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Essays on the Economic and Socio-behavioral Effectiveness of Large Scale Malaria Control Programs in Three sub-Saharan Africa Countries

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An abstract of
A dissertation submitted to the Faculty of the James T. Laney School of Graduate Studies of the Emory University in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Health Policy and Health Services Research at the Department of Health Policy and Management of the Rollins School of Public Health

2013

Abstract

Essays on Economic and Socio-Behavioural Effectiveness of Large Scale Malaria Control Programs in Three Sub-Saharan Africa Countries

By Joseph D. Njau

Increased global health funding has accelerated the rollout of effective malaria control packages. Little is known about the effectiveness of some of these interventions in terms of reducing socioeconomic inequalities, effective pathways for long-term and sustainable community engagements to malaria control efforts and also the cost- effectiveness of some interventions such as the universal malaria diagnostic testing in children under-five years of age.

We use Malaria Indicator Survey (MIS) data collected from three sub-Saharan Africa countries to explore the effectiveness of large scale malaria control implementation programs being undertaken in the region. Supplementary data are obtained from study countries' national malaria control programs, as well as published and unpublished study reports. Regression and decision tree models are used in the data analysis. Additionally, marginal effects and Blinder-Oaxaca decomposition techniques are employed to put the results in better perspective.

Targeted free bed-net distributions increased household overall ownership of bed-nets but the poorest households remained disproportionately underserved. Children in wealthier households were up to 12 percentage points less likely to test positive for malaria and were more likely to own and use bed-nets. Poorest households were significantly more likely to have children testing malaria positive. Meanwhile, maternal education was associated with a 4.7 percentage point reduction in childhood malaria infections. Adoption of malaria Rapid Diagnostic Test (mRDT) strategy was cost-effective across the three study countries relative to presumptive treatment strategy. The mRDT strategy exhibited higher probability to save children's lives relative to presumptive malaria treatment strategy.

Targeted free distribution of bed-nets did not achieve equitable bed-net access and use. Inequities were caused by factors other than financial constraints alone. Maternal education and choice of malaria control strategy are critical for successful and sustainable malaria control. Malaria control policies like adoption of mRDT strategy were variably cost-effective. Malaria control efforts should focus on tapping the current global momentum with coalition of diverse financing partners for effective and sustainable malaria control. Partners should be flexible enough when disbursing malaria control resources for countries to tailor control policies that reflect their epidemiological, social and economic needs.

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Chapter 1

General Introduction

Global Malaria Burden

According to the World Health Organization (WHO), there were an estimated 655,000 malaria deaths in 2010[1]. Other studies have suggested that malaria deaths could be more than twice the numbers reported by the WHO at a staggering number of 1,238,000 total deaths worldwide in 2010 alone[2]. Reports indicate that most of these tragic deaths occur in children under-five years of age and pregnant women with nearly 90% of the deaths recorded in sub Saharan Africa[3]. These two subgroups are particularly susceptible to the disease partly because of their weak immunity to malaria infections. Apart from the clinical burden of malaria disease, the economic and social burden of the disease is enormous [4, 5]. Whereas macroeconomic studies have estimated malaria burden to be responsible for up to 1.3% negative growth of GDP[6, 7], microeconomic studies have shown that households bear up to 75% of all malaria expenditures ranging from 0.39 to 3.84 per capita per year in sub-Saharan Africa[8-11]. Additionally, the World Bank estimates the annual economic losses caused by malaria in sub Saharan region at 12 billion[12]

Historical Context of Global Malaria Funding and Control Efforts

Following its formation in the post-world war II, the WHO championed a largely successful malaria elimination campaign in most of industrialized economies during the 1950s [13-15]. Unfortunately, the global campaign to eradicate malaria was less galvanized in other parts of the world and failed miserably especially in highly endemic countries with most of underserved populations including sub-Sahara African (SSA) countries, Latin America, the Indian sub-continent and, also in South East Asia. Following these mixed results, malaria retreated from advanced economies to become a predominant disease of the very poor nations [16]. Despite being a tropical disease, malaria disproportionately affects poorest populations than relatively wealthier households even in high transmission settings like in the SSA. Nevertheless, the last decade has witnessed a resurgence of global interest to reduce the burden of diseases with particular focus in developing countries[17]. Massive resources have been directed to fighting diseases of major economic burden including Malaria, HIV/AIDS, Tuberculosis and Neglected Tropical Diseases (NTDs)[‡]. Following the establishment of a private Bill & Melinda Gates foundation in the late 1990's, a multilateral Global fund envisioned to reduce the burden of diseases particularly in poor countries was subsequently launched in 2002. In the quest to achieve United Nations Millennium development goals (MDGs), both multilateral[§] and bilateral[**] aid agencies have shown more interest in addressing global health problems particularly the three major diseases known to inflict largest economic and social burdens on poor countries and especially the underserved populations. These diseases are HIV/AIDS, malaria and Tuberculosis. In the last 10 years alone, the US government through the President Emergency Plan for AIDS Relief (PEPFAR) and President Malaria Initiative (PMI) dedicated a total of over 16.2 billion dollars to reduce the burden of these tragic killer diseases[18]. Meanwhile, since its

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[‡] These are diseases with little name recognition in industrialized countries but they all cause severe disability in the world's poorest countries resulting into billions of dollars of lost productivity. They include; Leprosy, Lymphatic-Filariasis, Onchocerciasis, Schistosomiasis, Soil-transmitted helminthes and Trachoma.

[§] In 2005, the World Bank embarked on what it called 'Booster program for malaria control in Africa' with initial phase one commitment of 500 million USD to assist African governments' scale-up effective interventions for malaria control on the continent.

[**] These include aid agencies such as the United Kingdom's Department for International Development (DfID), United States Agency for International Development Aid (USAID), Canadian International Development Research Centre (IDRC), Japanese International Cooperation Agency (JICA) and others.

launch in 2002, the Global Fund has approved grants worth over 22 billion USD to fight against HIV/AIDS, Tuberculosis and Malaria mostly in developing countries and in transitioning economies [19].

The increased funding for global health and particularly malaria has been applauded by humanitarians, public health and development experts. Most of these resources are being spent on scaling up of effective malaria control interventions spanning from improvement of malaria prevention strategies to improved clinical management of malaria cases. However, consensus is quickly converging to the fact that unless these resources are matched with quick and substantial public health gains, donor fatigues would soon creep-in resulting into deleterious consequences to the global health agenda[20-23]. To avoid such disastrous outcome, experts agree on the need to revise the current malaria management policies to ensure that there is high and better returns on these investments. Malaria is long known for its resilience and insidious assault on its helpless poor victims. Prospects for substantial and sustainable gains in its control given the dearth of resources in SSA are worrisome, unless the current global funding momentum is maintained. To ensure such maintenance, there is every need to revisit existing prevention and treatment strategies with the goal to enhance better integration of socioeconomic studies with natural science to maximize and sustain malaria control achievements already on the horizon. A focus on issues related to socioeconomic disparities and socio-behavioral factors is crucial for achieving both effective disease management and efficient resource allocation. For instance, up until 2010, malaria treatment protocols particularly in poor resource settings relied on WHO endorsed policy of presumptive malaria treatment[24]. Over-time, evidence has accumulated showing that the policy resulted to over-prescription of antimalarial drugs which in some cases led to deleterious consequences [25, 26]. Researchers believe that less than 50 percent of all febrile illnesses are malaria caused with other diseases like pneumonia and acute respiratory infections being responsible for most of the children under-five years of age fevers[27-30].

Moreover, because of the nature of international malaria funding, most of malaria control efforts have focused on clinical and epidemiological aspects of the disease with less emphasis on its socioeconomic and behavioral dimensions [31, 32]. Malaria control policies have also had little success in using sector-wide approaches to maximize malaria prevention and control gains [14, 33-35]. As a result, our knowledge on intricate relationship between malaria infections and other socio-cultural as well as behavioral factors including education is severely limited. In some situations our understanding of these relationships is at worst incoherent[36]. Better understanding and integration of these aspects is crucial for successful and more effective scale-up of malaria control programs.

Finally, the malaria policy environment existing during the time this study was conducted is interesting and important to understand. This study comes at a time when there is renewed interest and global commitment to control and ultimately eliminate malaria worldwide. The renewed interest offers a great opportunity to offer policy suggestions for better and more effective malaria control program implementation. This study in uniquely placed to provide useful policy guidance for the concerted global efforts to eradicate malaria especially in places like sub-Saharan Africa where the burden of malaria disease is most experienced.

Problem Statement

Since the late 1990's malaria funding has increased substantially from less than US$ 0.3 billion in 1998 to almost US$ 2 billion in 2010 [37, 38]. In the latest global malaria report however, the World Health Organization (WHO) warned that funding for malaria programs seem to have leveled in 2010 and slightly declined in the subsequent year 2011 [1, 39]. The report also indicated that the pace of malaria burden reduction had stalled in the preceding two years compared to substantial achievements made in the consecutive five years ending before the year 2011[40, 41]. Following these revelations, it is extremely important for researchers and policy makers to reevaluate the effectiveness of current malaria control packages to ensure that only interventions with promising impact continue being implemented. This study uses nationally representative households' malaria indicator survey and administrative data to evaluate the effectiveness of existing malaria control strategies. Following the findings of this study, policy recommendations targeting donor and local governments on a set of malaria control packages that should be enhanced and those needing recast will be suggested. We propose to conduct an evaluation of the socio-economic effectiveness of malaria control policies in three key areas relevant for successful malaria control program implementation in the sub-Saharan Africa and other malaria endemic countries.

We first evaluate the effectiveness of existing bed-net distribution strategies in mediating the relationship between household socioeconomic disparities and a set of key malaria control interventions in children under-five years of age. Despite malaria being largely referred as the disease of the poor, our understanding of how malaria control programs reach the poorest sub-populations remains limited [42-45]. While the geographical distribution of malaria and its impact on world's poorest economies is well documented[6, 46, 47], the poorest continue to disproportionately bear the most burden of the disease even in relatively uniformly communities with high malaria transmission settings[48, 49]. Various programs such as universal free bed-net distribution, Affordable Medicines Facility-malaria (AMFm) and others have all been aiming at improving access to effective malaria control packages among the very poor people around the world [50-54].

Nevertheless, the design and implementation of pro-poor programs have often resulted to mixed outcomes regardless of how well-intentioned such programs may be. Better off groups usually find ways to benefit more from such programs as they use the services more than disadvantaged groups. In the meantime, poor people often times receiving less care for reasons such as lack of knowledge, lack of power, inaccessibility of facilities that provide decent care , unresponsive health providers and sometimes poor mechanism to identify the poor or some hidden costs associated with accessing such services[51, 55]. The implementation of targeted free- bed nets and later universal free bed-net distribution in SSA is one of such pro-poor programs which aimed at removing the financial barrier poor people face when accessing effective malaria control packages like mosquito nets[50, 56]. However, it remains unclear how successful the program has been in improving access of these interventions by the neediest populations [57-60]. Based on the amount of resources being used to scale up interventions such as targeted or universal free bed-net distribution as well as the AMFm whose goal is improve access of effective malaria interventions among poorest populations, evaluating the effectiveness of these interventions should remain a policy priority. Both malaria endemic countries and also the donor community ought to be interested in finding out how effective these programs are with the goal to provide evidence for helping design pragmatic malaria control policies. We therefore use nationally representative data from three countries to explore how targeted free bed-net distributions have mediated the relationships between household socioeconomic inequalities and a set of childhood malaria control indicators particularly, malaria infections, household bed-net ownerships and bed-net use by children under-five years of age.

Secondly, the breadth and strength of current malaria control policies in incorporating non clinical interventions such as the socio-behavioral to maximize gains in malaria prevention and control is least understood. The relationship between socio-cultural, behavioral, anthropological and educational factors on one hand, and malaria infections, prevention and treatment on the other hand are not exhaustively explored[31, 34]. This study aims to particularly focus on delineating the pathways through which maternal education level relates to childhood malaria infection rates. For many years, demographers and economists have been fascinated by the nature of the relationship between education and health [61-65]. There has been numerous studies from developing countries demonstrating some strong statistical relationships between maternal education and child nutritional status, vaccine uptakes, and overall child survival [66, 67]. While there has been many studies looking at the relationships between maternal education and child vaccination uptakes, nutritional status and survivorship there has been less attention given to existing relationships between maternal education and childhood malaria infections[68-71]. At the time when the world strives to achieve the millennium development goals of halving child mortality by 2015[72], it is extremely important to understand the role of maternal education if any, in reducing childhood malaria infection rates. To accomplish such analysis, the study will first describe the potential pathways through which maternal education relate to childhood malaria infection rates. The second part of the study will be to use MIS data in exploring these relationships and consequently make policy recommendations for effective sector-wide malaria control implementations.

Finally, despite recommendations by the WHO for countries to implement universal malaria testing whenever feasible, the debate on the effectiveness of such a policy far from settled. This study aims to establish whether universal malaria testing through use of rapid diagnostic testing (mRDT) in children under-five years of age is a cost-effective strategy. For many years, malaria endemic countries relied on presumptive malaria diagnostic and treatment with particularly emphasis on children under-five years of age [73-75]. In the year 2010, the World Health Organization issued a new guideline requiring universal malaria testing for patients of all age groups before administering any treatment whenever feasible[24]. The goal of the new strategy was to reduce inappropriate malaria treatment and also the negative consequences of treating non-malarial illnesses with antimalarials. While the policy guideline has been hailed by many as a step to the right direction, some opponents of the policy have issued cautious warning that it may not be the best lifesaving solution especially in areas with moderate to high malaria transmissions[76-78]. Moreover, the adoption of the new treatment guideline by malaria endemic countries has been disappointingly slow and arduous because of poor financing and program implementation challenges [79, 80]. Among others, the major challenges include, resource mobilization, poor clinician compliance to mRDT test results, inaccessibility of the tests in the private retail market, mRDT storage challenges and arguably their reported poor sensitivity and specificity[76, 79, 81, 82]. Critics of the policy also argue that the new guideline is lacks enough economic evidence to support its implementation for malaria treatment in children under-five years of age. These debates have provided enough ammunitions to criticize the WHO's new malaria treatment guidelines [75, 77, 78, 83]. By answering the economic question on whether use of mRDT for diagnosis and treatment of malaria in children under-five years of age would be a cost-effective policy strategy, this study will provide some additional evidence and impetus for more swift policy implementation.

Study Objectives

The overall objective of this work is to explore whether increased global attention and funding for malaria control is matched with being successful implementation of effective malaria control packages.

