will be particularly hard hit in the current world slowdown.

most national malaria prevention and treatment programs. They pertain to 9 provinces, each with a Provincial Health Office responsible for supervising district health programs.

The program is funded by a combination of Government of Zambia as well as national and international aid partners. From its own revenues and various support lines, the Government of Zambia budgeted US$25,419,342 for the Department of Public Health's Malaria Control & Management activities in 2008.[13] This amounted to 61% of the department's budget. The total 2008 malaria prevention and control budget, including in-kind contributions from non-governmental institutions, was estimated at US$59,816,211,[14] though actual contributions may not have always matched pledges or projections.[15]

The largest component of the 2008 budget was the provision of insecticide-treated mosquito nets (ITNs). The US$32,047,124 allocated to this activity accounted for 54% of the NMCP's overall 2008 budget, although budget allocations did not always match actual expenditure, sometimes due to donors failing to deliver on their commitments. For example, in 2008, the government budgeted for 3.5 million nets but ended up distributing only about one million; only 1/6 of the Ministry of Health funds budgeted for nets in Lusaka, Copperbelt, and Central provinces were actually expended.

Of all the malaria prevention modalities of the program, bednets suffer from the greatest problem in terms of a mismatch between distribution and effectiveness. The standard guideline is that everyone in households not sprayed with indoor residual spraying should sleep under a bednet every night.   However, some report sleeping under a bed net to be uncomfortably hot or claustrophobic, while others report irritation to the chemical treatments. Utilization remains well below the 85% target. There are also frequent reports of people not using nets at all, sometimes keeping them as a sign of wealth or indeed, using them for other purposes (such as wedding veils and fishing nets).

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[13]Government of Zambia. *Estimates of Revenue and Expenditure: Activity-Based Budget 2008.* Lusak

[14] Government of Zambia, Ministry of Health. *2008 National Malaria Control Action Plan: Actions for Scale-up for Impact on Malaria in Zambia.* Lusaka.

[15] Zambia's NMCP has impressively well-coordinated the harmonization of donors to increase efficiency and prevent redundant usage of funds. Some of the largest contributors to the national program include the Global Fund to Fight HIV/AIDS, Tuberculosis and Malaria (GFATM), the United States Agency for International Development (USAID) and the United States President's Malaria Initiative (PMI), the World Bank, the World Health Organization, the United Nations Children's Fund (UNICEF), the Japanese International Cooperation Agency (JICA) and the Bill and Melinda Gates Foundation (through the Malaria Control and Evaluation Partnership in Africa—MACEPA).

The other primary preventive intervention, indoor residual spraying ("IRS"), was carried out in 36 of Zambia's 72 districts, targeting primarily urban and peri-urban areas with relatively high population densities. Its projected cost was US$8,583,000

Treatment is another major component of the national malaria control program. The NMCC's strategic plan targets achieving "Prompt and Effective Case Management" (PECM), with a goal of ensuring that at least 80% of malaria patients receive effective treatment within 24 hours of the onset of symptoms. After noting decreasing efficacy of Sulphadoxine/ pyrimenthamine (SP) and chloroquine, Zambia became one of the first countries to introduce artemisinin-based combination therapy (specifically artemether plus lumefantrine, with the brand name Coartem). ACTs, free in the public sector, became the first-line treatment for all malaria cases during the 2002-2003 malaria transmission season, but it wasn't until the 2005-2006 season that the drug reached all districts in the country. Until 2007 the country faced continuing challenges to retain national stocks. The national supply stabilized in 2007; since that time there have not been complete national stock-out periods, though logistical challenges in distribution to the provinces, districts and health facilities still remain. (Sipilanyambe et al. 2008).

The total allocation for PECM in 2008 was US$11,137,502, approximately 19% of the total program budget. Of this money, US$2,554,720 was designated for malaria diagnostics, primarily for the purchase of 2 million rapid diagnostic tests (RDTs). The procurement of 3.8 million courses of treatmen of Coartem® was the largest component of the case management budget, costing US$5,320,000 (note that Coartem is heavily subsidized by its manufacturer, Novartis).

In 2008, the subsidized price to developing country governments of a course of Coartem treatment was $.80 (Frost and Reich, 2008). In the public sector, national treatment guidelines dictate Coartem as the first line of treatment, with quinine (available in tablets and intravenously) reserved for those who fail to respond to Coartem. Chloroquine and Fancidar (a combination of Pyrimethamine and Sulphadoxine) are no longer to be used for malaria treatment in the public sector, though Fancidar remains the indicated preventive treatment given to pregnant mothers. In practice, however, Fancidar is often used as a first or second line treatment for patients, especially for those who have negative malaria test results. Coartem remains unavailable in Zambia's small private sector health system due to its expense.

When ACTs were introduced in 2003, the high initial cost of the drug prompted an effort to improve diagnostics to control the drug prescriptions. In addition to promoting the increased availability of microscopes and trained laboratory technicians, RDTs were first purchased in 2004 for facilities where microscopes were unavailable. RDTs use modern molecular biological technology to allow diagnosis by a health worker with limited training in just fifteen minutes. RDTs are a new technology. Global production of RDT kits rose from roughly 3 million in the year 2000 to 28 million units in 2005 (Frost and Reich, 2008).

There is an important interaction between availability of RDTs and use of ACTs. When RDTs are not available, there is a strong tendency for health workers to treat all fevers as malaria, and dispense ACTs accordingly. When RDTs are present, a significant fraction of fevers are determined not to be malaria. Until 2007, the national Integrated Management of Childhood Illnesses (IMCI) guidelines dictated that all children under 5 with fevers were to be presumptively treated for malaria. National malaria policy guidelines revised in 2008 state that it is against national policy to dispense Coartem to any patient weighing more than 5kg (about 3 months old) without a confirmed malaria diagnosis through RDT or microscope. However, reaching compliance among clinicians with this remains one of the biggest challenges in the national program. A 2007 study found that of 58.4% of patients with a negative blood smear and 35.5% of those with a negative RDT result were prescribed an antimalarial drug (Hamer et al. 2007). 2008 performance assessments at health facilities reveal that some centers are still not using RDTs at all. Unlike Coartem, which is on a "push" system and comes to the clinic whether they request it or not, RDTs are on a "pull" system and need to be requested, resulting in some clinics not having RDTs or not using them. Data compiled at our malaria workshops shows that the availability of RDTs is associated with greatly lower reported cases of malaria and lower use of ACTs.

The wholesale price of RDT is about $.70, and for ACTs is roughly in the same range (Frost and Reich, 2008). Even though these prices would seem to say that there is no point in using RDTs before dispensing ACTs in order to save on costs, the public health benefits of not overusing ACTs are enormous, since restricting use will prevent the development of resistance. In addition, ruling out malaria allows for better management of negative cases.

Smaller components of the 2008 budget included: Information, Education, Communication/ Behavior Change Communication (IEC/BCC), and Advocacy (US$2,219,000), Monitoring and Evaluation (M&E) (US$2,183,500), Operations Research (US$986,178), Emergency and Epidemic Malaria Preparedness Plan (US$982,000), and Entomological Activities (US$800,400 USD). US$877,507 was allocated for program management at the national secretariat in 2008.

A 2008 health facility census recorded 1,554 health facilities, including public, private and church-run health centers. Two thirds of these facilities are located in Zambia's rural areas. There are 98 referral hospitals in the country.[16] All districts have an active cadre of lay community health workers (CHWs) who supplement permanent health centers. However, the level of care CHWs can provide varies widely by district. A current Home Management of Malaria initiative (HMM) seeks to train CHWs to administer rapid diagnostic tests and provide artemisinin-based combination treatment (ACT) to patients at their homes; the program is

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[16] Government of Zambia, Ministry of Health. *Health Facilities in Zambia: A Listing of Health Facilities According to Level and Location for 2008.* Lusaka: February 2008.

currently being scaled up, but continues to face logistical difficulties in providing drugs and supplies to all trained volunteers.

3.2 Non-malaria changes in the Zambian Health

As mentioned above, the anti-malaria initiative was not the only change in the Zambian health environment over the period we examine. During the period 2003-06 there were a series of other programs occurring, mostly in HIV, tuberculosis, and child health. In addition, the reduction in malaria may have led to decreases in other diseases either through reduced co-morbidity or through the freeing up of resources within the health care system.

In 2004, funds from the US President's Emergency Plan for AIDS Relief (PEPFAR) began arriving in Zambia. According the US Embassy, PEPFAR funds in Zambia were $149 million in 2006, which was spent on prevention, treatment, and care. One targeted area for spending was prevention of mother-to-child transmission, which has the potential to sharply reduce child mortality.

While the efforts to combat child mortality by reducing tuberculosis and the transmission of HIV to children have undoubtedly contributed to the declines in child mortality observed, the interactions between these two diseases and malaria are hard to pin down. One of the main effects of childhood exposure to malaria is anemia, which makes children more vulnerable to other diseases such as tuberculosis and diarrhea. The same could clearly be said the other way around: progress made in terms of diarrheal diseases or tuberculosis means healthier children with better immune system.