Specific Objectives

The specific objectives of this thesis include:

i. Explore the impact of targeted distribution of free bed-nets in mediating the relationship between household socioeconomic inequalities and a set of childhood malaria control indicators

ii. Explore existing linkages between maternal education and childhood malaria infections

iii. Conduct a cross country economic evaluation of universal malaria rapid diagnostic tests (mRDT) relative to presumptive malaria treatment in children under-five years of age

Structure of the Thesis

This thesis comprises of seven chapters. Chapter 1 presented a short background, stated the research problem under investigation and also outlined the overall objectives of the study. Chapter 2 reviews and summarizes existing literature for the three sub-objectives outlined in chapter one and also highlights the malaria policy environment at the time the study was executed. Chapter 3 describes the data used in the analysis, methodology and data analysis challenges. Chapter 4 presents sub-objective one in details with methods, results and discussions of the results. Chapter 5 deals with the analysis of sub-objective two, presents findings and their policy implications. Chapter 6 delves to the economic evaluation of universal malaria testing relative to presumptive treatment in children-under5. Finally, chapter seven presents overall discussions, summarizes key findings and policy implications of the study. It also highlights some study limitations while identifying priority areas for future research.

Chapter 2

Literature Review

Introduction

This chapter we review literature on broad topic of health inequalities and how inequalities in health have been addressed in malaria control programs and research. We briefly describe efforts to overcome inequalities in malaria disease which is widely known as the disease of the poor. We argue that evidence for successfulness of programs like universal bed-net coverage and the affordable medicines facility-malaria (AMFm) in reducing inequalities in accessing malaria preventive and treatment tools by those most in need, is not well established. Furthermore, we review literature on the relationship between maternal education and child health with particular interest on malaria infections as outlined in the study objective two. Based on existing evidence, we argue that malaria control programs have not been holistic enough to include other non-health sectors like education in order to maximize the control efforts. We conclude this sub-section by pointing to the fact that the existing linkages between maternal education and childhood malaria infections need to be explored further for better and more sustainable malaria control programs. Finally, we review evidence on use of rapid diagnostic tools as a standard malaria diagnostic strategy. Studies indicate the economic evidence in support of using mRDTs for treatment of malaria in patients of all age groups remains sparse. Poor clinicians' compliance to test results, differences in malaria transmission intensity as well as the prices of RDTs and antimalarial drugs make it difficult to clearly demonstrate the cost-effectiveness of using the mRDT strategy relative to presumptive malaria treatment.

Malaria interventions and health inequalities

Inequalities in access and use of preventive and treatment of various health ailments have been well documented worldwide [84-86]. The 1980 Black Report on health inequalities in the United Kingdom was precedent for most of today's studies on health inequalities [87-89]. Issues focusing on inequalities in access for preventive and treatment of malaria related illnesses in sub-Saharan Africa and other malaria endemic countries have particularly received heightened attention especially in recent years[90-92]. The fact that malaria disproportionally affects poorest people makes the disease an interesting laboratory for studies on health inequalities [48, 49, 93]. It is estimated that about 20% of world's poorest population bears almost 60% of the malaria burden seeing highest morbidity and mortality rates[7]. In the meantime, the same substratum of the population receives the worst standard of care[94]. In order to improve access for preventive and treatment of malaria among the world's poorest, radical solutions such as the call for global subsidy for antimalarial drugs and universal free-bed net distributions have been proposed [3, 50, 54, 56, 95-97]. The effectiveness of such solutions in reducing inequalities in access to these lifesaving interventions is not well established [43, 58, 59, 98-100].

For many years, the effectiveness of bed-net use in reducing malaria infections across people of all age groups has been well documented [101-104]. While the usefulness of bed-nets use in reducing clinical malaria is indubitable, debates on the best ways for rapid and equitable scale-up of mosquito bed-nets remain unsettled[50, 105-108]. Malaria researchers have for many years been divided along the political economy philosophical ideologies. Support for strategies to scale-up bed-nets distribution has fallen along the lines of those believing in strengthening the role private sector for sustainable health care service delivery[109] versus those seeing healthcare as a human right issue needing central planning mechanism to reduce inequalities in accessing effective and high quality health care services including lifesaving malaria control tools[56, 110-112]. Those supporting the role of private sector market in health care service delivery tend to support social marketing and cost-sharing as the best bed-net scale-up distributions strategy [113-115]. Meanwhile, researchers and policy makers with strong feeling for equitable access of healthcare services have often argued for targeted or universal free bed-net distribution as the best strategy to overcome inequalities in accessing effective malaria control tools[3, 110, 116]. Inherent to their support for such strategy is the belief that economic uncertainties for most part accounts for the poor access to these lifesaving health interventions. Despite increased call and implementation of free bed-net distribution in most malaria endemic countries, studies continue to show inequities in accessing these lifesaving malaria control tools [43, 117-119]. Most of past studies advocating for free bed-net distributions as the best way to achieve equitable access for these interventions are often based on conclusions drawn from case-control studies which are known for misrepresenting the real world scenarios[120, 121]. Such case-control studies may not necessarily be generalizable because of infrastructural and other large scale program implementation challenges which may threated the feasibility of reaching out to the neediest populations[57, 58] .

Inequalities in accessing effective malaria control interventions such as ownership and use of bed-nets continue to be unabated because of multiple reasons. Among others, is the fact that interventions such as one advocating for free bed-net distributions have been designed and implemented on the assumption that majority of people in malaria endemic countries are financially incapable of buying nets and therefore subsidized or free bed-nets distribution would help overcome such financial hurdles [43, 119, 122, 123]. Nevertheless, studies are increasingly coming to grips with realization that access barriers are increasingly caused by more than lack of financial resources. Existence of reliable physical infrastructures including health facility buildings, roads and other communication infrastructures is critical for effective and equitable health service delivery[55, 124]. For many of malaria endemic countries in sub-Saharan Africa, this limitation poses serious obstacle to equitable health service delivery including those related to malaria prevention and treatment. At least two studies have reported low access for bed-nets because of geographic and demographic barriers to these lifesaving interventions [125, 126]. In one of the studies, it was established that members of households closest to health facilities were more likely to own bed-nets than those residing far away[125]. Another barrier to accessing bed-nets was associated with age of household members. In households where there were no young children aged less than five years, it was unlikely that such households would report ownership of any mosquito net. Gender was also found to be another factor determining household report of bed-net ownerships. Households with a woman of reproductive age reporting to have attended antenatal services in the last six months were significantly more likely to report ownership of bed-nets than those without such characteristics[57].

Furthermore, willingness to pay for bed-nets in Nigeria was found to be an important determinant of households reporting ownership of at least one bed-net. Individuals expressing higher willingness to pay for bed-nets were more likely to own nets than those with lower willingness to pay for same products[117]. In Tanzania, a study on equitability of net ownership concluded that apart from financial barriers, there were other important determinants of net ownerships. These were listed as whether the household was located in rural areas as well as negative perceptions by members of the households on the effect of insecticides on the health of net users[118]. Moreover, another study from Ethiopia suggested that perceived level of malaria risk could play a vital part for a household to own or use a mosquito net. In this study, households whose heads were farmers were more likely to own at least one net compared to those whose heads were traders[127]. The article further reported that households with respondents expressing some good knowledge on causes of malaria were more likely to own a net than those who didn’t know the major cause of malaria disease. Same findings were also reported in a separate study from rural Tanzania [128, 129]. This further demonstrates that barriers to bed-net ownership and use can go beyond financial constraints to incorporate individual’s knowledge about the disease, perceived risk of disease, individual perceptions about malaria and bed-nets themselves.

In conclusion, there is enough evidence indicating that financial vulnerability does enhance the probabilities for households to be less likely to purchase and access health care services such as malaria preventive tools [119, 130]. However, a review of literature also shows that there are other additional important barriers to access effective malaria control tools like mosquito nets. As shown in this review, inequities in accessing various malaria control services may be caused by several other factors including household demographics and gender composition, perceived risk to contracting malaria, geographic location of households, information availability, physical infrastructure, willingness to pay and household's head major source of income or specialty. For better understanding on how effective the current malaria control interventions have been, one has to tease out the contributions of each of these aforementioned factors in reducing inequalities in access and use of malaria control tools.

The role of Socio-behavioral factors in improving child health and malaria control programs

Malaria control programs have often been criticized for their parochial approach to addressing the problem instead of adopting holistic and more integrated strategy [14, 33, 34, 131-133]. A study conducted in Solomon Islands concluded that impregnated nets could not fully substitute for vector control and, health education was strongly associated with significant reduction of malaria burden [94, 134]. For many years, the clinical and economic burden of malaria has been arguably well documented [7, 94]. However, there has been less effort devoted to understanding the intricate relationships between malaria burden and socio-behavioral as well as cultural factors [31, 93, 94]. As it has been emphasized by socio-behavioral researchers, it is important to understand the process through which social and cultural factors affect the biomedical burden of malaria [31, 135]. Despite existence of whole range of studies reporting on the relationships between maternal education, health, survivorship, nutrition and children's vaccine uptakes [66-71], there have been no similar efforts undertaken to understand the role of maternal education on childhood malaria infection rates. Better understanding of these relationships has the potential to reduce the clinical burden of malaria especially in young children. A study from Nigeria concluded that bed-net ownership among households with young children was highly correlated with having a woman who knew that bed-nets prevented malaria infections[136]. The importance of understanding the role of socio-behavioral factors in malaria control has led some social scientists developing a new concepts like ‘social vulnerability’ with the goal to better understand how vulnerability inhibits malaria control efforts [137, 138]. This new approach highlights the importance of social-cultural factors that make some sub-groups or individuals more susceptible to malaria and other disease burdens [139, 140]. This new socio-behavioral analytical framework aims to establish the link between socio-cultural and economic vulnerability, to accessing preventive and treatment services for various diseases including malaria.

Since late 1970’s researchers have been fascinated by the intricate relationships that exists between maternal education and health. More specifically, their analyses has delved to understanding the relationship between maternal education and improvements in child health including their nutrition status, survivorships and access to various healthcare services including lifesaving vaccines. Owing to the fact that the cognitive pathways through which maternal education impacts child health are not as straight forward, there has been wide range of descriptions of these relationships[61, 141-143].

A better understanding on how maternal education relates to childhood malaria infection rates has the potential to play a significant role by substantially reducing both the clinical and socioeconomic burden of malaria infections in children under-five years of age[144-147]. Our task in this study is to attempt and describe the underlining pathways through which maternal education may relate to childhood malaria infections. Our analytical framework builds on other studies’ descriptions on possible pathways through which maternal education may relate to childhood overall health and survivorship.

Generally, there is no evidence that formal education imparts any specific health messages to students including those related to malaria infections, prevention and treatment. However, people with some level of formal education have been found to be fairly better off when it comes to experiencing disease burdens and particularly malaria [4, 36, 148]. It is therefore argued that education does improve people's overall knowledge about health and make them more receptive to health messages [149-151]. It is by being receptive to educational messages therefore; maternal education may play a vital role in mitigating childhood malaria and other disease infections as they readily avail themselves through different health messages simmering through various public health channels for their own benefits. Additionally, formal education equips individuals with some problem-solving skills which they would otherwise, have no direct access[152].

Maternal education has also been shown to delay child bearing for young mothers as well as encourage small family sizes[153, 154]. By influencing decisions on child bearing and number of children a woman bears, maternal education can alter family formation patters in favor of reducing child mortality and consequently childhood malaria infections[155]. By avoiding early marriages, women accord themselves sometime to grow, mature and also become financially stable. These are necessary ingredients for a healthy family and also for protecting their children from malaria infections. With financial instability, women are more vulnerable and may lack cash to enable them make right decisions about timely access for treatment when their children fall sick. Delays in reproducing children and good birth intervals have the potential to enable mothers attend to the details of child bringing and can easily monitor the health of their children to know when they are sick or needing urgent medical attention.

Furthermore, maternal education has been shown to empower women socially and economically [156-159]. Historically, intra-household decision making has been patriarchal with women roles being underappreciated. Such gender restrictions have significantly robbed women of some important matriarchal roles in child health and up-bringing. With more women attaining education, their roles in decision making have improved substantially as they are able to finance such decisions on their own as well as living with their financial and social consequences. Maternal education therefore, brings not only autonomy for women in decision making but also increases the family economic fortunes helping to address children issues including their wellbeing. With improved socioeconomic status, educated mothers can afford better health care services and effectively protect their children from contracting diseases like malaria. A study in Canada reported that household expenditures were closely linked to traditional gender roles whereby a substantial part of women's incomes were spent on childcare compared to men[160]. Maternal education therefore increases incomes and also may influence decisions on where to live with most of those educated deciding to live. Such class of women tends to marry wealthier husbands and also live in relatively better-off neighborhoods with improved health services and infrastructures which in turn help improve their children's health.

Finally, maternal education has been shown to improve their social networking enabling them timely access relevant information including lifesaving interventions. Social networking is increasingly becoming an important forum for accessing different information including news about employments, micro financing facilities, availability of different social and health services such as bed-net distribution campaigns, vaccinations and others. Educated mothers typically enjoy broader social networks because of the sheer number of peers they've gone to school together and also the active life formal education places on them. A study in Gambia reported that mothers in rural areas were influenced by their peers and other women activities like village music groups to attend antenatal clinic day more than mothers living in urban settings where such support was inexistent[161]. In the era of widespread of mobile phones and use of social network media, social networks can play an important role in improving children's health[162]. Educated mothers are better placed to benefit from such social networks because of their increased social and economic confidence than would be the case for uneducated mothers.

Therefore, the past studies on the relationship between maternal education and child health have exhibited some strong patterns between the two. While the description of how maternal education influences child health and survivorship remains widely variable, the studies have consistently shown some positive relationships of the two. However, in the malaria literature, there is very limited information on this subject matter. The epidemiology of malaria categorizes children under-five years of age and pregnant women as the most malaria susceptible subpopulations. This classification highlights the importance of understanding how maternal education may relate to childhood malaria infections as well as infections in pregnant women. In this study, we want to focus on exploring the relationship between maternal education and malaria infection rates in children under-five years of age.