4. Rollout of the program

4.1 National Data

Table 4 shows the rollout of the three of the key pieces of the malaria prevention program: ITNs, IRS, and RDTs.[17] The table shows the degree to which the program accelerated in 2006 and 2007. Half a million nets were distributed in 2003, but only 176,082 in 2004 (as far as we know, this was because foreign donors failed to provide them that year). The number returned to half a million in 2005, then 1.2 million in 2006 and 2.4 million in 2007.[18] As discussed above,

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[17]National Malaria Control and Scaling Up for Impact: The Zambia Experience through 2006
Richard W. Steketee, Naawa Sipilanyambe, John Chimumbwa, James J. Banda, Abdirahman Mohamed, John Miller, Suprotik Basu, Simon K. Miti, and Carlos C. Campbell
[18] NMCC and WHO say any Long Lasting Insecticide Treated Net are effective if distributed in the last 3 years. Earlier nets given that were not treated lasted for shorter periods of time, but some retreatment kits were distributed for those nets.

the decline in bednet distribution in 2008 was not planned as of the beginning of that year. There were to have been 3.5 million nets distributed. Starting in 2008, all bed nets distributed were Long Lasting Insecticide Treated Nets (LLITNs), which according to the WHO and NMCC should last for three years. Prior to 2008 nets distributed were a mixture of LLITNs and other types.

In the initial design of the malaria initiative, IRS was to be restricted to only areas of very high population density. The scope of IRS was expanded in discrete jumps through 2008. The number of households increased dramatically (almost ten-fold) between 2004 and 2008. By the latter year, roughly 43% of the population was covered by spraying. IRS is generally conducted at the end of the calendar year, before the onset of the rainy season when malaria is high. IRS must be re-applied each year.

The shift in strategy toward increased reliance on IRS was driven by two factors: first, it is seen as more cost effective. Second, reports of low utilization of bed nets led to a shift toward IRS, where a sprayed household was "guaranteed" to stay treated for the year.

The last column of Table 4 shows the rapid growth of RDT use, which only happened at the very end of our sample period.

We are still working on getting data on ACTs.

According to the 2007 DHS, 91% of women in urban areas and 84% rural took some form of anti-malarial treatment during their last pregnancy and 68% (61% rural) received IPT during an ante-natal visit. On average 38% of women used IPT in the 2001 DHS.

4.2   Regional variation in the rollout

The fundamental strategy of the anti-malaria initiative was to push distribution and use of bednets in high-malaria, rural areas. Initially, IRS was targeted only at urban areas; later the scope of IRS was expanded to include half the districts in the country.

4.2.1   ITNs

The NMCC goal is to ensure that 100% of households in non IRS-targeted areas have at least one mosquito net for every three people, with utilization rates of at least 85%. Insecticide-treated mosquito nets are distributed by the NMCC directly and through a number of partners to specific populations. Programs target mothers and infants, vulnerable populations (orphans, economically

deprived populations, HIV+/AIDS patients), and the general public through commercial and subsidized sales, targeted distributions and free mass community distributions. Table 5 compares the DHS and NMCC database at the provincial level. The first two columns are based on NMCC data on the number of nets distributed (total and per capita) by province. The 2001 DHS finished collecting data in May 2002, while the 2007 began collecting data in April of 2007. The number of nets in the table is the total from quarter 3 of 2002 through quarter 1 of 2007. The next three columns use data from the 2001 and 2007 waves of the DHS on the fraction of children under five living in a house with at least one bednet. It is not clear whether one would expect a bigger correlation between bednet distribution and the *level* of bednet ownership in 2007 or the *change* in bednet ownership between 2001 and 2007. In any case, both correlations are high: .73 and .62, respectively. The last three columns show data on whether the child slept under a bednet. Overall, bednet use more than doubled over this period, reaching 43%. Across provinces, the correlation between the change in bednet ownership and the change in bednet use is .72. The correlation between bednet distribution 2002-07 and the level of bednet use in 2007 is .63, while the correlation between bednet distribution and the change in bednet use is .57.

4.2.2   Indoor Residual Spraying

Table 6 compares data from the DHS and the NMCC on IRS by district. We use data spraying in 2006 (before the rainy season), which was the last spraying before the 2007 DHS. The table also shows urbanization rates from the 2000 census. The nine provinces fall into three groups. Four provinces, all with very low rates of urbanization, had no official spraying, and fewer than 5% of households report having received spraying.[19] In three provinces, official data show 9-16% of households sprayed, and DHS data report roughly commensurate coverage. Finally, the two most highly urbanized provinces were targeted for intensive spraying: Copperbelt (63% of households) and Lusaka (73%). In both provinces there is a significant shortfall between official estimates and the DHS. This is particularly severe in Lusaka, where only 29% of children in the 2007 DHS reportedly lived in sprayed structures. Figure 7 shows the rollout of spraying at the district level. The initial 5 districts targeted in 2003 were Kabwe, Kitwe, Livingstone, Lusaka and Ndola. These are urban areas, where not much nets distribution was happening at the time, and where spraying was considered a relatively economical option due to the relatively high population densities. The first scale-up came in 2005, with spraying extended to Chililabombwe, Chingola, Kalulushi, Luanshya, Mufulira, Chongwe, Kafue, Solwezi, Kazungula, and Mazabuka. In general, spraying was targeted to urban areas where

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[19] There was private sector spraying being done in some districts that did not overlap with government spraying until potentially 2008. The main private sector spraying without government involvement was in areas where there were small mines of various minerals (for example, Mumbwa District).

health facilities reported high levels of malaria incidence, so that spraying is often concentrated around the health facilities reporting to the NMCC via the HMIS.

5.   Assessing the Link from Rollout to Incidence

Ideally, we would like to be able to use data on inputs to better health (that is, preventive measures or disease treatments) and health outcomes in order to learn the efficacy of different inputs. Such an endeavor faces obvious problems with identification.

Clearly, the timing and spatial distribution of health interventions are not random. Different modalities are used in different locations because health planners make optimizing choices of what will work best where.   Similarly, the provision of resources may respond to perceived needs. For example, extra resources may be pushed to areas where health conditions have deteriorated or are forecast to deteriorate in the future. Finally, the efficiency with which health resources are provided may be correlated with other factors that directly affect health. For example, a district with an especially competent public health staff may be able to obtain additional resources, but may also have had a lower rate of disease incidence even in the absence of these additional resources (in the field we noted that that drug supplies, record keeping and quality, take-up of new treatment guidelines and drugs ,and involvement of community health volunteers and neighborhood health committees were all highly dependent on the performance of health staff at all levels of the system, and that the level of performance varied significantly).   In this face of these potential obstacles to identification, we will only be able to identify the causal effect of health interventions to the extent that there is some (measureable) randomness to the pattern by which such interventions are applied.

If there is statistical power to identify the effects of inputs to better health on health outcomes, it will generally only be in cases where these inputs deviate from the optimal plan or when inputs respond to conditions in some non-continuous fashion.

Since we do not have a formal model of optimizing choice of treatments, it is not possible to formally specify deviation from that optimal plan and use these. For now, we simply describe the rough correlations between the rollout of different malaria control modalities and available health outcomes.

5.1 Bed Nets

In addition to the other statistical problems discussed above, assessment of the link from ITN distribution to health outcomes is complicated by the facts that ITNs have limited effective lifetimes, and that the length of time over which they remain effective has been changing.

5.1.1   ITNs in the DHS

The first measure of malaria we use in the DHS is a binary indicator that equals one if the child had a fever over the two weeks preceding the interview. The data are pooled from the 2001 and 2007 waves of the DHS. The unit of observation is a child under age five. We include dummies for individual years of age and a dummy for being in the 2007 wave. In addition, all specifications control for district fixed effects, sex, mother's age, mother's age squared, mother's education, mother's marital status, mother's employment status, urban, female household head, number of household members and household assets (electricity, radio, tv, fridge and bike).

In the first two columns of Table 7, we use whether a household owns a bednet or whether the child slept under a bednet the previous night as measures of input to malaria control. In both cases, we do not think that the coefficient can be interpreted structurally, because both ownership and use of the bednet are affected by disease conditions and other household characteristics related to health outcomes. In the third column, we use bednet distribution per capita as recorded by the NMCC in the district in the period between the two DHS surveys as the independent variable. – the variable is zero for all 2001 observations The coefficient is quite significant, and implies that a distribution of one net per person in the district lowers fever prevalence by about 20 percentage points. In column 4 we instrument for household ownership with per-capita distribution in the household's district (the first stage is reported in Table 8).

In columns 5 and 6 we do a placebo test, using diarrhea in the two weeks preceding the interview as a dependent variable; we use OLS in column 5 and apply the same IV strategy used in column 4 in column 6. Diarrhea is an important health outcome, but reductions in prevalence should not be related to bednet distribution. The bed nets have no significant effect.

One concern with the results in Table 7 is that, as mentioned above, the distribution of nets is not random. Since all the regressions include district fixed effects, the fact that more nets are distributed in districts with permanently higher malaria is not a concern. However if nets are distributed in response to temporary changes in malaria prevalence, our results could be biased. For example, suppose that nets are targeted to districts experiencing temporarily high malaria prevalence. In this case our estimate would be biased to show nets being more effective than they really are. To attempt to remove this bias, in Table 9 we control for baseline fever prevalence, that is, regress the change in fever between the two DHS surveys on bednet coverage as well as the fraction of children with fevers in the two weeks prior to the 2001 DHS survey. The coefficient on baseline prevalence is slightly less than one, indicating a moderate degrees of convergence over time. The coefficient on bednet distribution per capita falls by roughly half but remains significant while the coefficient on household bednets becomes insignificant.