Cost-effectiveness of Malaria Interventions: The case of universal malaria rapid diagnostic tests (mRDT) in young children

For many years, presumptive malaria management was the mainstay of malaria diagnosis and treatment in virtually all malaria endemic countries in sub-Saharan Africa regardless of whether treatment occurred at home or at formal health facilities. Owing to the overlap of symptoms between malarial and non-malarial fevers, this strategy resulted to substantial malaria over-diagnosis [27, 163, 164]. Studies conducted in East Africa found that 48% - 80% of outpatients with negative blood slides were being prescribed with antimalarials [165, 166]. Malaria over-diagnoses have far reaching adverse clinical and economic consequences. Apart from unnecessary drug misuse, the practice may result to poor case diagnosis and delays in receiving proper treatment among patients with non-malarial febrile illnesses[167]. This in part, may result to unnecessary increase of mortality in patients of all age groups and more particularly, in young children[168, 169]. Studies have shown that across the entire sub-Saharan region, up to 61% of febrile illnesses clinically diagnosed as malaria are in fact, caused by non-malarial pathogens[26]. Such possible scenarios occur because non-malarial fever symptoms are clinically very similar to malaria[170, 171] or, sometimes clinicians tend not to trust malaria test results and would often prescribe antimalarial drugs even in cases where patients have negative malaria tests[27, 172]

The misuse of antimalarial drugs through over-diagnosis and poor prescription practices have resulted to malaria parasite drug resistance problem with popular antimalarial drugs like chloroquine becoming obsolete. Following these developments, most malaria endemic countries have switched their treatment algorithms to more efficacious antimalarials like artemisinin-based combination drugs[3, 173]. While these drugs have been hailed as the new hope for worldwide malaria treatment, their costs have been noted to be up to 20 times more expensive when compared to traditional antimalarials[91, 174, 175]. The high price tags of the new antimalarials have posed some serious challenges in accessing these efficacious drugs especially by the majority of poor households in the malaria endemic world [169, 176-178]. In the recent years however, with increased demand for these new drugs, large scale production and introduction of various financing mechanisms have been undertaken to ease their high prices [179-181]. However, because of the threat of drug resistance problem, countries have also been urged to adopt new malaria treatment strategies and incorporate universal malaria testing before any treatment is administered and whenever feasible[24, 182].

The new WHO recommendation for universal testing has received mixed response from both researchers and policy makers. Among others, the mixed response to the new policy has resulted to a painfully slow mRDT policy adoption process in most malaria endemic countries [183, 184]. While the policy has received positive endorsements from prominent researchers and policy makers, it has also been criticized in some circles as being the hallmark of poor and disastrous public health policy endeavor[78]. Some critics of the policy have also accused the WHO for its long history of sending ambiguous messages on malaria diagnosis and treatment. They argue that the world health body ambiguity has resulted to perverse clinical negligence by most malaria endemic countries. [75, 83]. For instance, the question the legitimacy of the policy given the WHO’s support for other controverting programs such as the integrated management of childhood illnesses (IMCI) which had presumptive malaria treatment as one of its core component. Overall, the arguments in favor of universal adoption of malaria diagnosis and treatment can be summarized as follows, (i) there are readily available cheap and reliable malaria diagnostic tools, (ii) antimalarial drugs have increasingly become expensive and therefore, unaffordable to majority of poor people, (iii) there has been overall steady decline in malaria prevalence and (iv) malaria over-diagnosis results to inadequate treatment of non-malarial illnesses while threatening the efficacy of the currently approved antimalarial drugs.

Meanwhile proponents of continuation of presumptive malaria treatment in children-under five years are concerned that universal malaria testing may result to higher morbidity and mortality especially in young children whose immunity is still naïve in dealing with malaria infections[77]. They believe that, there remain important evidence gaps to guide such critical malaria policy action. They also believe that the weak and fragmented health systems prevalent in most malaria endemic countries are yet to demonstrate the capacity to efficiently and successfully implement such policy shifts as reported by some studies[82]. This is evidenced by poor commodity logistics prevalent in most primary health care facilities coupled with poor storage facilities. They further argue that a policy formulation driven by anxiety about drug costs and optimism that malaria is being defeated may result to hurried policy change which could result to more harm than good. Nevertheless, they believe that minimizing the risk of death or severe disease in children remains the number one priority for presumptive treatment strategy. It is also believed that while rapid diagnostic tests perform better in research studies, there is very limited data on their performance in routine settings and early indications suggest a relatively poor sensitivity at overall rate of 65% with a worrying variability between sites ranging from as low as 19% to as high as 86% [82]. Following this shortfall, critics question the extent to which malaria policy makers would be willing and prepared to take risks of high morbidity and mortality caused by missed malaria cases. They believe that such scenarios would be perverse especially in settings with high malaria transmission settings[78].

Finally, opponents of universal malaria testing argue that recent economic evaluations of rapid diagnostic tests relative to presumptive malaria treatment only support treatment of contingent on RDT diagnosis, especially in areas with very low malaria prevalence[185, 186]. Even with such recommendation, they warn that such models are reliant on a ‘best guess’ scenario of the risk of no treatment in truly infected child. Additionally, these studies conducted their evaluation for malaria patients of all age groups regardless of heightened biological vulnerability when children-under the age of five years are involved. To make matters even worse, the ‘best guess’ in often cases assumes that malaria infection occurs in semi-immune child which puts very young children at a relatively higher fatality risk. While there is limited data suggesting very low risk of failure to detect true malaria in febrile children[187], it is argued that such studies are based on active follow-up, and do not measure the risk of serious morbidity and mortality from failed diagnostic process in real-life settings. Under such given situations there are considerable barriers to accessing treatments mindless of the additional retreatments that may potentially be required. Therefore, despite malaria prevalence declining in most malaria endemic countries, malaria prevention efforts across sub Saharan Africa remain inadequate[41].

Because of these contending viewpoints, we believe that more evidence on the effectiveness of adoption of mRDT especially in young children need to be generated for new policy making or strengthening purposes. With nationally representative data from three countries with varied malaria epidemiology, our study is in a much better position to fill-in the existing gaps on the cost-effectiveness of universal mRDT use with particular focus on children-under five years of age. Our findings will help generate additional evidence needed to help resolve the current debate stalemate.

Review Synthesis

We have reviewed studies on inequalities in malaria control interventions service delivery, the role of integrative epidemiological, socio-behavioral and cultural factors on effective malaria control strategies and finally, the debates on rationale and effectiveness of universal rapid malaria testing. On the delivery of malaria control services, it has been shown that despite efforts to overcome barriers to access some of lifesaving malaria interventions, the poorest of the poor continue to bare the largest burden of the disease and also report least access to effective interventions. Furthermore, we reviewed literature on socio-behavioral dimensions of malaria with particular focus on the impact of maternal education on child health and survivorship. Through the review, we were able to show that there exist some important gaps that need to be addressed. The role of maternal education on childhood malaria infections has not been adequately addressed. Finally, on the cost-effectiveness for adopting universal malaria testing in children under-five years of age, there are still some important gaps that need to be addressed in order to confidently assert the cost-effectiveness of mRDT use in children under-five years of age.

With the use of nationally representative cross-sectional survey data and some supplementary administrative data on costing and program effectiveness, this study aims to address some of the identified gaps. In this study as described in the problem statement, we will delve on the impact of targeted free bed-net distribution in overcoming socioeconomic disparities in malaria infections and control. The second goal will be to explore the cost-effectiveness of universal malaria testing by rapid diagnostic tests in all children under-five years of age and finally, the study will look at the relationships between maternal education and childhood malaria infections. The goal is to generate good evidence to help in the design of the next generation of malaria control policies throughout sub-Saharan Africa and other malaria endemic countries. Given the renewed interest for global malaria control and long history to find appropriate and effective malaria control policies, we believe that the study is timely and needed as the world struggle to generate population-based evidence that will help shape future malaria policies.

Existing Malaria Policy Context

To appreciate the policy implications of this study outlined in the subsequent chapters, it is important to understand the policy environment surrounding malaria control activities at the time this study was conducted. At the turn of this century, the global malaria control strategies had started to undergo major policy transitions. In the interest of this study we hereby, focus on two critical policy implementations relating to malaria prevention and treatment strategies with direct implications to the findings and policy implications of the study.

The first malaria control policy relates to designed malaria prevention strategies. Following the publication of the effectiveness of bed-net use for malaria control randomized control studies in early to late 1990's[103, 188], researchers and policy makers were keen to scale up bed-net ownership and use especially among vulnerable populations. Debates on strategies to scale-up bed-net use centered around social marketing of bed-net ownership and use through the private sector, subsidized bed-net distribution, targeted bed-net distribution to malaria vulnerable groups and universal free bed-net distributions[50, 107, 109]. Therefore, because of poor funding for malaria control programs, at the time MIS data were collected, most malaria control programs were built on targeted free and subsidized bed-net distributions. While the debate on universal free bed-net distribution was gathering momentum, there were little if any program that was actively involved in universal free-bed-net distribution strategy. In more recent years however, malaria countries, donors and humanitarian activists have expressed and strongly supported universal free bed-net distributions[121, 189]. The bed-net distribution channels for majority of the countries however, have remained being primarily through existing health facilities platform[126]. The main drawback associated with this platform is the geographic barrier it especially places on socioeconomically marginalized populations. There is also a large number of people who seek care at private drug outlet shops where free distribution of bed-nets continue to be unavailable.

The second critical malaria control policy initiative in existence at the time was focused on management of malaria parasite drug resistance problem. The WHO called for policy shift from obsolete antimalarials to more efficacious drugs with strong support for artemisinin-based combination drugs[190, 191]. By the time MIS data collection were being carried out for the very first time, almost all malaria endemic countries had adopted artemisinin-based combination drugs as their first line drug of choice for malaria treatment[41]. At the time these drugs were being adopted, their global supply was limited and prices were up to 20 times more expensive than traditional drugs[192]. Despite successful international antimalarial drug price negotiations with major drug producers which resulted to substantial price declines, there has still been concerns on accessibility for antimalarial drugs especially by the poorest[97, 193, 194]. Experts are also concerned that given lack of investments for new generation of antimalarial drugs, the available drugs need to be protected and prescribed only when necessary to avoid acceleration of drug resistance problem. It is out of such concerns that the WHO issued a new malaria management policy guideline in 2010 requiring all malaria endemic countries to adopt universal malaria testing across patients of all age groups whenever feasible[24].

The current global malaria control efforts enjoy the strongest international support in malaria control history since the failed World Health Organization malaria eradication campaign of 1950s. With strong support from private sector led by philanthropies like the Bill and Melinda Gates Foundation, Hollywood celebrities and others; the attention accorded to malaria control efforts by the both public and private sector is at its highest level in history. Existence of international funding mechanisms like the Global Fund to fight against AIDS, Tuberculosis and Malaria (GFATM) and the World Bank offers yet another strong reason behind the current malaria control and elimination optimism. This study comes at opportune time and its recommendations will surely be welcomed by those involved in the global fight for malaria control and consequently its elimination. The next chapter describes the study sites, data sources, analytical strategies and data limitations.

Chapter 3

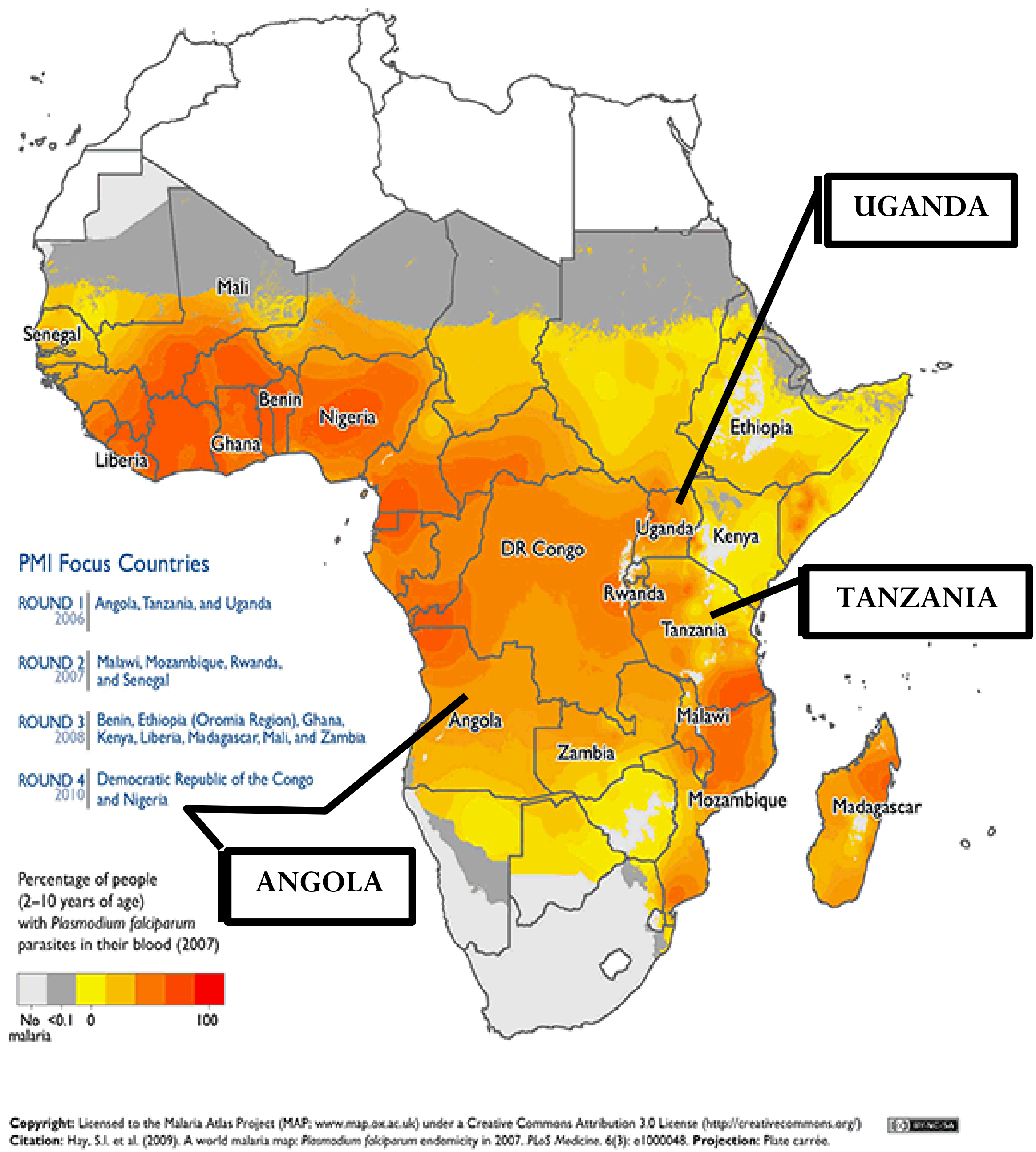
Description of Study Sites, Data Source and Limitations

Description of study sites and malaria control initiatives

The operationalization of the Global Fund for HIV/AIDS, Tuberculosis and Malaria (GFATM) beginning year 2002, establishment of President Malaria Initiatives (PMI) in 2005 as well as bilateral, multilateral and private sector global health initiatives have all seen significant increase of resources in support for malaria control efforts worldwide[38, 195-200]. The increased resource support for malaria control has particularly benefited underserved poor populations in sub Saharan Africa, Latin America and Southeastern Asia. The PMI in particular has increasingly taken a leading role in efforts to reduce the burden of malaria especially in SSA. Following its official launch in 2005, Angola, Tanzania and Uganda were named as the first cohort of countries to begin benefit from the initiative. PMI goal was to support these countries reduce malaria deaths by 50% through accelerated scale-up of proven curative and preventive interventions [201].

This study uses data from these three countries to evaluate the effectiveness of increased global funding. Apart from PMI funding, these countries have enjoyed relatively stable bilateral and multilateral funding for their health and more specifically malaria control programs. The study explores the relationship between increased funding for malaria control in these countries and their impact in reducing inequities in accessing malaria preventive services, cost effectiveness of universal malaria testing in children under-five years of age and the role of socio-cultural processes, particularly maternal education in reducing childhood malaria infections. Additional country details on baseline malaria indicators are attached in the appendix section.

Figure 1: Map of Africa exhibiting the three sub-Saharan Africa study countries



Source: *Courtesy of the President Malaria Initiative*

Angola

Despite being one of oil rich countries with one of the fastest growing economies in the world, a third of Angolan population are poor and rely on subsistence farming. According to PMI's Angola malaria operation plan (MOP) the three decades of civil war ended in 2002 leaving behind a very poor health infrastructure with almost 80% of its public health facilities destroyed[202]. In 2006 the country had one of the world's highest under five mortality estimated at 250 deaths per 1000 live births. According to Angola's National Malaria Control Program, 35% of under-five mortality is attributable to malaria with stable transmission in most of the northern part of the country.

Immediately after PMI was launched around May 2005, the program embarked on supporting malaria control strategies identified by Angola National Malaria Control Program. One of the immediate undertaking focused on the support for increased scale-up of insecticide treated bed-nets (ITNs) in areas with high malaria transmissions. Angola ITN scale-up strategy consisted of both free distribution and market-based approach through social marketing. To help achieve Angola's national malaria control goals, PMI supported free ITN distribution in seven of the 18 administrative provinces within the country. The strategy was focused on hyper-endemic and meso-endemic malaria provinces of Cabinda, Zaire, Malanje, Moxico, Lunda Norte, Lunda Sul and Uige[203]. A total of 813,000 long lasting ITNs were distributed to households with children aged less than five years during the nationwide measles immunization campaign which included delivery of oral polio vaccine, vitamin A, and anthelminthics. The campaign took place from July to August 2006 and during the campaign, a demonstration on proper hanging, care and use of ITNs. The demonstrations and instructions were considered important components of the immunization campaign with PMI providing specific funding to Population Services International (PSI) to specifically execute this task. At least one net was provided free to each child under five coming for immunization in all of the seven provinces. The distributed nets were purchased or donated by PMI, UNICEF/Global Fund, and a private oil company ExxonMobil. Prior to the free bed-net distribution campaign, Angola had one of the lowest bed-net use estimated at less than 11%[202].

Tanzania

At the time PMI was launched in 2005, malaria was the single most important cause of morbidity and mortality especially among children under-five years of age in Tanzania. About 95% of Tanzania's population is estimated to be threatened by malaria causing about 14 to 19 million clinical episodes. In 2005 malaria was estimated to cause up to 36% of all children under-five mortality cases and 20% of pregnant women deaths. The clinical and economic burden of malaria in Tanzania constitutes one of the largest in the world with a study finding up to 39% of health expenditure budget in Tanzania being spent on malaria prevention and treatment initiatives alone[8].

Following its long history of testing the efficacy and effectiveness of ITNs use, Tanzania adopted a national ITN voucher program for scaling up bed-net distribution and ownership in Tanzania in 2004[114, 188, 204, 205]. With initial support of funding from the Global Fund, the strategy was part of nation-wide malaria prevention by enhancing ITN coverage among vulnerable pregnant women and children aged less than five years. Distribution of these bed-nets was heavily reliant on existing health facility infrastructure in Tanzania where vouchers were issued to women attending their first antenatal care visits at fixed price of less than $3.00. These women would use the vouchers to redeem bed-nets from participating private sector bed-net retailers. The earlier nets were non-long lasting treated nets but were usually bundled with insecticide sachets for later treatment when used. While overall ownership and use of bed-nets through this program improved, the coverage was generally low. Following the 2005 Davos World Economic Forum (WEF) in which heated debates on ways to improve ITN coverage in malaria endemic countries were held, malaria policy makers in Tanzania started to reflect on ways to improve ITN coverage[205].

Following these debates, the Zanzibar National Malaria Control Program (ZNMCP) adopted a targeted free mass ITN distribution campaign in all 10 districts of Zanzibar[206]. The Global Fund and the President Malaria Initiative supported the implementation of this program beginning August 2005 to early 2006. The program covered all pregnant women and children under the age of five years. Meanwhile, in the mainland Tanzania, UNICEF and International Red Cross Society supported free distribution of bed-nets to pregnant women and children below the age of five in pockets of districts and regions with high malaria burden and low ITN coverage. Over 900,000 bed-nets bundled with insecticides were made available for distribution in 14 districts as follows: one district of Rufiji from the Coastal region, two districts of Tanga Urban and Pangani in Tanga region, all six districts from Lindi region and also all five districts of Mtwara region in southern Tanzania[[99, 205, 207]. Therefore, the combined population of the 24 districts (both Zanzibar and mainland Tanzania) was estimated to be over 2.8 million people. For the rest of the remaining districts in Tanzania, implementation of national bed-net voucher system was continued.

Uganda

Over 90% of the Ugandan population is at constant risk of contracting malaria. Malaria is responsible for 30 -50% of all outpatient visits to health clinics in Uganda. According to PMI malaria operational plan, nearly half of all inpatient deaths among children under-five are malaria caused. Annual direct malaria treatment cost for the year 2003 was estimated at $41.6 million[208]. Given its well documented burden of malaria, Uganda was easily selected by PMI program to be among the first cohort of countries benefiting from the initiative. PMI pledged to support Uganda’s National Malaria Control Program (NMCP) strategies by coordinating closely with national and international partners to complement their funding efforts. The major PMI activities included among other, the support of ITN distribution in the conflict districts of northern Uganda through large scale health campaigns, well-child, antenatal clinics and social marketing[209].

To improve ITN scale-up, the Ugandan NMCP adopted a mixed model approach which included: distribution of free ITN to vulnerable groups through ANC clinics and NGOs, large scale campaigns to targeted populations and the sale of ITN through the retail market. The mixed model approach was complemented by annual net retreatment campaigns to ensure that ITNs maintained their effectiveness. PMI supported the distribution of ITNs to pregnant women through ANC clinics in war ravaged 24 districts of northern Uganda. These were Lamwo, Amuru, Kitgum, Nwoya, Oyam, Gulu, Pader, Kole, Lira, Alebtong, Otuke, Agago, Apac, Dokolo, Amolatar, Adjumani, Katakwi, Masindi, Nebbi, Arua, Kotido, Hoima, Abim and Napak[210]. By the time MIS data collection was done in 2009, over 300,000 ITNs had been distributed in these northern districts with estimated population of over 1.5 million people. In conjunction with the distribution of ITNs, health workers at antenatal clinics were trained to both explain the need for ITNs and also to demonstrate their proper use. Together with ITN distribution In addition to PMI resources for purchasing ITNs, Uganda's NMCP was funded through Global Fund Round II funds to purchase nearly 2 million long lasting nets for distribution within the country. Some of these nets were distributed in the northern districts and others were distributed in central and southern districts identified by NMCP as high malaria burden places.

While PMI supported numerous other malaria control efforts including malaria case management, improvement of malaria diagnostics and treatment, vector control and others; this study focuses on exploring the programmatic impact of large scale free ITN distribution in the 26 northern districts. In areas where PMI supported the free ITN scale up campaigns, the distribution involved: district sensitization of key district officials, training of volunteer community medicine distributors (CMDs), registration of beneficiaries (i.e. pregnant women and children under five), distribution of LLINs to registered beneficiaries, collection of reports completed by district officials, and follow-up by CMDs a week later to ensure that the nets were properly hung[211]. Appendix 2 provides some background information for the three study countries.

Data Sources

This study primarily uses Malaria Indicator Survey (MIS) data to accomplish its main objectives. In addition to household MIS, national administrative data and expert opinions were used to complement the MIS data and enable successful completion of the analyses. For the household survey data, the study uses nationally representative MIS datasets from each of the three countries. We use MIS datasets collected from Angola, Tanzania and Uganda during the year 2006 – 2009[††]. MIS data collection was primarily geared to investigate prevalence of malaria, bed-net ownership and use among children aged 6 – 59 months. All MIS data used in this analysis are all regarded as first nationally representative and most comprehensive baseline surveys for PMI programs. All data were obtained from MEASURE DHS survey resource.

Malaria Indicator Survey (MIS) is cross-sectional, nationally representative data currently being collected in over 15 malaria endemic African countries. This study proposes to use this data in exploring the potential socioeconomic implications of the current malaria control strategies in terms of recasting the existing relationships between household socioeconomic disparities and key childhood malaria control indicators, cost-effectiveness of some of the interventions enjoying strong international financing support and also the social-cultural implications for improving malaria control strategies. Households MIS data offers the best opportunity to explore these important questions which for a long time have been elusive to malaria researchers because of lack of nationally representative malaria datasets.

In addition to MIS datasets, the study uses administrative costing data obtained from national malaria programs in each of the three countries. Data on the program implementation costs of purchasing and distributing antimalarials together with malaria rapid diagnostic testing kits were obtained from each country's ministries for health. In cases where the information was not available from the ministries, international partners like PMI, Global Fund and other bilateral arrangements helping to purchase and distribute such commodities were consulted to help provide the information. It is

[††] A detailed sampling design and survey implementation procedures for each of the three countries can be accessed in country survey reports. See http://malariasurveys.org/surveys.cfm?country and http://www.measuredhs.com/publications/publications-search.cfm

important to note that after careful consideration of the costs of program implementation, the costing perspective taken in the analysis is ‘programmatic implementation perspective’ meaning that any costs relating to adequate service delivery. This approach resulted to some costs especially in Angola being very high when compared to other government/provider perspective costs of service delivery. The reason for such high costs is based on the fact that the government of Angola barely has any strong public infrastructure like drug distribution network to adequately serve its population. For this reason, program implementing partners have often outsourced some health care and commodity delivery services to the private sector for enhancing reliability and timeliness of service delivery. Additional information about each country’s malaria control implementation programs were obtained from PMI country’s malaria operation plans (MOPs) and other unpublished reports from each of the three study countries.

Finally, data on effectiveness of some interventions such as use of mRDT and efficacy of antimalarial drugs needed for the economic evaluation component of this study were obtained from published and unpublished studies and in rare occasions where data were unavailable, malaria expert opinions were introduced. For the effectiveness of mRDT use, the study used the assumption of proper case diagnosis and treatment as well as survival rates to determine and compare the economic effectiveness of the two malaria diagnoses and treatment strategies. Moreover, information on household and individual health seeking behaviors, clinicians’ compliance to malaria test results, proportion of childhood non-malarial fevers caused by invasive bacterial or virus infections, malarial and non-malarial case fatality rates, progression of febrile illnesses to severe disease and others were all obtained from completed and published past studies. For details of these studies, see appendix 1 with the list of all studies used as a basis for our input variable estimates.

Description of MIS data collection process

The design of MIS data collection is in such a way that it ensures national representativeness. The data used in this study was the first cross-sectional micro surveys collecting information on malaria prevalence, prevention and treatment indicators. Each survey participating country was encouraged to take a leading role in the data collection activity lasting from late 2006 in Angola to late 2009 in Uganda. In all three countries, a two-stage cluster sampling technique which relied heavily on each country’s national census cluster sampling approaches were employed. Therefore, the sample of households and individuals within MIS data are generally comparable across countries. MIS typically uses standardized household questionnaires with set of questions focused on individual’s knowledge of malaria, prevention and treatments. The questionnaires also have bed-net rosters linked to a list of all household occupants who slept under each net the previous night to ascertain household bed-net ownership and use. Moreover, questions on household wealth, demographics and care seeking practices are also asked. One of biggest strength of MIS data is their ability to collect blood samples from consenting pregnant women and children under five to test for malaria parasitemia and also anemia levels.

MIS data collection in Angola begun November 2006 and was completed in April 2007. The survey was executed by two private organizations under Angola’s national malaria control program (NMCP) directed by its Ministry of Health. The organizations tasked to execute the survey were: the *Consultoria de Servicos e Pesquisas – COSEP,* *Consultoria Lda and the Consultoria de Gestao e Administracao em Saude-Consaude Lda.* Meanwhile, MIS data collection for Tanzania took place from October 2007 to February 2008. The survey was implemented by the Tanzania National Bureau of Statistics (NBS) in collaboration with the Office of the Chief government Statistician in Zanzibar under the supervision of Tanzania National Malaria Control Program (NMCP). For the case of Uganda, MIS data collection was collaboratively carried out by US based ICF Macro, the Uganda Bureau of Statistics, Uganda Malaria Surveillance Project running a Molecular Laboratory a semi - autonomous institute at Mulago Hospital and Uganda's Ministry of Health through its National Malaria Control Program (NMCP). The fieldwork in Uganda covered the period beginning November to December 2009.

Sample size and survey designs

The sample sizes in Tanzania and Uganda were stratified by administrative regions whereby, in Tanzania stratification was composed of 26 regions (21 in the mainland and 5 regions in the archipelago Zanzibar). For the case of Uganda a total 10 regions including the capital city of Kampala were identified. The Angola survey sample size was stratified into four major regions based on the epidemiology of malaria as follows: Hyperendemic in the north, Mesoendemic (stable) malaria transmission in the central part and Mesoendemic (unstable) transmission in the southern part of the country. In addition to these three, Luanda the capital city which is also categorized as Mesoendemic was given a regional status to form the fourth region.

Following these stratifications, the two-stage cluster sampling designs were implemented. The first stage selecting sample points or clusters from a list of enumerated areas covered in national population census for each of the three countries. These clusters are drawn from the stratified regions. A total of 475 clusters were selected in Tanzania, 170 clusters in Uganda and 120 clusters in Angola. In all three countries, these clusters were purposefully chosen to over-represent rural areas since most of people live in rural areas. Of the 120 clusters selected for Angola, 72 were from rural villages and 48 represented urban areas. Tanzania had 143 clusters from urban areas and 332 clusters from rural areas making a total of 475 clusters. Moreover, Uganda had 26 clusters from urban areas and 144 clusters from rural areas totaling 170 clusters. A household listing operation was then undertaken in all the selected areas prior to the field work.