Finally, in Table 10 we aggregate to the level of districts and do a regression in first differences. The dependent variable is the change in fever prevalence between the two waves of the DHS. The measure of malaria control is the change in bednet ownership, in column 1, and ITN distribution in the five years prior to the survey in the other columns. The results look very similar to the individual level regressions. In particular the effect of ITN rollout falls by about half once we control for baseline fever prevalence, but remain significant.

In Table 11 we look at child mortality data in the DHS for evidence of the effects of ITNs. As in Tables 7 and 9, we report in columns 1 and 2 results in which the independent variable of interest is whether the household owns a bednet and whether children slept under a bednet the previous night. (note that this latter variable applies the household in which the child was born, not the child him/herself. We cannot use the child specific use variable here since it is missing for all the deceased children). We do not interpret these estimates structurally, since there are biases that go in both directions: households that care more (or know more) about their children's are more likely to have their children sleep under a bednet, which would yield an overestimate of the true effect. On the other hand, one might also expect some learning from the parents' side: if one kid has died over the last 5 years, they may actually be more likely to let their (remaining) kids sleep under bed nets than other parents. In column 3, we include use district ITN coverage as the explanatory variable. The coefficient of is borderline significant, but of a large magnitude (-.044). It implies that a full coverage with bednets (one net per capita) in the years prior to the surveys lowers child mortality by 4.4 percentage points from an average baseline level of 12.7 in the 2001 survey.

One concern with the mortality regressions is that mortality covers the whole 5 years prior to the survey, while all the household level information we have (ownership and use of bed nets, assets etc) is for the year of the survey. When restricting the sample to those who have died over the last 3 years (rather than 5), similar results emerge; with a 1 year restriction, the sample becomes too small for identification. One last interesting finding is the negative estimate on female. This matches raw DHS data: under five mortality in 2007 was estimated at 151 for males and 124 for females.

5.1.2 ITNs in the HMIS

Using the HMIS, we can take advantage of much higher frequency data on disease impact and distribution of ITNs than is available in the DHS. Table 12 presents descriptive statistics for our panel of HMIS data. We match malaria inpatients, malaria deaths, and non-malaria deaths, all for children under five, with data on net distribution.

Table 13 shows regressions of health outcomes in a district on net distribution in the same calendar year as well as the two preceding years. The top part of the table looks at absolute

numbers of cases and nets distributed; in the bottom part cases and normalized by the under-five population and nets are normalized by district population. Because malaria incidence peaks in the first quarter of the year, while nets are distributed throughout, but often late in, the year, our expectation is that the greatest impact on disease in a year should be net distribution in the previous year. The table shows that this expectation holds true. The coefficient on net distribution in the previous year is always negative and significant as a predictor of malaria cases; nets in the current year are not. Interestingly, nets distributed two years earlier are also often insignificant as a predictor of malaria cases.

The interpretation of the coefficient on once-lagged nets in columns 2 and 3 of the top panel is as follows: 100,000 nets distributed leads to a reduction of about 900 under-five malaria inpatients and to a reduction of 25 child deaths reported at health facilities in the average district. Recall that the HMIS records only about one fourth of deaths. If we assume that the reduction in HMIS mortality in the regressions is only 25% of the true benefit, 100,000 nets mean approximately 100 child lives saved.

The lower part of the table, where cases and nets are scaled by population, yields estimates similar in magnitude. Full coverage of bed nets (one per person) leads lowers malaria inpatients by 26 cases per 1000, which is a reduction of 35% relative to the mean. Similarly, malaria deaths per 1000 are 0.8 lower, which is a reduction of 42% relative to the mean.

5.2 Indoor Residual Spraying

The manner in which IRS was rolled out suggests that it might be a good candidate for econometrically identifying the effects of the program on disease outcomes. In the initial design of the malaria initiative, IRS was to be restricted to only areas of very high population density. The scope of IRS was expanded in discrete jumps in 2008, but we do not yet have data on this. Further, unlike bednets, IRS must be re-applied each year to be effective. IRS is generally conducted at the end of the calendar year, before the onset of the rainy season when malaria is high.

5.2.1 IRS in the DHS

Table 14 shows regression of child fever on spraying, similar to the regression for bednets in Table 7. When spraying is included along on the right hand side, the estimated coefficient appears positive, which seems to be driven by a strong negative correlation between the initial fever burden and the rollout of the spraying. By the time of the 2007 DHS, spraying was done in 15 districts, which on average had a fever prevalence of 37% in 2001, significantly below the national average of 45%. In 2007, the average fever prevalence in the spraying target areas is actually slightly above the non-spraying areas, which is pretty much what the result in column 1 shows.

This result looks the same when we run the regressions at the individual level (households reporting whether or not they have been sprayed over the 12 months preceding the interview) as shown in column 2.

To minimize the potential convergence bias we focus on the 2007 survey only in columns 3 and 4. In column 3, we use spraying at the household level only; in column 4, we take the fraction of households sprayed within the cluster (typically 15 households with children per cluster) as explanatory variable. The coefficient becomes negative, but is not significant. Within a given district, targeted households and clusters appear to have similar fever prevalence rates to non-targeted ones.

We are not quite sure what to make out of this result; if the numbers are correct, it could either be that spraying misses its target (people get infected outside, or spraying is done before the rain and then washed away), or, alternatively, that households that don't get spraying have lower risk or do more prevention

5.2.2 IRS in the HMIS

As with the ITN analysis, the use of the HMIS has the main advantage of offering higher frequency data when it comes to evaluating the disease impact of the IRS spraying. Given that spraying loses its protective effect within about a year, close to all spraying in Zambia arranged through the NMCP is done in the last quarter of the each year when the rains start and mosquito populations rapidly re-emerge after the dry season. Under ideal conditions, IRS spraying is supposed to protect household members throughout the rainy seasons, and to be repeated at the end of each year with the new rainfalls.

In Table 15 A, we try to identify the effects of IRS spraying on the levels of malaria inpatients, malaria deaths and deaths due to other causes with a simple IRS spraying target dummy. The IRS target dummy variable equals 1 if the district was in the spraying program in a given year, and is zero otherwise. As Figure 7 shows, the rollout of the IRS implemented by the NMCP spraying was incremental; any district enrolled in the program since 2003 has been receiving spraying in all subsequent years. In columns 1-3, we run simple regressions without controlling for the contemporaneous net distribution; the effects of IRS spraying on malaria inpatients and malaria deaths are negative, but only marginally significant. The estimated coefficient in column 2 implies that being a target district is associated with 22.5 fewer malaria deaths per year and district. Once we add controls for bed net rollout in columns 4-6, the estimated effects on the number of under-5 malaria inpatients and deaths become larger and more significant. A simple comparison of the estimated coefficients in column 5 implies that the effect of becoming a target spraying is comparable to the distribution of 100,000 nets in the preceding year in the average district.

The results become much weaker, however, when we express patients and mortality numbers in population terms, and regress disease burden per capita on per capita measures of bed

net and spraying rollout in Table 15 B. While the coefficient on bed net distribution remains highly significant (and similar in magnitude to the ITN regressions where we do not control for spraying), the spraying coverage does not appear to have any effect on the number of malaria patients per 1000 children under 5 in this specification; the estimated effect on under-5 malaria death is just not significant. (The relative magnitude of the coefficients estimated in column 5 implies that providing full spraying coverage has about half the effect of providing full net coverage.)

Overall, the estimated effects of the IRS campaign in the HMIS are surprisingly weak given the design of the spraying rollout. As Figure 8 shows, the IRS campaign is generally directly focused around health facilities. Trying to maximize the impact of the campaign, programs generally concentrate their efforts to the (catchment) areas directly surrounding facilities reporting a high malaria caseload in the given period. Given the stochasticity of local malaria incidence, particularly high incidence years in a particular area are likely to be followed by more moderate years, so that the simple difference-in-difference model estimated above should lead to an overestimation of the true effect. The fact that the effects are weak even in the HMIS is thus rather puzzling, and further corroborates the rather weak evidence emerging from the DHS analysis.

6. Conclusions

6.1 Future direction for research

As mentioned in the Introduction, the current paper is part of a larger project in which the authors hope to use the Zambia malaria initiative to better understand the economic effects of malaria. It is worth stepping back for a moment to see why the Zambian experience is particularly useful in this regard. Discussion in the policy community of imperative for improving health in developing countries often points to the economic benefits that accrue from better health as an important secondary justification for such programs. The question of how disease affects economic growth is well established in the literature. Much of the discussion of the economic effects of malaria among policy makers, for example, cites estimates from the work of Macarthur and Sachs (2001). Trying to estimate the effect of health on economic outcomes runs into serious identification problems, however. Omitted factors that affect health may affect income directly, or health may respond directly to improvements in income. The standard solution for such an identification problem is to find instrumental variables that directly affect health. These instruments could be some purely exogenous factor or possibly the result of some discontinuous response of health inputs to local conditions. For example, Acemoglu and Johnson (2007) use variations in technological progress in controlling different diseases during the post World War II period to instrument for health changes at the national level. Even though malaria is viewed as one of the most economically important diseases, most recent studies of its economic effects have had to rely on data from episodes of malaria eradication in South Asia and

Latin America that took place half a century ago (see Lucas, 2007, and Bleakley, 2007). As discussed above, the large scaling up of resources devoted to malaria control in Zambia was not primarily the result of factors on the ground in the country itself. Rather, developments on the world stage, including the development of new technology and a new alignment of priorities within the development community, led to Zambia being chosen as a test case for the possibility of rapidly scaled up malaria control. Thus, at the aggregate level, the timing of the reduction in malaria in Zambia may be viewed as largely exogenous. Of course, Zambia was chosen as the first country to receive such intensive support and treatment because it was viewed as a having the institutional capacity to succeed, and the same factors that were expected to lead to success against malaria might have been expected to have independent economic effects, so the identification is not perfect. Nonetheless, the suddenness with which resources were applied suggests that reasonable identification may be possible. Beyond the inferences that can be drawn from developments at the national level, our hope is that additional identification can be achieved by looking at the manner in which the campaign against malaria was rolled out within Zambia.