From the compiled household list taken from each cluster, the second stage of sample selection was performed. A systematic sampling of households from the list of households in each cluster was undertaken to determine which households will be visited for an interview. For each cluster in Angola, approximately 25 households were selected. In Tanzania, approximately 16 households were selected from each sampling unit from urban places and about 18 households per each sampling unit from rural places. Finally, in Uganda 28 households were selected from each cluster. A total of 2,500 households were selected in Angola, 8,400 households in Tanzania and 4,400 households in Uganda. Because from each administrative or malaria endemic region there was almost equal sample size drawn, the sample size was not self-weighting at the national level. Survey weighting factors for all three countries were therefore included in each country's data file so that the results would be nationally representative. All women age 15 – 49 years who were either permanent resident of the households in the selected sample or visitors present in the household on the night before the survey were eligible to be interviewed in the survey. All children age 0 -59 months who were listed in the household were eligible for the anemia and malaria testing component of the survey in each of the three study countries.

MIS Questionnaires and Malaria testing

A standard questionnaire for all participating countries was adopted by all survey teams. Two set of questionnaires were used. One asked questions about the general household and the second one asked questions about specific individuals commonly referred as women questionnaire. Household questionnaire was used to list all usual members and visitors in selected households. Basic demographic information on individuals living within the household such as age, sex, education and relationship to the head of the household was collected. Additionally, the questionnaire collected information on the characteristics of household's dwellings such as water source, toilet facilities and household's construction materials. Other information included ownership of durable goods, mosquito nets, use of the mosquito nets, indoor residual spraying and other malaria control practices. The household questionnaire also collected blood samples on two biomarkers: hemoglobin in all children under age five and also all pregnant women, and presence of malaria parasites in children below five years of age.

The individual or women questionnaire was used to interview all consenting women age 15 -49. Questions covered array of topics including background characteristics, education, reproduction, pregnancy and use of intermittent preventive treatment in pregnancy (IPTp) for malaria control as well as questions on management of childhood fevers. All questionnaires were translated into local national languages (Portuguese in Angola and Kiswahili in Tanzania) except for Uganda which had to translate the questionnaire into six commonly spoken local languages. The six covered languages were *Ateso-Karamajong, Luganda, Lugbara, Luo, Runyankore-Rukiga* and *Runyoro-Rutoro*.

One of the primary objectives of MIS data is to provide information about the extent of malaria infection among children age 0 – 59 months. To achieve this, the survey had to collect blood samples to test for malaria parasites. Because there is a strong correlation between malaria infection and anemia, the survey also performed anemia tests by collecting blood on microvutte for hemoglobin analysis. To determine whether children were anemic, hemoglobin analysis was carried out on site using battery-operated portable HemoCue analyzer which produces a result in less than one minute.

To determine the rate of malaria infection, thin blood smears taken from all children age 0 -59 months and also in pregnant women consenting to the tests were analyzed. The analysis involved use of rapid diagnostic tests (RDTs) for malaria to give prompt results and treatment in case participants tested positive. For the rapid malaria tests, Paracheck Pf™ device (Orchid Biomedical, India) was used. This is capable of detecting *Plasmodium falciparum (Pf)* --- dominant cause of malaria infection in sub Saharan Africa--- using specific histidine-rich proteain-2 (HRP-2) in blood. The test toolkit includes a loop applicator that comes in a sterile packet to capture a tiny volume of blood. The test has relatively high sensitivity and specificity and is deemed appropriate for clinical and epidemiologic assessment of malaria, especially placental malaria. The tool has increasingly been advocated for, as alternative malaria tests especially in places where reliable microscopy is not available[212].

Each team of interviewers was accompanied by trained field technicians to draw blood samples from survey participants for the tests. RDT tests were performed according to manufacturer’s instructions. Results were recorded as positive or negative. Parents or responsible adults for children were advised about the malaria test results. A standard malaria treatment for each country was offered to all children testing positive as well as any child testing negative but had a history of fever in the past two weeks. For details of questions asked during the MIS data collection see appendix 3 which lists the household and women’s questionnaires used in each of the three study countries.

Analytical Framework

This study uses quantitative methods to establish the statistical relationships between the dependent variables of interest and a set of control covariates. In two of the sub-studies, multi-level logistic regression models were used to overcome the inbuilt hierarchical structure of MIS datasets. The technique is employed in order to allow for the identification of individual and community level influences on the outcome variables of interest. Multi-level modeling ensures that parameters of interest are efficiently estimated with appropriate correction of the standard errors. Moreover, the study estimates different models using different control mechanisms before establishing the most appropriate model fit based on different statistical and theoretical criteria. In the final estimates, marginal effects probabilities are reported and discussed in details. Additionally, in the study looking at the relationship between maternal education and childhood malaria infection rates, Oaxaca decomposition technique was performed to determine the proportions of malaria infection rates explained by maternal education as compared to the proportions explained by other factors. Finally, in third sub-study looking at the cost-effectiveness of universal malaria testing, a decision tree model to determine the relative effectiveness of the strategy compared to presumptive malaria treatment was used.

To accomplish these studies, two different software packages were utilized to analyze data. For the statistical regression models, STATA, version 11 *(Stata Corp., College Station, TX, USA)* software was used to complete the analysis and also estimate the marginal effects and the Oaxaca decomposition analysis. Meanwhile; a TreeAge Pro suite 2009 software was used to develop malaria diagnosis and treatment decision pathways *(copyright© 1988-2009 TreeAge software, Inc., 1075 Main Street Williamstown, MA 01267)*.

Data Limitations

The biggest limitation of MIS data is the fact that the data is cross-sectional and cannot be used to ascribe any causal-effect mechanisms. Because of this limitation, our analysis is only limited to exploring the statistical relationships between dependent and independent variables. Secondly, our study is using existing data to retrospectively explore the relationship between variables. Since the study was retrospectively designed after MIS data were collected, there are some indicators that may have not been accurately measured or adequately represent the variables of interest. For instance, MIS data does not have a very good measure of individual and household social-networking indicator which we use as an important control when exploring the relationship between maternal education and childhood malaria infections. Thirdly, data on program effectiveness were patchy and in some cases inadequate in explaining how effective various malaria control interventions have been. Provider perspective costs of delivering some of malaria control programs like universal malaria testing may in some situations be inaccurate because these were collected long time after the activities had taken place. Related to this is the fact that in few areas the analyses had to rely on expert opinion to fill-in the data gaps that were experienced. However, other than the methodological challenges the researchers were face with in the analysis, these limitations do not invalidate the general findings of the study. We believe that the analytical solutions that were implemented adequately addressed these shortcomings to ensure that our study conclusions and policy implications are scientifically plausible.

Chapter 4

Exploring the impact of targeted distribution of free bed-nets in mediating the relationship between household socioeconomic disparities and a set of childhood malaria indicators

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Abstract

Background: The last decade has witnessed increased funding for malaria control. Malaria experts have used the opportunity to advocate for rollout of such interventions as free bed-nets. A free bed-net distribution strategy is seen as the quickest way to improve coverage of effective malaria control tools especially among poorest communities. Evidence to support this claim is however, sparse. This study explored the effectiveness of targeted free bed-net distribution strategy in achieving equity in terms of ownership and use of bed-nets and also reduction of malaria prevalence among poor children.

Methods: We used malaria indicator survey (MIS) data from Angola, Tanzania and Uganda. Hierarchical multilevel logistic regression models were used to analyse the relationship between variables of interest. Outcome variables were defined as: childhood test-confirmed malaria infections, household ownership of mosquito net and children's use of any mosquito nets. Marginal effects of having free bed-net distribution on households with different wealth status were calculated.

Results: Angolan poorest children were more likely to be parasitemic by 11.9 percentage, in Tanzanian and Ugandans were 8.3 and 10.5 percentage points respectively ($p<0.001$). We estimated and present results on the marginal effects based on the impact of free bed-net distribution on a child's malaria status given their socioeconomic background. Poorest households were less likely to own net by 18 percentage points in Tanzania and in Uganda by 5.8 percentage points whereas, in Angola wealthier households had a 14.3bed-net ownership advantage over poorest households ($p<0.001$). Wealthier household had a higher margin of using nets than poorest people in both Tanzania and Uganda by 11.4 and 3 percentage points respectively ($p<0.001$).

Conclusion: Targeted distribution of free bed-nets did not overcome existing structural bottlenecks hindering poorest people from accessing effective malaria control tools. Use of bed-nets was disproportionately lower among poorest children except for Angola where bed-net use across the two groups was almost equal. With bed-net distribution strategies shifting from targeted to universal distribution, emphasis should be on continual monitoring and evaluation of the new strategy to ensure that resources are used efficiently to benefit the poorest. Efforts should on improving access these life-saving interventions in order to accelerate global malaria control efforts.

Background

During the last decade, malaria endemic countries have witnessed a historic increase in the amount of resources dedicated to fight the disease [199, 213, 214]. Bilateral and multilateral institutions such as the Global Fund to fight AIDS, Tuberculosis and Malaria, the World Bank and the US President's Malaria Initiative (PMI) have more than doubled funding to help ease the burden of malaria, especially in sub Saharan Africa (SSA). Additionally, non-profit private sector initiatives, such as the Bill and Melinda Gates Foundation, have also played an important role in changing the debates on financing, design and implementation of malaria control programs.

Malaria researchers and policy makers have taken advantage of heightened global malaria awareness to shift their focus to the rapid expansion of effective malaria control programs while downplaying issues related to sustainability of these programs. Following the increased awareness, malaria control policies such as implementation of large scale indoor residual spraying with insecticides and universal free bed-net coverage campaigns have seen increased financial support, especially in SSA[50, 111, 121, 215, 216] . Meanwhile, the last ten years has seen complete overhaul of policies addressing malaria case management in endemic settings. Most countries with high malaria burden have changed their treatment algorithms by adopting more efficacious but expensive artemisinin-based combination drugs [217, 218]. Countries have also been urged to improve malaria diagnostics through adoption of universal testing of all suspected malaria cases by use of either microscopy or rapid diagnostic tests (RDTs) [24, 173]. Support for preventive treatments in high endemic areas through adoption of intermittent preventive treatments in pregnant women, infants and school-age children have also increased substantially [219-222]. The long-term health, economic and social impact of adopting these changes is not well understood[94, 223]. However, given the relationship between malaria and poverty[49], it is important to understand how the current large scale malaria control policies are impacting different segments of populations especially the very poor.

Although initial strategies to scale up insecticide-treated nets (ITNs) relied on cost-recovery, social marketing and targeted distribution strategies (focused on biological and socioeconomically vulnerable groups), increased funding has allowed for universal free bed-net distributions in many SSA countries. While some countries have welcomed the new financing mechanisms and aligned their policies accordingly, some have shifted largely to respond to donor mandates alone, and others have defied the call for universal free bed-net distribution as they continue with implementation of targeted bed-net distribution [50, 110]. Supporters of universal free bed-net distribution have consistently favored the strategy as the most feasible way to equitably reach the poor with lifesaving interventions[224]. They also argue that cost sharing and targeted interventions dampen demand, enhance inequities and consequently exacerbate the malaria burden[224]. Despite their arguments, there are potential pitfalls. First, the claim that free bed-net distribution enhances equity is mainly based on limited case-control studies which may be unrepresentative of real world conditions[120, 121]. As a result, such studies are not necessarily generalizable because of infrastructural and large scale program implementation challenges which may threaten the feasibility of reaching out to those most in need [57, 58]. Secondly, given the current global fiscal austerity measures sparked by the global economic recession and the concomitant overreliance on international development assistance, the long-term consequences of this strategy in terms of its sustainability remain uncertain [225-227]. Finally, there has been some skepticism about uniform solutions to a relatively diverse health problem and whether the disease can ever be eradicated [108, 228-230]. Economists have also expressed concerns on the need for malaria interventions to do more by incorporating economic tenets on value for money as well as aspects of program sustainability[231].

Therefore, any proposed solutions to African economic, sociopolitical and health including those related to malaria must first recognize and adapt to the continent's diverse socioeconomic and epidemiologic settings. Despite constituting the largest disease burden globally, malaria epidemiology in SSA varies widely [46, 232]. The variations in malaria policies, strategies and epidemiology can be attributed to a number of factors including weather and climate, altitude, physical infrastructure such as water drainage systems, level of economic development reflected in population incomes, household structures and investments in public health programs. It is important to explore how large scale malaria control programs such as targeted free bed-net distribution may impact malaria control efforts especially among the poorest people. One study attempted to evaluate the health impact of a large scale malaria control program in Zambia [233]. However, the study did not explore how such large scale interventions benefited various groups of people with different socioeconomic backgrounds. A recent study from Malawi reported that people living closest to the health facilities were most likely to have bed-nets than those living far away from health clinics[125]. Another study in Zambia reported households with a woman having attended antenatal clinic or with children under-five years of age were twice more likely to have bed-nets than those without[57]. In Angola, people residing more than 15km outside the capital city of Luanda were almost six times more likely to test positive for malaria when screened at the health clinic than those living in the inner-city[234]. Apart from these few studies, little is known about the impact of the large scale implementation of malaria programs such as universal bed net campaigns, on household socioeconomic disparities and malaria burden or access and use of effective malaria control tools.

This study aims to understand how implementation of targeted free bed-net distribution shape the relationship between household socioeconomic status and selected malaria control indicators. The study uses wealth as a proxy for household socioeconomic status in exploring these relationships. More specifically, a set of malaria control indicators in children under-five years of age defined as RDT and microscopy confirmed positive results on the day of interview, household ownership of bed-nets and children's use of nets will be explored and compared across districts/provinces with and without targeted free bed-net distribution.

Description of Study Sites and malaria control efforts

The assessment of this study was conducted in a cohort of three first PMI funded countries from sub-Saharan Africa. The countries started to receive PMI funding in support of malaria control effectively from year 2006 after the launch of the program. The countries range from moderate to high malaria transmission settings with Uganda reporting the highest burden clinical malaria while Angola had the least cases of clinical malaria across all age groups.

Angola

Despite its oil wealth and fast growing economy, a third of Angola's population is poor and relies on subsistence farming. The three decades of civil war ended in 2002 leaving its footprints marked by dilapidated health infrastructure with nearly half of its total population lacking any access to healthcare services [235]. In 2006 the country had one of the world's highest under-5 mortality rates estimated at 250 deaths per 1000 live births. According to Angola's National Malaria Control Program, 35% of under-five mortality is attributable to malaria with stable transmission in most of the northern part of the country[202]. Following its launch in 2005, PMI embarked on supporting malaria control strategies identified by Angola National Malaria Control Program. The insecticide treated net (ITN) scale up strategy in Angola consisted of both targeted free distribution and a market segmentation approach through social marketing. PMI, in collaboration with UNICEF Angola, supported targeted free ITN distribution in seven of Angola's 18 administrative provinces. The strategy was focused on the highly malaria endemic provinces of Cabinda, Zaire, Malanje, Moxico, Lunda Norte, Lunda Sul and Uige [236]. A total of 813,000 long lasting ITNs were distributed to households with children under-5 years during the nationwide measles immunization campaign, which occurred from July to August 2006, and also included the delivery of oral polio vaccine, vitamin A, and an anthelminthic. In addition to free net distribution, a demonstration on the proper method to hang, care for, and use the ITN was provided. At least one free net was provided to each child under-5 years presenting for immunization in each of the seven provinces. Prior to the targeted free bed-net distribution campaign, Angola had one of the lowest rates of bed-net use by children under-5 years, estimated at less than 11 percent [237].