Some of the issues that we hope to investigate in later work include:

Fertility

A substantial literature discusses the link between changes in mortality and changes in fertility. In particular, it is often argued that declining infant and child mortality initially leads to a rise in the total fertility rate, as actual deaths fall short of expectations, but that in the long run TFR declines because of reduced uncertainty (See Kalamli-Ozcan, 20xx). In the case of malaria, there is an additional set of considerations, because the disease works to lower fecundity directly (See Adrienne Lucas paper on Sri Lanka).

Figures from the DHS early release show that TFR in Zambia rose from 5.9 to 6.2 over the period 2002-2007 (6.9 to 7.5 in rural areas, while urban TFR was flat at 4.0). The period between DHS surveys corresponds well to the period of rollout of the malaria program.

Productivity

One way in which malaria affects economic outcomes is by directly lowering the labor input of workers, both through absenteeism and reduced physical capacity due to anemia. There are some cases where we hope to observe directly the productivity effects of malaria control. We are working on obtaining data from Zambia Sugar, the country's largest producer, in the city of Mazabuka. Zambia Sugar undertook a private eradication effort that predated the national effort by several years. Malaria morbidity has traditionally been quite high among cane cutters, who must work in swampy conditions. We hope to obtain data on changes in absenteeism over time (this data was actually collected once already, but has subsequently been lost).

Education

Many economists have stressed malaria's effect on educational attainment as an important channel through which the disease affects economic outcomes. By matching data from Zambia's educational statistics system on absenteeism, grade progress, and dropout rates to data on the rollout of the anti-malaria initiative, we hope to investigate how much health improvements have lead to an increase in educational attainment.

6.2 Sustainability and Further Progress

The progress already made against malaria and other sources of premature mortality in Zambia represents a major humanitarian success.

One issue raised by progress so far is whether it will be possible to finish the job, and reduce malaria incidence to near zero. The history of anti-malaria campaigns in the years after World War II contains several episodes in which malaria was substantially eliminated. Eradication is also the NMCC's eventual goal, even if it isn't possible in the short term. There are currently some discussions on pilot projects in a few districts to do a massive test and treat campaign to reduce parasitemia to near zero. Zambia was chosen as a test country for scale-up for a couple of reasons--one was definitely that the institutional capacity, good governance, and political will existed to make use of the resources. But, it is also the case that the climate is favorable to eventual complete eradication because of the cold winters that ensure mosquito populations are reduced to near-zero for at least some period annually.

Until malaria is completely eliminated in the country, however, a serious concern is the sustainability of gains achieved so far. As discussed above, Zambia has already been through an episode in which significant progress against malaria was followed by a resurgence of the disease. Similarly, in Zambia's neighbor Zimbabwe, malaria was almost completely eradicated, but the political environment led to the end of an effective malaria control regime and the disease has subsequently returned to epidemic levels. In the current Zambian environment, disease vectors remain present and a significant number of humans continue to host the disease. This means that unlike places where eradication has been complete, there is always the potential for a rapid resurgence (which could be all the more devastating as cohorts with lower acquired immunity enter the population). Maintaining the low current level of malaria mortality and morbidity will thus require continued application of inputs at near the current level. The life of a net averages three years, so maintaining a ratio of one net for every two persons will require approximately 2 million nets distributed per year. Indoor spraying, of course, must be conducted annual. Thus there will be only limited scope for a reduction in spending and effort devoted to malaria control.

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Table 1: Change in accuracy of HMIS   data set

	Observations, pre-workshop data set	Observations corrected	%
Outpatients Under 5	888,537	13,623	1.53%
Outpatients Over 5	1,178,427	18,887	1.60%
Inpatients Under 5	325,169	3,457	1.06%
Inpatients Over 5	418,481	5,181	1.24%
Deaths Under 5	177,991	1,010	0.57%

| Deaths Over 5 | 187,598 | 1,132 | 0.60% |

Table 2: Inpatient and Mortality Data from the HMIS

	All Facilities				Always Reporting Facilities			
	Malaria in-patients under age 5	Malaria in-patient deaths under age 5	Malaria in-patients age 5 and over	Malaria in-patient deaths age 5 and over	Malaria in-patients under age 5	Malaria in-patient deaths under age 5	Malaria in-patients age 5 and over	Malaria in-patient deaths age 5 and over
2000	139,555	5,039	100,451	3,882	37,636	1,452	24,691	905
2001	173,412	5,598	121,566	4,352	42,960	1,775	28,353	1,098
2002	167,697	4,937	119,289	4,530	40,519	1,392	25,664	1,021
2003	172,727	4,808	129,392	4,727	39,091	1,258	26,617	1,000
2004	140,679	4,056	104,290	4,352	30,397	1,149	21,627	895
2005	143,297	3,489	99,993	3,979	29,182	867	19,872	816
2006	144,547	3,235	100,073	3,096	30,131	790	20,224	711
2007	122,054	2,680	85,482	2,355	28,687	795	17,793	619
2008	71,317	1,680	58,259	1,566	19,213	605	14,514	507
	All Facilities				Always Reporting Facilities			
	Non-Malaria in-patients under age 5	Non-Malaria in-patient deaths under age 5	Non-malaria in-patients age 5 and over	Non-malaria in-patient deaths age 5 and over	Non-Malaria in-patients under age 5	Non-Malaria in-patient deaths under age 5	Non-malaria in-patients age 5 and over	Non-malaria in-patient deaths age 5 and over
2000	159,272	11,653	240,140	15,701	35,142	2,862	57,134	3,392
2001	193,386	12,002	262,814	16,624	39,411	2,760	62,381	3,636
2002	179,422	11,983	304,451	18,802	35,193	2,562	68,208	4,016
2003	182,796	11,213	306,048	19,756	37,200	2,571	67,876	4,032
2004	147,212	9,810	301,048	20,967	29,263	2,212	65,800	4,118
2005	165,885	9,641	318,904	20,709	30,223	1,932	67,134	3,972
2006	161,540	9,315	311,404	20,045	28,319	2,048	64,981	3,875
2007	164,721	9,575	309,821	17,106	29,095	2,100	66,174	3,697
2008	131,062	6,416	244,615	12,883	26,955	2,167	62,833	3,605

Table 3: Seasonality and Changes over Time

	Under 5 Deaths per 1000 – All Causes		Under 5 Deaths per 1000 – Malaria Only	
	(1)	(2)	(3)	(4)
Second quarter	-0.326***	-0.324***	-0.136***	-0.111***
	(0.0486)	(0.0652)	(0.0202)	(0.0270)
Third quarter	-0.726***	-0.584***	-0.360***	-0.258***
	(0.0488)	(0.0656)	(0.0203)	(0.0271)
Fourth quarter	-0.431***	-0.318***	-0.235***	-0.152***
	(0.0488)	(0.0657)	(0.0203)	(0.0272)
Pre 2004		1.186***		0.522***
		(0.0869)		(0.0359)
Second Q. * pre		-0.00536		-0.0563
		(0.0976)		(0.0404)
Third Q. * pre		-0.317***		-0.227***
		(0.0978)		(0.0405)
Fourth Q. * pre		-0.251**		-0.185***
		(0.0978)		(0.0405)
Year 2001	0.0697	0.0697	0.0438	0.0438
	(0.0728)	(0.0726)	(0.0302)	(0.0300)
Year 2002	-0.148**	-0.149**	-0.0830***	-0.0832***
	(0.0728)	(0.0726)	(0.0303)	(0.0300)
Year 2003	-0.346***	-0.346***	-0.121***	-0.121***
	(0.0728)	(0.0726)	(0.0302)	(0.0300)
Year 2004	-0.733***	0.608***	-0.255***	0.249***
	(0.0728)	(0.0744)	(0.0302)	(0.0308)
Year 2005	-0.808***	0.534***	-0.294***	0.209***
	(0.0728)	(0.0744)	(0.0302)	(0.0308)
Year 2006	-0.931***	0.411***	-0.330***	0.174***
	(0.0728)	(0.0745)	(0.0303)	(0.0308)
Year 2007	-1.008***	0.334***	-0.384***	0.120***
	(0.0730)	(0.0746)	(0.0303)	(0.0308)
Year 2008	-1.344***		-0.505***	
	(0.0746)		(0.0310)	
Constant	2.584***	1.178***	0.872***	0.316***
	(0.0595)	(0.0668)	(0.0247)	(0.0276)
Observations	2562	2562	2562	2562
R-squared	0.550	0.554	0.417	0.426

Standard errors in parentheses. All estimates include district fixed effects.
*** p<0.01, ** p<0.05, * p<0.1
Data source: HMIS.