Tanzania

Approximately 95% of the population is estimated to be at risk of malaria which causes between 14 and 19 million clinical episodes annually. In 2005, malaria was estimated to cause up to 36% and 20% of all deaths among children under-5 and pregnant women respectively [238]. Following results from studies on efficacy and effectiveness of ITN use in Tanzania, a market-based national ITN voucher program to scale up bed-nets was adopted in 2004 [114, 188, 204, 205]. With initial support of funding from the Global Fund, the strategy was part of nation-wide malaria prevention targeting vulnerable groups, i.e. pregnant women and children under-5s. Distribution of these bed-nets relied on the private market and existing public and private health facility infrastructure. Vouchers for ITNs were issued to women attending their first antenatal care visits at fixed price of less than US $3.00. These women used the vouchers to redeem bed-nets from participating private sector bed-net retailers. While overall ownership and use of be[207]d-nets through this program improved, the coverage was generally below the national and international targets. Therefore, Tanzania's National Malaria Control Program (NMCP) took advantage of increased international financing for malaria to implement an alternative targeted free ITN distribution strategy[205]. The new strategy was first piloted by UNICEF and International Federation of Red Cross in selected areas with high malaria burden. Targeted free distribution of bed-nets to pregnant women and children under-5s was implemented in the 15 districts with the lowest ITN coverage[‡‡]. Over 900,000 bed-nets bundled with insecticide were made available for distribution in mainland Tanzania [99, 205, 207] .

[‡‡] These were: Tanga Urban and Pangani Districts in Tanga region, Rufiji District in the Coastal region, Lindi Rural, Lindi urban, Ruangwa, Liwale, Kilwa and Nachingwea all from Lindi region; and also Tandahimba, Newala, Masasi, Nanyumbu, Mtwara Rural and Mtwara Urban from the southern Mtwara region.

Meanwhile in Zanzibar a targeted free ITN distribution campaign was implemented in all 10 districts (5 districts in each of the two islands of Pemba and Unguja) [206]. The Global Fund and the PMI supported the implementation of this program beginning August 2005 to early 2006. As in mainland Tanzania, the program covered all pregnant women and children under-5. Therefore, total districts receiving targeted mass free ITN distribution in Tanzania were 25 with an estimated population of over 2.8 million people.

Uganda

Over 90% of the Ugandan population is at constant risk of contracting malaria. Malaria is responsible for 30 -50% of all outpatient visits to health clinics and almost half of all inpatient deaths among children under-5. Annual direct malaria treatment cost for the year 2003 was estimated at $41.6 million[208]. PMI pledged to support Uganda's NMCP strategies including a large scale ITN distribution in the conflict districts of northern Uganda[209, 210].

To improve ITN scale-up, the Ugandan NMCP adopted a mixed model approach which included: distribution of free ITN to vulnerable groups through ANC clinics and NGOs, large scale campaigns to targeted populations and the sale of ITNs through the retail market. The strategy was complemented by annual net retreatment campaigns to ensure that ITNs maintained their effectiveness. PMI supported the distribution of ITNs to pregnant women through ANC clinics in 24 districts in northern Uganda[§§] [210]. By the time data collection was completed in 2009 for the Malaria Indicator Survey (MIS), over 400,000 free ITNs had been distributed to over 1.5 million people in northern

[§§] The 24 districts were: Nebbi, Nyadri, Arua, Koboko, Yumbe, Moyo, Adjumani, Amuru, Gulu, Kitgum, Pader, Oyam Apac, Lira, Dokolo, Amolorar, Amuria, Kaberamido, Katakwi, Abim, Kotido, Kaabong, Moroto and Nakapiripiri

Uganda. Following the bed-net distribution campaign, health workers at antenatal clinics were trained and urged to explain the need for ITNs and also demonstrate their proper use[211].

Materials and Methods

This study is based on data from cross-sectional nationally representative Malaria Indicator Surveys (MIS) conducted in three sub Saharan African countries: Angola (2006), Tanzania (2007/08) and Uganda (2009). These countries were the first beneficiaries of PMI funding established in May 2005. MIS data were collected in 2006 for the first time as part of international efforts to monitor progress toward malaria control efforts in SSA. As part of these surveys, blood samples were collected and tested for both malaria parasites and anemia in all children under-5 and in self-reported pregnant women. Microscopy and/or RDTs for malaria were performed to accurately help estimate the burden of malaria in children under-5. Additionally detailed information on household ownership and use of bed-nets, malaria treatment seeking behaviors, demographic, social and economic characteristics of women of reproductive age, children under-5 and a selection of men/household heads were collected[***].

To generate nationally representative sample sizes, MIS relied heavily on each country's national census data to guide cluster sampling procedures. Since malaria burden is usually thought to be higher in rural areas than in urban settings, MIS stratified these populations separately and oversampled participants from rural areas. For each rural/urban population segment, a multistage cluster sample design was implemented. A total of 1,119 eligible households from Angola, 4,340 in Tanzania and 2,296 in Uganda

[***] Additional information about MIS and detailed sampling design for each of the three countries can be accessed in country survey reports. See http://malariasurveys.org/surveys.cfm?country and http://www.measuredhs.com/publications/publications-search.cfm.

successfully completed the malaria indicator surveys. These constituted an overall response rate of over 95%. To understand the varied bed-net scale up strategies adopted by each of the three countries, additional information was obtained from each country's PMI malaria operation plans (MOPs), unpublished reports and consultation with national malaria control program country teams.

Outcome variables

Three main outcome variables of interest are investigated in this study. These binary outcome variables capture whether a child tested positive for malaria parasites on the day of the interview (positive=1), the household had at least one net (yes=1), and a child slept under a net during the night preceding the interview (yes=1). For each outcome variable, separate multivariate logistic regression models with estimates of marginal effects were performed. A set of control variables relevant for each of the three equations and from each study country were included as dependant covariates.

Empirical Analysis

Since the MIS data has a hierarchical structure, the central assumption of linear independence in ordinary logistic regression models is violated. To address this particular problem, the analysis uses a multi-level modelling technique to account for both the hierarchical structure and to allow the identification of individual and community level influences on the outcomes[239]. Practically, malaria policies and strategies as well as its epidemiology vary across countries and across regions. Within a given country, these variations depend on a number of factors such as weather, climate, altitude, physical infrastructure including water drainage systems, level of economic development reflected by the population's incomes, household structure as well as investments in public health programs. Therefore, cluster analysis is the most appropriate strategy to address these intra-regional/country variations. Additionally, multi-level modelling enables efficient estimates of parameters with corrected standard errors and allows for clustering of observations within units[240]. In this study, the estimation strategy provides a measure of the extent to which the odds of a child being malaria positive, a household owning a net and reported child's use of a net vary across different cluster units. Based on these estimates, we predict the probabilities for each dependent variable and also calculate their marginal effects using the STATA software package, version 11 (Stata Corp., College Station, Tx, USA).

Based on past studies a list of household and community/country level explanatory variables expected to correlate with our study's outcome variables were included in each of our estimation models. Additionally, pairwise correlation analyses between dependent variables and relevant covariates were performed to help determine the most relevant independent variables for inclusion. For this analysis, a three tier-level of important variables were included. These are: (i) Individual level demographic characteristics such as age, education, gender and marital status, (ii) Household level characteristics such as wealth, place of domicile, proximity to health facility and the level of media exposure household members enjoy, and finally, (iii) Community, regional and country level characteristics such as regional malaria transmission intensity, administrative divisions and existence of targeted free bed-net distribution program.

Interaction terms

This constitutes interaction between wealth variable and existence of any bed-net distribution campaigns within a given community. This is expected to capture the relationship between household wealth status and any existing package of free distribution of bed-nets to households aimed at protecting household members from malaria disease. Since the analysis uses logistic regression models, we also estimate marginal effects for each of the important control variables [241, 242] . We predict marginal effects of having targeted free bed-net distribution on respective outcome variables of interest in relation to households' wealth status. We also test a scenario for not having free bed-net distribution given the wealth status of the households and their impact on outcome variables.

Therefore, the general form of the random intercepts multilevel logistic regression model for each of our three outcome variables may be expressed as follows:

$$Logit\ M_{1ijk} = SES'_{1ijk}\beta_{11} + X'_{ijk}\beta_{12} + u_{1jk} + v_{1k} \ \ldots\ldots\ldots\ldots (1)$$

$$Logit\ N_{2ijk} = SES'_{2ijk}\beta_{21} + X'_{2ijk}\beta_{22} + u_{2jk} + v_{2k} \ \ldots\ldots\ldots\ldots (2)$$

$$Logit\ E_{3ijk} = SES'_{3ijk}\beta_{31} + X'_{3ijk}\beta_{32} + u_{3jk} + v_{3k} \ \ldots\ldots\ldots\ldots (3)$$

Where M_{1ijk} is the probability of a child *i*, in j^{th} household and administrative region *k*, being malaria positive on the day the survey was conducted; SES'_{ijk} is a composite of household socioeconomic disparities (education level of the household head, household wealth and living in urban or rural domicile); X'_{ijk} is a vector of other independent covariates including the interaction terms between malaria program implementation and household socioeconomic status. The β*'s* are associated vector of regression parameter estimates and u_{jk} and v_k are the residuals at respective household and administrative region levels. Other outcomes: N_{2ijk} in equation (2) captures the probability of a household owning at least one bed-net of any type and, E_{3ijk} in equation (3) represents the probability of at least one child within the household sleeping under any bed-net on the night before the survey was conducted. All residuals are assumed to be independent, normal and homoscedastic (i.e. zero mean and constant variances)[243, 244].

Results

The majority of surveyed households in Tanzania and Uganda were from rural areas, 82% and 86% respectively, whereas in Angola only 51% of households were from rural areas. The average household size was roughly the same across the three countries at 5.1 in Angola, 5.3 in Tanzania and 4.8 in Uganda. Heads of households reporting no formal education ranged from 21% in Uganda and 28% in Tanzania to 30% in Angola. Female headed households in all three countries were less than 30%, with Uganda the highest at 29%.

Table 1: Descriptive Statistics from Cross-Sectional National Malaria Indicator Surveys (MIS) for children aged 6 – 59 months

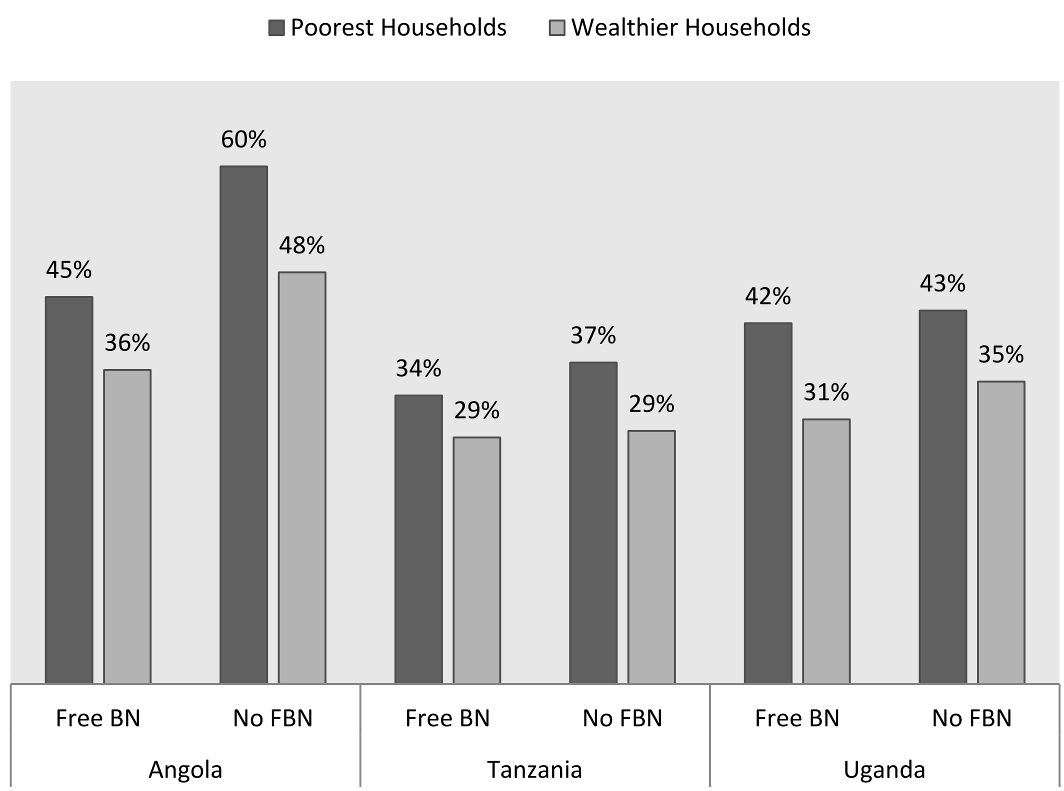
Key Outcome and Control Variables	**Angola (1,119)**	**Tanzania (4,340)**	**Uganda (2,296)**
Year of the National MIS	2006/07	2007/08	2009
Households living in Rural Areas	571 (51%)	3559 (82%)	1974 (86%)
Children with confirmed malaria infections	214 (20%)	782 (18%)	895 (39%)
Overall households with Bed-nets	369 (33%)	2,952 (68%)	1,400 (61%)
Households reporting children's use of bed-nets	246 (22%)	1,650 (38%)	941 (41%)
Female Headed Households	243 (22%)	765 (24%)	666 (29%)
Average Household Age	44 Years	45.8 Years	41.47 Years
Average Household Size	5.1	5.33	4.82
Average Household number of children <5	1.87	1.69	1.11
Household Heads Education Levels			
No formal Education	336 (31%)	1,216 (30%)	482 (22%)
Some Primary, Secondary or College Education	772 (69%)	3,039 (70%0	1,791 (78%)
Household wealth category			
Poorest	492(44%)	1650 (38%)	918 (40%)
Wealthier	615(56%)	2,648 (62%)	1354 (60%)
Households living in areas receiving Free Bed-net Distribution (FBDs)			
Households from areas receiving targeted FBDs	**515 (46%)**	**1,387 (32%)**	**918 (40%)**
Proportion of children with malaria in FBDs	109 (21%)	412 (26%)	242 (33%)
Households with bed-nets in area receiving FBDs	206 (40%)	1000 (63%)	477 (65%)
Children using bed nets in area receiving FBDs	109 (21%)	665 (42%)	344 (46%)

Households reporting ownership of at least one mosquito bed-net was 33% in Angola, 61% in Uganda and 68% in Tanzania. Overall bed-net use by children under-5 was highest in Uganda at 41% and lowest in Angola at 22%.