Table 4: Rollout Data at the National Level

	Number of bednets distributed	Population covered by spraying	RDT Distributed
2002	112,020	-	0
2003	557,071	324,137	0
2004	176,082	679,582	0
2005	516,999	1,163,802	172,257
2006	1,163,113	2,836,778	25,700
2007	2,446,102	3,286,514	243,600
2008	964,748	5,558,822	2,015,500

Source: NMCC

Table 5: ITN Distribution, Ownership, and Use

	Total nets distributed between 2001 and 2007 DHS[a]	Nets distributed per person between 2001 and 2007 DHS[a,c]	Percentage of children in household owning at least one net 2001[b]	Percentage of children in households owning at least one net 2007[b]	Change in ownership DHS 2001 - DHS 2007[b]	Percentage of children sleeping under net 2001[b]	Percentage of children sleeping under net 2007[b]	Change in child net use DHS 2001 to DHS 2007[b]
Central	188,405	0.15	0.23	0.68	0.45	0.13	0.37	0.25
Copperbelt	224,425	0.12	0.31	0.74	0.43	0.20	0.43	0.23
Eastern	206,439	0.12	0.25	0.71	0.46	0.20	0.37	0.17
Luapula	417,351	0.43	0.36	0.86	0.50	0.31	0.74	0.42
Lusaka	264,591	0.16	0.31	0.68	0.37	0.20	0.30	0.10
Northern	244,078	0.15	0.21	0.57	0.36	0.17	0.41	0.24
North-Western	290,202	0.39	0.36	0.73	0.38	0.27	0.43	0.16
Southern	342,484	0.22	0.18	0.60	0.42	0.10	0.25	0.16
Western	598,199	0.64	0.32	0.87	0.55	0.22	0.55	0.33
Total	**2,776,174**	**0.26**	**0.28**	**0.72**	**0.43**	**0.20**	**0.43**	**0.23**

Notes:
a) Source: NMCC.   b) Source: DHS.

Table 6   **IRS Coverage 2007 and Self-Reported coverage**

Province	Fraction of population officially covered by spraying in 2006	Percentage of children in 2007 DHS living in sprayed households	Urbanization (2000)
Central	0.12	0.12	.24
Copperbelt	0.63	0.41	.78
Eastern	0.00	0.02	.09
Luapula	0.00	0.01	.13
Lusaka	0.73	0.29	.82
Northern	0.00	0.04	.14
North-Western	0.09	0.14	.12
Southern	0.16	0.13	.21
Western	0.00	0.02	.12

Source: NMCC, DHS (2007), Zambia Census

Table 7: Bednets, child fever and child diarrhea, DHS

Dependent variable	Child had fever over last two weeks				Diarrhea	
	(1)	(2)	(3)	(4)	(5)	(6)
Household owns bednet	-0.0213*			-0.921***		-0.124
	(0.0111)			(0.267)		(0.255)
Child slept under net		-0.0106				
		(0.0110)				
Bednet distribution pc			-0.209***		-0.0286	
			(0.0487)		(0.0703)	
Child age 1	0.0639***	0.0641***	0.0648***	0.0672***	0.181***	0.181***
	(0.0122)	(0.0122)	(0.0122)	(0.0154)	(0.0252)	(0.0315)
Child age 2	0.0142	0.0150	0.0150	0.00604	-0.0307	-0.0319
	(0.0132)	(0.0134)	(0.0132)	(0.0150)	(0.0252)	(0.0297)
Child age 3	-0.0728***	-0.0730***	-0.0713***	-0.0798***	-0.195***	-0.196***
	(0.0125)	(0.0127)	(0.0125)	(0.0154)	(0.0247)	(0.0262)
Child age 4	-0.121***	-0.120***	-0.121***	-0.122***	-0.275***	-0.275***
	(0.0127)	(0.0129)	(0.0127)	(0.0159)	(0.0216)	(0.0236)
2nd wave dummy	-0.243***	-0.250***	-0.197***	0.101	-0.0736***	-0.0335
	(0.0115)	(0.0109)	(0.0169)	(0.107)	(0.0257)	(0.0967)
Constant	0.546***	0.548***	0.548***	0.406***	0.735***	0.773***
	(0.0752)	(0.0759)	(0.0749)	(0.117)	(0.138)	(0.196)
Observations	11193	11027	11193	11193	11187	11187
R-squared	0.129	0.128	0.131	-0.513	0.065	0.063

Robust standard errors in parentheses

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

All specifications control for district fixed effects, sex, mother's age, mother's age squared, mother's education, mother's marital status, mother's employment status, urban, female household head, number of household members and household assets (electricity, radio, tv, fridge and bike).

Table 8:   First Stage Results for Column 4 (and 6) in Table 7

Dependent variable	HH owns bednet
	(1)
ITN per capita	0.230***
	(0.0662)
Child age 1	0.00210
	(0.0104)
Child age 2	-0.0106
	(0.00925)
Child age 3	-0.0107
	(0.0104)
Child age 4	-0.00518
	(0.00934)
2nd wave dummy	0.322***
	(0.0231)
Constant	-0.146*
	(0.0804)
Observations	11193
R-squared	0.317
Kleibergen-Paap F-Stat	11.65
Kleibergen-Paap weak identification p-value	0.0014

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$
Includes control for district fixed effects, sex, mother's age, mother's age squared, mother's education, mother's marital status, mother's employment status, urban, female household head, number of household members and household assets (electricity, radio, tv, fridge and bike).

Table 9: Control for baseline level in micro-level regression, DHS

Dependent variable	Child had fever over last two weeks				Diarrhea	
	(1)	(2)	(3)	(4)	(5)	(6)
Household owns bednet	-0.0141			-0.695		-0.0429
	(0.0105)			(0.496)		(0.597)
Child slept under net		-0.00428				
		(0.00895)				
Bednet distribution			-0.104***		-0.00656	
			(0.0364)		(0.0922)	
Child age 1	0.0640***	0.0644***	0.0645***	0.0665***	0.181***	0.181***
	(0.0121)	(0.0121)	(0.0121)	(0.0148)	(0.0328)	(0.0326)
Child age 2	0.0119	0.0129	0.0124	0.00701	-0.0312	-0.0315
	(0.0130)	(0.0130)	(0.0130)	(0.0131)	(0.0323)	(0.0312)
Child age 3	-0.0706***	-0.0704***	-0.0700***	-0.0770***	-0.194***	-0.195***
	(0.0109)	(0.0109)	(0.0110)	(0.0121)	(0.0281)	(0.0265)
Child age 4	-0.122***	-0.120***	-0.122***	-0.122***	-0.276***	-0.276***
	(0.0115)	(0.0118)	(0.0116)	(0.0126)	(0.0263)	(0.0260)
Baseline fever preval.	0.867***	0.888***	0.806***	0.393	0.168	0.143
	(0.0944)	(0.0933)	(0.0973)	(0.400)	(0.227)	(0.495)
Constant						
Observations	11193	11027	11193	11193	11187	11187
R-squared	0.136	0.135	0.136	-0.229	0.065	0.065

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$
All specifications control for district fixed effects, sex, mother's age, mother's age squared, mother's education, mother's marital status, mother's employment status, urban, female household head, number of household members and household assets (electricity, radio, tv, fridge and bike).

Table 10: District-level Differences, DHS

	(1)	(2)	(3)	(4)	(5)	(6)
	Dependent variable: Change in fever prevalence					
Change in ownership	-0.136					
	(0.0935)					
ITN rollout per capita		-0.188**	-0.0778**	-0.0778**	-0.0711*	-0.0761*
		(0.0739)	(0.0357)	(0.0367)	(0.0399)	(0.0402)
Baseline fever			-0.977***	-0.976***	-1.045***	-1.048***
			(0.0983)	(0.0981)	(0.124)	(0.125)
Change in mother education				-0.0452	-0.0427	-0.0346
				(0.0430)	(0.0416)	(0.0407)
Change in mother working					-0.0341	-0.0392
					(0.0340)	(0.0328)
Change in average age						-0.0545
						(0.0558)
Constant	-0.214***	-0.222***	0.191***	0.193***	0.220***	0.222***
	(0.0446)	(0.0253)	(0.0428)	(0.0424)	(0.0510)	(0.0515)
Observations	70	70	70	70	70	70
R-squared	0.044	0.107	0.617	0.622	0.627	0.637

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 11: Bednets and Child Mortality

Dependent variable	Death of child				
	(1)	(2)	(3)	(4)	(5)
HH owns bednet	-0.00968				
	(0.00690)				
Kids in HH slept with bednet		-0.0486***			
		(0.00608)			
ITN district coverage			-0.0443*	-0.0361*	0.0116
			(0.0255)	(0.0216)	(0.00808)
Female	-0.0199***	-0.0199***	-0.0199***	-0.0185***	-0.00540**
	(0.00538)	(0.00535)	(0.00539)	(0.00489)	(0.00214)
2nd wave	-0.0364***	-0.0307***	-0.0289***	-0.0265***	-0.0107***
	(0.00629)	(0.00587)	(0.00926)	(0.00805)	(0.00361)
Sample restrictions	none	none	none	Last 3 years	Last 3 years Older 2
Constant	0.270***	0.254***	0.271***	0.232***	0.0171
	(0.0478)	(0.0474)	(0.0479)	(0.0426)	(0.0176)
Observations	13201	13201	13201	12835	11941
R-squared	0.032	0.036	0.032	0.034	0.022

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
All specifications control for age and district fixed effects, mother's age, mother's age squared, mother's education, mother's marital status, mother's employment status, urban, female household head, number of household members and household assets (electricity, radio, tv, fridge and bike).

Table 12: Descriptive stats district level panel HMIS

	Obs	Mean	Std.Dev	Min	Max
Malaria inpatients under 5	645	1922	1531	0	8169
Malaria deaths under 5	645	55	55	0	325
Other deaths under 5	645	142	181	0	1770
Nets ('000)	648	9	20	0	182
District population ('000)	648	157	153	19	1341
Malaria inpatients per 1000 children under 5	645	72.01	46.54	0	343.87
Malaria deaths per 1000 children under 5	645	1.91	1.37	0	8.81
Other deaths per 1000 children under 5	645	4.67	3.59	0	21.57
Nets per capita	648	0.06	0.12	0	0.71

Table 13 B: ITN Distribution and Malaria

	Malaria inpatients under 5	Malaria deaths under 5	Other deaths under 5	Malaria inpatients under 5	Malaria deaths under 5	Other deaths under 5
	(1)	(2)	(3)	(4)	(5)	(6)
Nets current year				-0.680	-0.0913	-0.101
				(1.875)	(0.0767)	(0.169)
Nets previous year	-8.888***	-0.255***	-0.143	-9.422***	-0.342***	-0.210
	(2.307)	(0.0651)	(0.156)	(2.643)	(0.0813)	(0.165)
Nets two years ago				-4.856	-0.315***	-0.488*
				(3.881)	(0.0972)	(0.260)
Constant	2263***	68.53***	166.9***	2264***	68.70***	167.0***
	(53.05)	(2.744)	(4.921)	(60.00)	(3.014)	(5.257)
Observations	573	573	573	501	501	501
R-squared	0.872	0.741	0.904	0.881	0.774	0.904

Robust standard errors in parentheses are clustered at the district level. All specifications include year and district fixed effects. Nets are in thousands.
*** p<0.01, ** p<0.05, * p<0.1

Table 13 B: ITN Distribution and Malaria Relative to Population

	Malaria inpatients per 1000 children under 5	Malaria deaths per 1000 children under 5	Other deaths per 1000 children under 5	Malaria inpatients per 1000 children under 5	Malaria deaths per 1000 children under 5	Other deaths per 1000 children under 5
	(1)	(2)	(3)	(4)	(5)	(6)
Nets per capita				6.088	-0.121	-1.543
				(9.872)	(0.309)	(1.102)
L1 nets per capita	-26.25***	-0.778***	-0.709	-30.14**	-0.852**	-1.797*
	(9.279)	(0.271)	(0.769)	(12.74)	(0.382)	(1.077)
L2 nets per				-33.50	-0.0370	-3.839**

capita

	(1)	(2)	(3)	(4)	(5)	(6)
capita				(36.40)	(0.817)	(1.557)
Constant	59.75***	1.316***	3.673***	89.62***	2.295***	5.334***
	(2.751)	(0.0930)	(0.191)	(2.836)	(0.0940)	(0.185)
Observations	573	573	573	501	501	501
R-squared	0.811	0.634	0.744	0.824	0.637	0.771

Robust standard errors in parentheses are clustered at the district level. All specifications include year and district fixed effects.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 14: IRS Results, DHS

Dependent variable	Child had fever over last two weeks			
	(1)	(2)	(3)	(4)
Percentage of district population sprayed	0.102***			
	(0.0192)			
Household sprayed (self-report)		0.0482**	-0.0162	
		(0.0195)	(0.0199)	
Fraction of households sprayed in cluster				-0.00778
				(0.0394)
Age child	-0.0367***	-0.0367***	-0.0206***	-0.0207***
	(0.00277)	(0.00277)	(0.00330)	(0.00331)
2nd wave dummy	-0.283***	-0.257***		
	(0.0122)	(0.0108)		
Constant	0.614***	0.622***	0.361***	0.357***
	(0.0733)	(0.0733)	(0.0919)	(0.0921)
Observations	11524	11523	5671	5672
R-squared	0.123	0.121	0.047	0.046

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

All specifications control for district fixed effects, sex, mother's age, mother's age squared, mother's education, mother's marital status, mother's employment status, urban, female household head, number of household members and household assets (electricity, radio, tv, fridge and bike).

Table 15 A: Spraying only vs. spraying and ITN

	Malaria inpatients under 5	Malaria deaths under 5	Other deaths under 5	Malaria inpatients under 5	Malaria deaths under 5	Other deaths under 5
	(1)	(2)	(3)	(4)	(5)	(6)
Spraying target dummy	-241.5	-22.57*	0.539	-308.9*	-24.72**	-0.278
	(189.1)	(12.15)	(17.62)	(176.4)	(12.12)	(17.28)
Lag 1 Bed nets in '000				-9.351***	-0.298***	-0.113
				(2.324)	(0.0702)	(0.147)
Constant	1713***	42.18***	129.7***	2262***	68.51***	166.9***
	(70.43)	(2.690)	(11.44)	(51.98)	(2.513)	(4.905)
Observations	573	573	573	573	573	573
R-squared	0.866	0.760	0.905	0.873	0.766	0.905

Robust standard errors in parentheses are clustered at the district level. All specifications include year and district fixed effects.
*** p<0.01, ** p<0.05, * p<0.1

Table 15 B: Spraying only vs. spraying and ITN

	Malaria inpatients per 1000 children under 5	Malaria deaths per 1000 children under 5	Other deaths per 1000 children under 5	Malaria inpatients per 1000 children under 5	Malaria deaths per 1000 children under 5	Other deaths per 1000 children under 5
	(1)	(2)	(3)	(4)	(5)	(6)
Fraction sprayed	6.199	-0.416	0.792	2.526	-0.558	0.722
	(9.660)	(0.370)	(0.559)	(9.760)	(0.372)	(0.543)
Nets per capita				-25.38***	-0.984***	-0.484
				(9.548)	(0.257)	(0.704)

Constant	55.53***	1.273***	3.421***	59.29***	1.419***	3.492***
	(3.029)	(0.0892)	(0.208)	(3.555)	(0.0968)	(0.190)
Observations	573	573	573	573	573	573
R-squared	0.809	0.656	0.787	0.811	0.661	0.787

Robust standard errors in parentheses are clustered at the district level. All specifications include year and district fixed effects. Net distribution and spraying numbers reflect program activities in the preceding year.
*** p<0.01, ** p<0.05, * p<0.1