Childhood malaria infection rates: Of the three countries, only Uganda used both RDT and microscopy to confirm malaria parasitemia in children under-5. In Angola and Tanzania Paracheck Pf^{TM} rapid diagnostic tests were the only tools used to test and confirm malaria parasitemia in children under-5. Malaria confirmed cases in children under-5 were lowest in Tanzania at 18% and highest rate was recorded in Uganda, 39%.

Irrespective of the level of household bed-net ownership levels or any country specific characteristics, household wealth was strongly correlated with malaria positive results in children under-5s (Table 2). Other important covariates with at least 10% or less of statistical significance to outcome variable included: the size of the household in terms of number of people living within the household, bed net ownership, education level and gender of the household head, urban versus rural location, proximity to any formal health facility and regional variation in malaria endemicity.

Figure 2: Children malaria Infection rates by household wealth and bed-net distribution strategy



Following results from the multilevel regression models, we predicted the probability of a child being infected given its household wealth status and other covariates. The marginal effects for a child to be malaria test positive if he/she belonged to wealthier household was reduced by 3 percentage points for those from Angola, 6 percentage points for children from wealthier households in Tanzania and by 12 percentage points for children in Uganda (all at $p<0.001$). Additionally, the number of people living within a household in Angola was positively correlated with positive childhood malaria cases. The predicted marginal effects of size of households for malaria positive children in Angola was 2 percentage points ($p<0.05$) but was insignificant in both Tanzania and Uganda. Meanwhile marginal effects for bed-net ownership showed a moderate reduction of childhood malaria positive cases. In Angola a 6 percentage points reduction was estimated ($p<0.05$), Tanzania 3 percentage points ($p<0.10$) whereas in Uganda, bed-net ownership had largest reduction of childhood malaria positive cases by 10 percentage points ($p<0.001$). Households living far away from health clinics (over 3kms in Uganda and Tanzania) had their children reporting significant higher rates of malaria positive than those living closer to health facilities. The predicted marginal effects for children being malaria positive showed an increase of 8 and 10 percentage points in Tanzania and Uganda respectively ($p<0.001$). Unfortunately, same data on household proximity to health facilities were not available for Angola.

We further explored whether targeted free bed net distribution policy had any impact on reported malaria positive cases in children in all three countries. The odd ratios for the effect of free bed-net distribution on malaria parasites were significant ($p<0.05$) only for Uganda even though the predicted marginal effects showed a desired negative association between targeted free bed-net distribution and malaria positive cases for both Tanzania and Uganda. The policy did not seem to benefit the poorest people as envisioned. Despite targeted free bed-net distribution, predicted marginal effects estimated that children in poorest households in all three countries were more susceptible to malaria than children from wealthier households. In all countries, poor children were more likely to have malaria positive results than children from wealthier households. Targeted free bed-net distribution only was more likely to substantially reduce childhood malaria infections among wealthier households that among poorest households. Table 2 below shows that targeted free bed-net distribution reduced the likelihood of being malaria positive among poorest households in Angola by only 0.8, in Tanzania by 5.5 and in Uganda by 9.1 percentage points. Meanwhile the likelihood of being malaria positive among wealthier households within areas with free bed-net distribution in Angola was reduced by 10.1 percentage points whereas in Tanzania and Uganda it was reduced by 4.8 and 7.3 percentage points respectively.

Table 2: Multi-level model results with an outcome of RDT confirmed malaria parasitemia in children

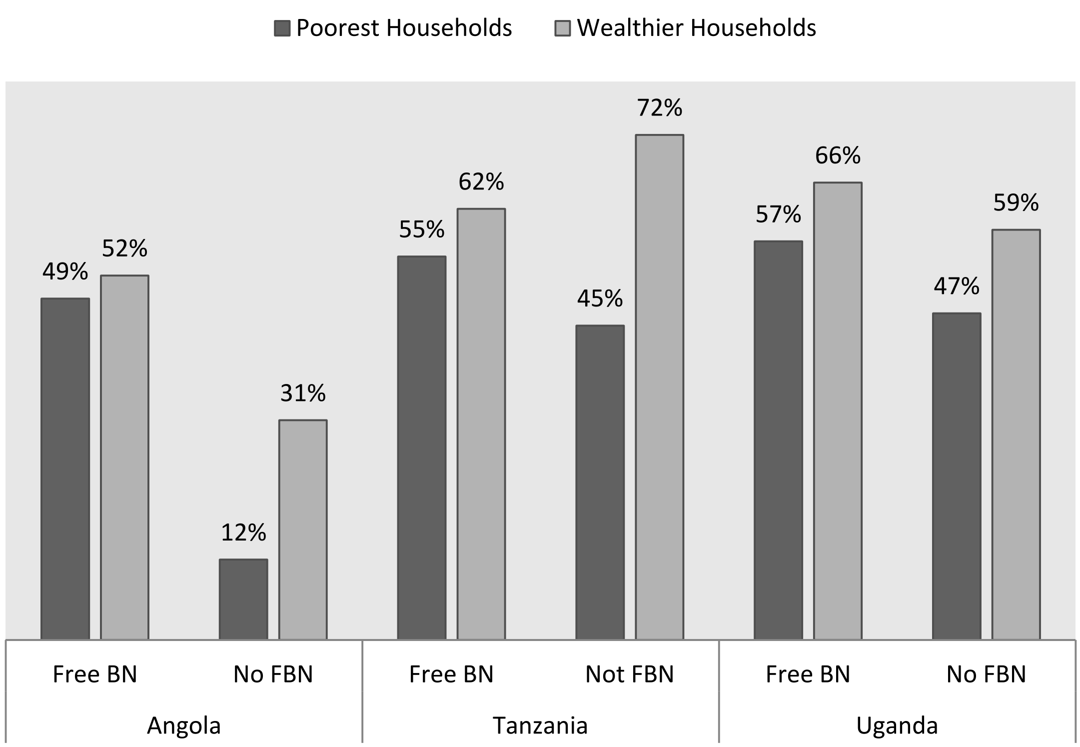
	ANGOLA		TANZANIA		UGANDA	
Total Observations (N)	**1,125**		**3,109**		**1,954**	
Children's RDT Confirmed Malaria	**OR**	**Confidence Intervals**	**OR**	**Confidence Intervals**	**OR**	**Confidence Intervals**
Age of household head	1.004	0.9940 – 1.0159	1.003	0.9974 – 1.0104	1.005	0.9973 – 1.0140
Gender (Male headed Households)	0.889	0.6184 – 1.2795	0.832*	0.6729 – 1.0304	1.051	0.8369 – 1.3211
Education of Household head	0.955	0.6836 – 1.3366	1.189*	0.9805 – 1.4431	1.074	0.8322 – 1.3865
Place of Domicile	1.116	0.6790 – 1.8367	1.448*	0.9910 – 2.1160	0.795	0.4715 – 1.3409
Household wealth	0.826**	0.4665 – 1.4654	0.692***	0.5683 – 0.8434	0.566***	0.4239 – 0.7572
Malaria Endemicity	0.950	0.6809 – 1.3264	2.005***	1.2160 – 3.3075	0.284**	0.0913 – 0.8879
Size of the Household	1.078**	1.0126 – 1.1489	0.997	0.9635 – 1.0319	0.975	0.9266 – 1.0261
Number of children aged < 5 years	0.985	0.8698 – 1.1166	1.359***	1.2347 – 1.4974	0.810***	0.7080 – 0.9281
Ownership of any bed net	0.761*	0.5591 – 1.0368	1.088	0.9177 – 1.2920	0.636***	0.5123 – 0.7911
Access to media	NA	NA	0.902	0.7698 – 1.0589	1.180	0.9290 – 1.4990
Proximity to Health Facilities	NA	NA	1.673***	1.4215 – 1.9700	1.600***	1.2838 – 1.9939
Existence of Free bed net distribution	3.413**	1.1457 – 1.1698	0.907*	0.5885 – 1.3988	0.201***	0.0676 – 0.6003
Interaction term (Free bed net/wealth)	1.301	0.7399 – 2.2894	0.940	0.6784 – 1.3029	1.341	0.8477 – 2.1231

Predicted marginal effects for free bed net distributions and wealth with reported positive malaria case in children

		Angola	**Tanzania**	**Uganda**
	Dependent variable: ***Malaria***	*Marginal Effects: (dy/dx)*	*Marginal Effects: (dy/dx)*	*Marginal Effects: (dy/dx)*
1	Wealth	-0.084*	-0.070***	-0.116***
2	Free bed net Distribution	-0.065*	-0.034	-0.081**
3	Scenarios for Interaction term (Free Bed nets/wealth)			
	No Free Bed nets in Poorer households	0.190***	0.257***	0.414***
	No Free bed nets in Wealthier households	0.154***	0.167***	0.291***
	Free bed nets in Poorer households	0.172***	0.202***	0.323***
	Free bed nets in Wealthier households	0.053***	0.119***	0.218***
	% Change among poor households	-0.8	-5.5	-9.1
	% change among wealthier households	-10.1	-4.8	-7.3

Ownership of any mosquito net: Education and gender of the household head as well as the urban versus rural location had a varied degree of significant relationship with household ownership of any bed-nets across the three countries. Household wealth exhibited by far the strongest association with ownership of bed nets (Figure 3). The predicted marginal effect for households in rural Angola to have bed-nets was 6 percentage points more than those in urban settings. In Uganda, rural households had a 2 percentage point's advantage of owning a bed-net over those in urban areas. Education and gender of the household head were other significant covariates for household ownership of any bed nets in Uganda and Tanzania (Table 3). Age of the household head, number of children under-5 and the size of the household were other important variables exhibiting significant relationship with household bed net ownership.

Figure 3: Bed-net ownership by household wealth and distribution strategy



About 46 percentage points of households in Angola were from 7 provinces which had received targeted free bed-net distribution whereas for Tanzania and Uganda such households were 32 and 40 percentage points respectively (Table 1). Of all three study countries, the dummy variable for implementation of targeted free bed-net distribution showed a significant relationship with households' bed-net ownership in Angola only. Nevertheless, we explored different scenarios of bed net distribution and calculated the marginal effects (Table 3). Targeted free bed-net distribution achieved 42 percentage points among poorest and by 56 percentage points bed-net coverage in wealthier households in Angola ($p<0.001$). In Tanzania, wealthier households in areas with targeted free-bed net distribution still had about 18 percentage points advantage over those in poorest households, whereas in Uganda, wealthier households only had a 5.8 percentage points advantage over the poorest households in places where targeted free-bed-net distribution was implemented.

Table 3: Multi-level model results for household ownership of bed-nets

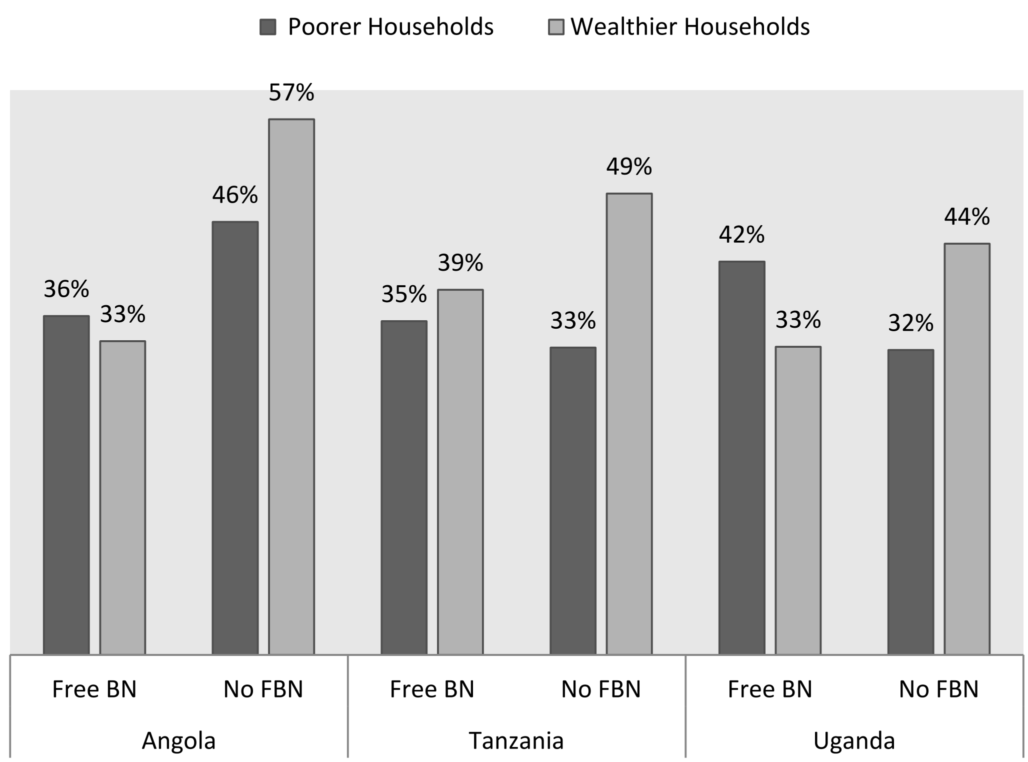
	ANGOLA		**TANZANIA**		**UGANDA**	
Total Observations (N)	**1,125**		**3,109**		**1,954**	
Household ownership of any bed net	**OR**	**Confidence Intervals**	**OR**	**Confidence Intervals**	**OR**	**Confidence Intervals**
Age of household head	0.987**	0.9770 – 0.9978	0.989***	0.9834 – 0.9948	0.991**	0.9838 – 0.9998
Gender (Male headed Households)	0.915	0.6549 – 1.2797	0.827**	0.6909 – 0.9913	0.778**	0.6237 – 0.9708
Education of Household head	0.795	0.5780 – 1.0959	1.212*	1.0254 – 1.4338	1.236*	0.9656 – 1.5825
Place of Domicile	1.086**	0.6788 – 1.7404	0.910	0.7218 – 1.1486	1.783**	1.0949 – 2.9042
Household wealth	1.086*	0.6141 – 1.7416	2.056***	1.7171 – 2.4623	1.744***	1.2846 – 2.3698
Malaria Endemicity	1.119	0.8155 – 1.5374	0.908	0.6888 – 1.1986	1.211	0.4231 – 3.4700
Size of the Household	1.074**	1.0120 – 1.1401	1.027*	0.9955 – 1.0599	0.997	0.9480 – 1.0489
Number of children aged < 5 years	0.921	0.8194 – 1.0372	1.113	1.0181 – 1.2182	1.030	0.9028 – 1.1766
Malaria Parasitemia	0.760**	0.5582 – 1.0349	1.091	0.9213 – 1.2928	0.634***	0.5107 – 0.7873
Access to media	NA	NA	1.056	0.9139 – 1.2204	0.845	0.6680 – 1.0707
Proximity to Health Facilities	NA	NA	0.383***	0.3321 – 0.4423	1.009	0.8110 – 1.2563
Existence of Free bed net distribution	1.098*	0.3813 – 3.1618	0.872	0.6697 – 1.1371	0.682	0.2477 – 1.8791
Interaction term (Free bed net/wealth)	1.247*	0.7292 – 2.1324	0.974	0.7315 – 1.2976	1.001	0.6385 – 1.5692