Figure 1: Malaria Deaths
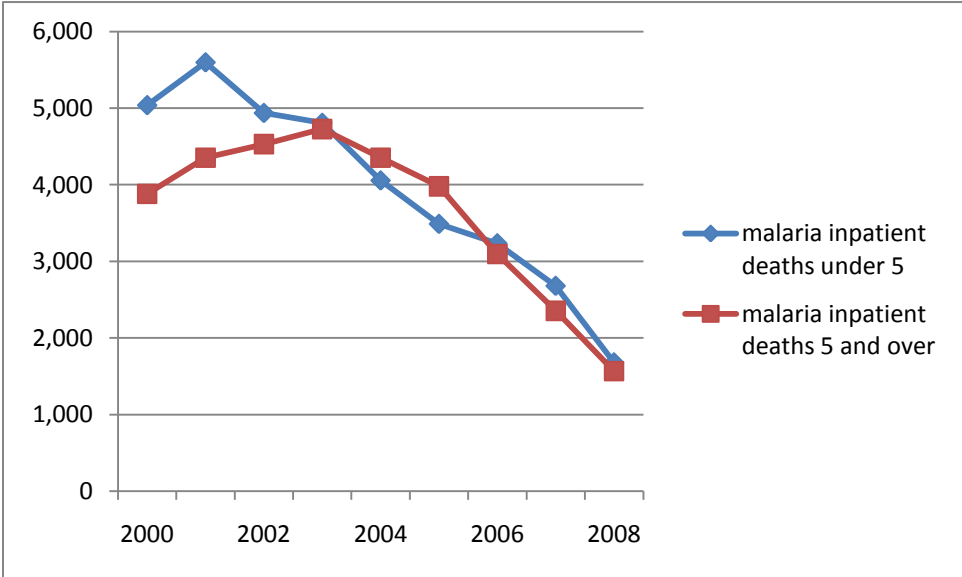
Source: HMIS

Figure 2: Deaths per 1,000 Children Under 5, HMIS
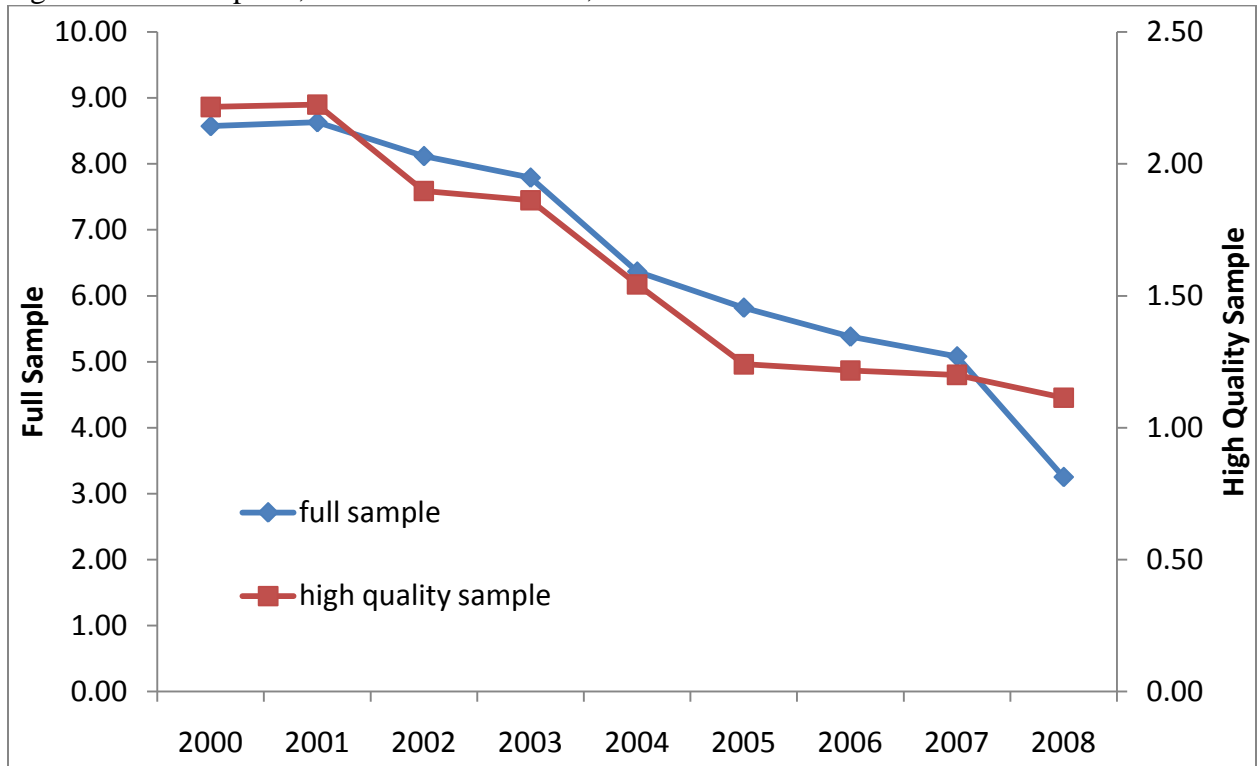
Figure 3:   Deaths by Province in DHS vs. HMIS
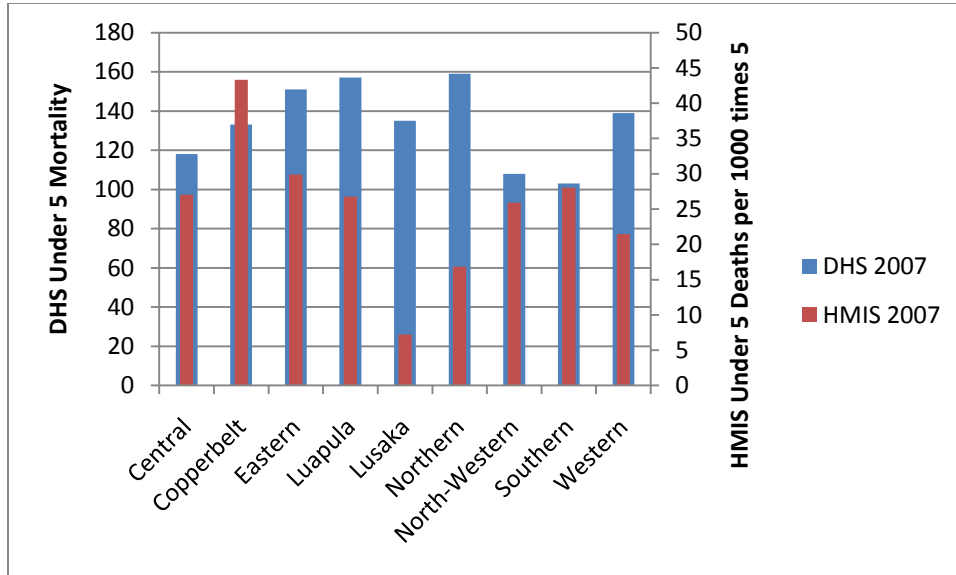
Figure 4: Mortality Changes: HMIS vs. DHS
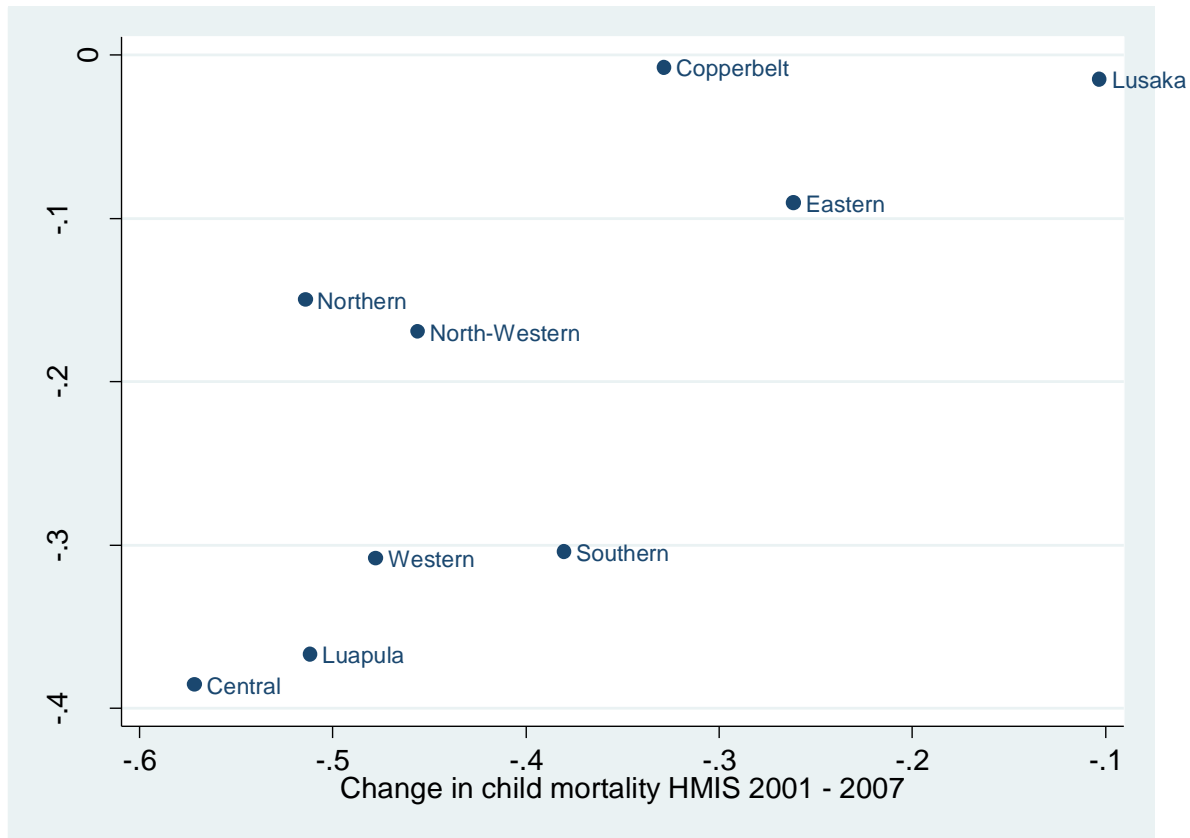
Note: Vertical axis is change in the under five mortality rate divided by the 2001 level.
Horizontal axis is change in HMIS deaths per 1,000 children divided by the 2001 level.

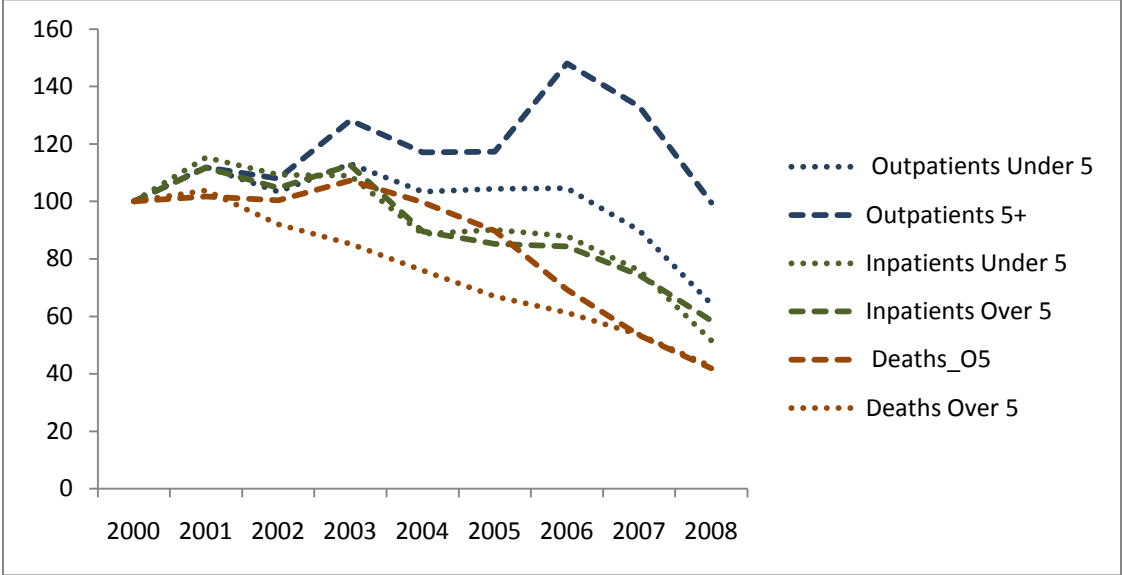Figure 5: Malaria Cases and Deaths, Chained Index
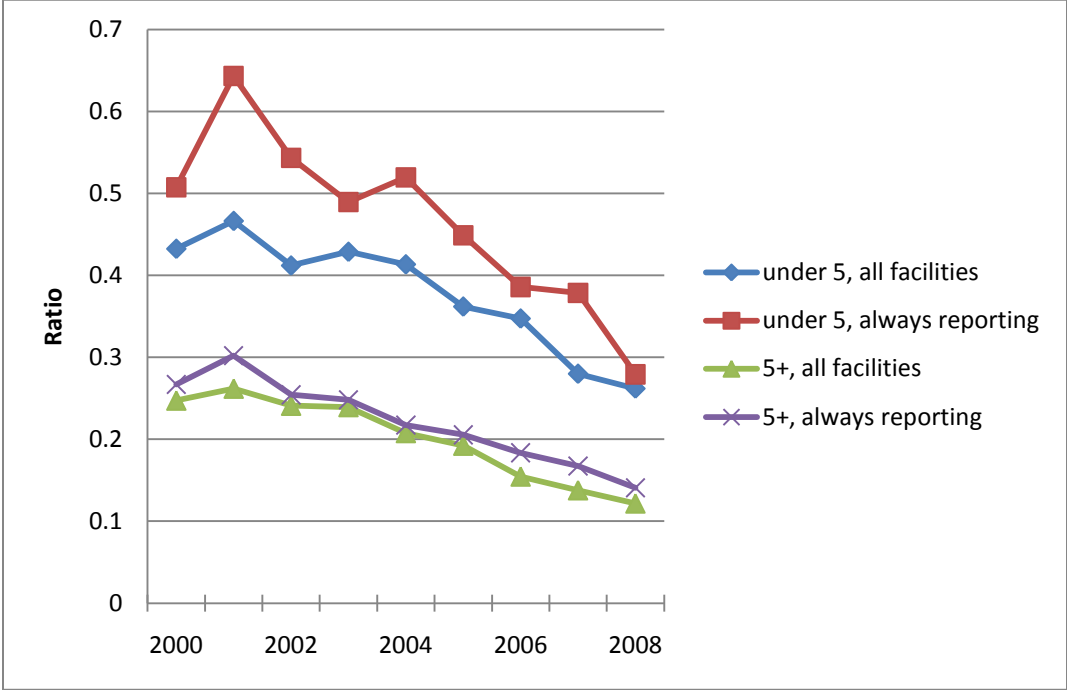
Figure 6: Ratio of Malaria to Non-Malaria Mortality
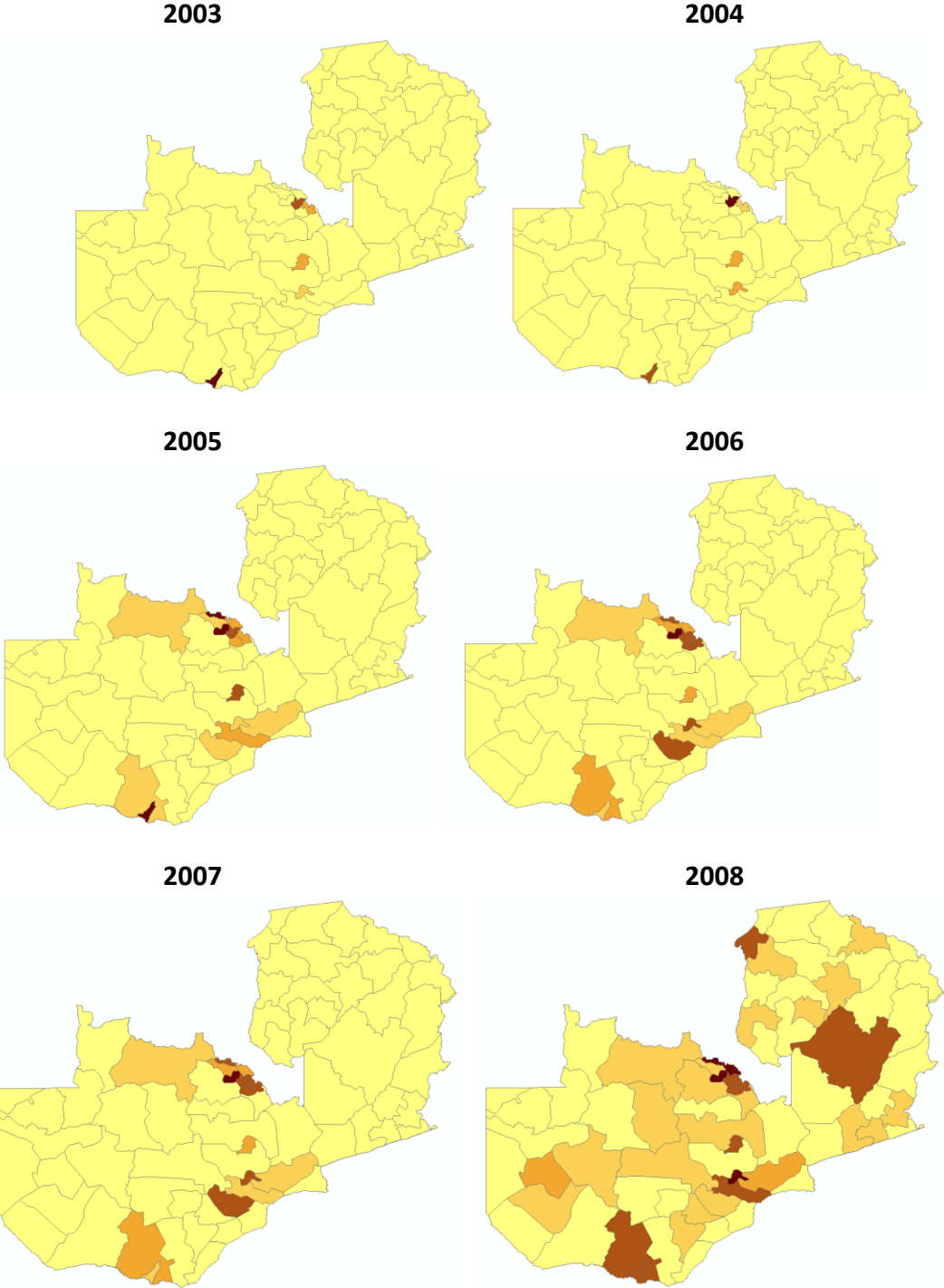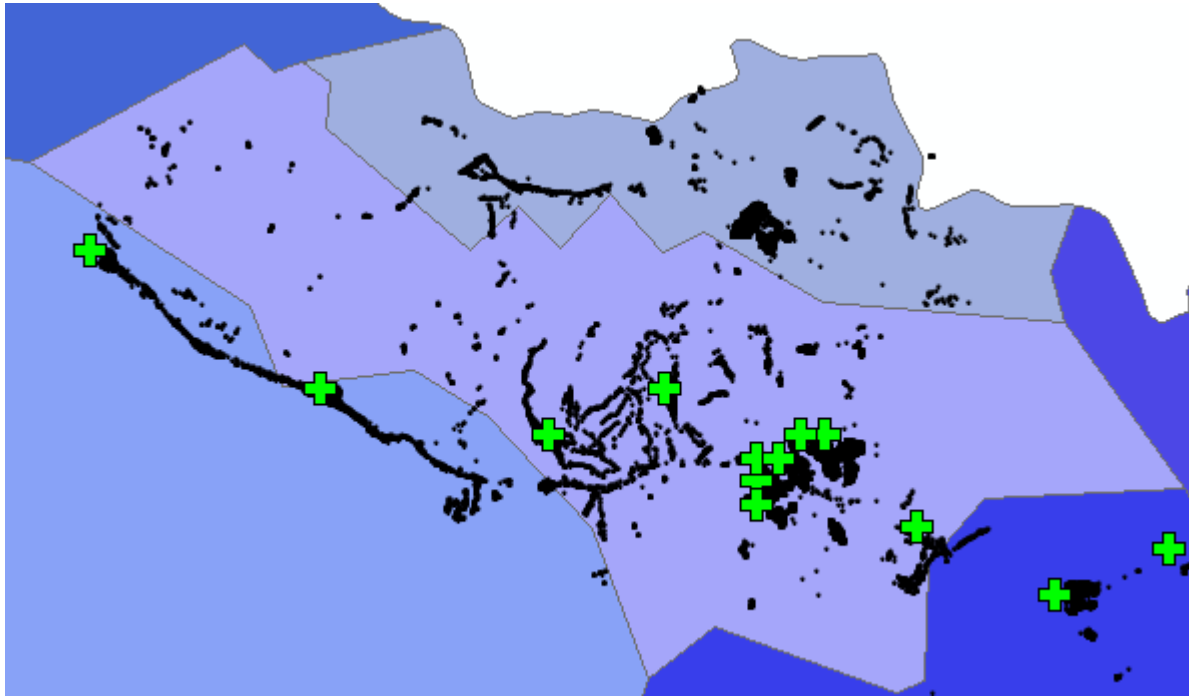
Figure 7: IRS Distribution by region

Figure 8: Health Facilities and Spraying in the Chingola District 2008

Source: NMCC. Green crosses represent health facilities, black dots sprayed structures. Grey lines are district boundaries.