Predicted marginal effects for free bed net distributions and wealth with reported household ownership of any bed net

		Angola	**Tanzania**	**Uganda**
	Dependent variable: ***Household bed net ownership***	*Marginal Effects: (dy/dx)*	*Marginal Effects: (dy/dx)*	*Marginal Effects: (dy/dx)*
1	Wealth	0.030**	0.207***	0.141***
2	Free bed net Distribution	0.104*	0.038	0.124*
3	Scenarios for Interaction term (Free Bed nets/wealth)			
	No Free Bed nets in Poorer households	0.297***	0.542***	0.542***
	No Free bed nets in Wealthier households	0.385***	0.706***	0.570***
	Free bed nets in Poorer households	0.420***	0.582***	0.656***
	Free bed nets in Wealthier households	0.563***	0.762***	0.714***
	% change among poorest households	12.3	3.4	11.4
	% Change among wealthier households	17.8	5.6	14.4

Children's use of any bed-net: Household wealth, age, education of the household head, number of children under-5, malaria endemicity and proximity to health facilities all showed some degree of significant relationship with children's use of bed nets. Overall, household wealth was the strongest predictor of children's use of bed nets across the three countries (Figure 4). Wealth had the strongest impact on children's bed net use in Tanzania with marginal effects estimated at 11% whereas in Angola and Uganda the predicted marginal effects were 6% and 4% respectively. The higher the numbers of children living within a household the better the chances for them to sleep under a bed net in all three countries.

Figure 4: Bed-net use by household wealth and distribution strategy



The predicted marginal effects on the impact of the number of children living within a household on bed net use varied from 1 percentage point in Angola to respective

4 and 5 percentage points in Tanzania and Uganda (Table 4). The odd ratios for free bed net distribution strategy on bed net use by children were significant in both Angola and Tanzania. We tested for the impact of free bed-net distribution on their usage among poorest and wealthier households. Our results showed that free bed net distribution improved their usage among poor households in Angola by 30 percentage points with a 9 percentage point advantage over children in wealthier households ($p<0.001$). For Tanzania and Uganda, the chances of increased bed-net use by children in poorer households due to free bed-net distribution strategy improved by only 22 and 24 percentage points respectively. Use of bed-nets among poorest households increased slightly in both countries but was not statistically significant when compared to bed-net use among children in wealthier households in each of the two countries.

Table 4: Multi-level model results for children's use of bed-nets

	ANGOLA		TANZANIA		UGANDA	
Total Observations (N)	**1,125**		**3,109**		**1,954**	
Children's use of any bed net	**OR**	**Confidence Intervals**	**OR**	**Confidence Intervals**	**OR**	**Confidence Intervals**
Age of household head	1.001	0.9909 – 1.0130	0.993**	0.9877 – 0.9987	0.981***	0.9738 – 0.9898
Gender (Male headed Households)	0.991	0.6951 – 1.4138	0.9496	0.7999 – 1.1272	0.810*	0.6517 – 1.0087
Education of Household head	1.247*	0.8928 – 1.7441	1.123	0.9547 – 1.3210	1.018	0.8021 – 1.2941
Place of Domicile	1.425	0.8747 – 2.3228	0.882	0.7269 – 1.0741	1.777**	1.0744 – 2.9402
Household wealth	1.173*	0.6845 – 2.0112	2.096***	1.7681 – 2.4858	1.747***	1.2953 – 2.3563
Malaria Endemicity	0.477***	0.3384 – 0.6748	0.974	0.7762 – 1.2229	1.224	0.4904 – 3.0569
Size of the Household	1.050	0.9886 – 1.1156	0.976	0.9492 – 1.0052	0.948**	0.9032 – 0.9965
Number of children aged < 5 years	0.935**	0.8197 – 1.0680	1.150***	1.0598 – 1.2480	1.214***	1.0683 – 1.3800
Malaria Parasitemia	0.789	0.5720 – 1.0887	1.109	0.9471 – 1.3003	0.547***	0.4431 – 0.6759
Access to media	NA	NA	0.9486	0.8310 – 1.0828	1.001	0.8007 – 1.2517
Proximity to Health Facilities	NA	NA	0.437***	0.3830 – 0.5004	1.086	0.8783 – 1.3437
Existence of Free bed net distribution	1.112	0.6954 – 1.7799	0.796*	0.6194 – 1.0238	0.931	0.3828 – 2.2655
Interaction term (Free bed net/wealth)	1.051*	0.5953 – 1.8587	1.161**	0.8803 – 1.5327	0.736	0.4748 – 1.1432

Predicted marginal effects for free bed net distributions and wealth with reported children's use of bed nets.

		Angola	Tanzania	Uganda
	Dependent Variable: ***Children's Bed Net usage***	*Marginal Effects: (dy/dx)*	*Marginal Effects: (dy/dx)*	*Marginal Effects: (dy/dx)*
1	Wealth	0.060**	0.115***	0.040**
2	Free Bed net Distribution	0.081*	0.073**	-0.029
3	Scenarios for the Interaction term (Free bed nets/wealth):			
	No Free Bed nets in Poorer households	0.270***	0.197***	0.236***
	No Free Bed nets in Wealthier households	0.194***	0.314***	0.260***
	Free Bed nets in Poorer households	0.309***	0.229***	0.247***
	Free Bed nets in Wealthier households	0.216***	0.343***	0.277***
	% Change among poorest households	3.9	3.2	1.1
	% Change among wealthier households	2.2	3	1.7

Discussion

Our results show that targeted free bed-net distribution programs across all three countries did not succeed to reduce inequalities in childhood malaria prevalence as well as access and use of bed-nets especially by the poorest households. Malaria test positive cases were proportionately higher in children from the poorest households than those from wealthier households. Marginal effects estimates showed that children from wealthier households were up to 12 percentage points less likely to have malaria parasites than those in poorest households. Meanwhile, while targeted distribution of free bed-nets substantially increased overall household ownership of bed-nets, the strategy did not reduce perverse household inequalities in bed-net ownerships. Wealthier household had a consistently higher probability of owning bed-nets by 14.3 percentage points for those living in Angola, 21 in Tanzania and 12 percentage points in Uganda over poorest households. Moreover, bed-net use among poorest households where targeted free bed-net distribution occurred was higher in Angola by 9 percentage points than among wealthier households with targeted free bed-net distribution program. In case of Tanzania and Uganda, there was overall improvement in bed-net use by poorest households but still their usage was disproportionately lower when compared to use among wealthier households. The use gap was largest in Tanzania by 11.4 percentage points while in Uganda wealthier households had a 3 percentage points of bed-net use advantage over poorest households.

Our analysis corroborates with other studies to confirm that malaria burden is often concentrated on the economically poor households [6, 224, 245]. Studies conducted in Kenya and Togo also established this socioeconomic phenomenon whereby, children in poor households and with poor nutritional status exhibited a greater risk of having highdensity malaria parasitemia, clinical malaria and severe anaemia than those in wealthier households or non-stunted children [246, 247]. Children living in poorest households are therefore more vulnerable to malaria than those living in wealthier households. In terms of household bed-net ownership, our findings indicate that targeted free bed-net distribution improved overall coverage but did not achieve parity across households with different wealth status. Other studies have also reported unequal distribution of bed-nets across countries in SSA [105, 106, 115, 189, 248-250]. Despite large scale implementation of targeted free bed-net distribution, unequal access to bed-nets across households remained relatively high especially in Tanzania and Uganda. Inequities in access to these life-saving malaria interventions could partly be attributed to the type of distribution channels chosen by each country and, to the high degree of variation in physical infrastructure which inhibited effective bed-net delivery mechanisms in some settings. In places like Angola where almost 80% of the health facility infrastructures were destroyed by civil wars, the success of such a strategy becomes even more daunting. The same can be said for northern Uganda where civil wars have ravaged the region for over twenty years debilitating most of the regions physical infrastructure to effective delivery of public health programs like bed-net distribution. Moreover, studies have also found that the poorest people often live far away from health clinics, which contributes to their inability to access bed-nets when distributed through such channels[49, 55, 56, 112, 126, 251-253].

Our current analysis was based on three malaria indicator surveys from Angola, Tanzania and Uganda. These surveys were conducted at the time when all three countries embraced targeted bed-net distribution as an effective strategy for scaling up bed-net coverage for malaria control. However, this analysis shows that targeted strategies failed to overcome bed-net ownership inequities a fact which was also realized by most malaria endemic countries as well as global malaria control program donors[56, 121]. Following this realization mass universal campaigns have been conducted across many countries as a 'catch up' strategy to address these inequities. To a larger extent, there have been huge gains in terms of increasing bed-net coverage especially over the last five years [254, 255]. Despite these gains, it is important to note that most countries have still continued to rely on targeted bed-net distribution as a strategy for their 'keep up'[206]. It is therefore important to conduct further analysis of more recent MIS data to explore whether the trend exhibited in this study is being reversed as some scholars have argued for increased universal free bed-net coverage[189].

Finally, our findings on low bed-net use among children under-five years of age of all socioeconomic backgrounds, underscore the need for better understanding of some of the important determinants of bed-net use across households with different socioeconomic status. A study conducted in two districts in Tanzania, found that in one district household wealth was major determinant factor for ITN use but in another district ITN use was not tied to wealth of the household. Furthermore, the same study found a near perfect equality in bed-net use in the second district compared to the first district in which wealthier households were more likely to use ITNs than poorest households[57]. In another study completed in Western Kenya highlands, the authors reported that bed-net use was positively correlated with education level of the household head[256]. A study in Uganda attributed low bed-net use among biologically vulnerable groups to low sensitization and education on proper use from health workers and other bed-net distributing agencies[229]. These studies showcase our limited understanding of the factors determining ownership and use of these important malaria control tools [257-260].

There are two important limitations of this study worth discussing. First, the study used a cross sectional malaria survey data from all three countries. Cross-sectional data may not be ideal for use when attempting to explore causal relationships but can offer some strong indication on the nature of statistical relationships between variables. Therefore, in this study we can only point to evidence indicating existence of some form of association between the dependent and independent variables of interest but cannot confidently infer any causal relationships. Secondly, the survey's sampling procedure deliberately oversampled rural households emphasizing the fact that malaria disease is predominantly a rural problem. This has resulted in lower statistical power in estimating the impact of childhood malaria prevalence and household ownership and use of bed-nets in urban areas. The sampling strategy undermines the fact that poorer households in urban settings can sometimes experience worse living conditions than those living in rural places.

Policy Implications

This study has shown that targeted free bed-net distribution policy in itself may not address the problem of unequal access to these life-saving interventions. Despite some improvements in bed-net ownership, targeted free bed-net distribution strategy as described here did not address the chronic problem of disproportional access to bed-nets especially among poor households. The conventional wisdom that targeted free bed-net distribution improves access to bed-nets as the strategy helps poor households overcome the financial barrier cannot explain why bed-net ownership did not improve for some of the poorest households after these were provided for free. Other structural bottlenecks may play an important role in limiting poor people from accessing these effective interventions. It is therefore important to understand these-other limiting factors; otherwise, policies such as the universal free bed-net distribution recently endorsed by the WHO are unlikely to achieve the desired outcomes. Moreover, with the exception of Angola, targeted bed-net distribution did not increase poorest households' children bed-net usage. Children living in poorest households with nets in Tanzania and Uganda reported less use of the bed-nets than those living in relatively wealthier households. This suggests that there are additional obstacles to net use in poorest households that malaria researchers and policy makers are yet to understand well. Unpublished study from Mali suggest that high mobility and unfavourable sleeping structures in poorest communities may inhibit bed-net usage even when these nets are available[261]. In Uganda, sleeping arrangements was found to be an important determinant for use of bed-nets by children-under5[262]. Therefore increased resources for targeted free bed-net distribution may not necessarily improve ownership and use among poorest households. However, it will be intriguing to see how this plays out in future surveys given the recent increased resources and support for universal free-bed net distribution.

Additionally, in order to address the inequities in bed-net ownership and use, researchers and policy makers need to re-examine the effectiveness of existing bed-net delivery strategies. The use of health facilities and ANC services alone may not be the best ways to reach out to the poorest households due to a number of reasons. First, poorest people often tend to use less of these services because of financial constraints which in turn put heavy economic burden on their lives. Secondly, poorest people often live far from health clinics and therefore face physical barriers to accessing health services as already shown by other studies[125, 126, 263-265]. The study results therefore suggest the need to explore alternative bed net distribution channels such as use of popular places like regular drug shops, market squares, social event venues including sports tournaments, and places of worship. Finally, intensified household level interventions should especially be accelerated in potentially densely populated areas. Resources should also be set aside for better understanding of factors that inhibit net use especially among the poorest households.

Conclusions

This study has shown that implementation of targeted free bed-net distribution in three African countries with substantial international donor support may have substantially improved coverage. However, the relationship between targeted distribution of free bed-net and reduction of childhood malaria infections, ownership and use of bed-nets among poorest households was less significant relative to wealthier households. Moreover, targeted free bed-net distribution did not improve bed-net use among those children under-5 living in poorest households in Tanzania and Uganda. In contrast, children under-5 from poorest households in Angola had higher likelihood of using mosquito nets than those in wealthier households. Despite failure to substantially reduce malaria burden and improve bed-net coverage in poorest households, the study found that targeted free bed-net distribution program was effective in identifying places with highest malaria disease burden.

The fact that targeted free distribution of bed-nets did not eliminate the structural bottlenecks that inhibit poorest households from accessing effective malaria control interventions poses some challenges to malaria experts. It emphasizes the need to revisit this distribution strategy with the aim of finding the most effective way to reach those most in need. Given the institutional and infrastructural challenges facing many SSA countries, it is not surprising that wealthier households would potentially benefit more from targeted free bed-net distribution programs than poorest households. At a time when universal bed-net distribution has been strongly endorsed by world health governing bodies as the mainstay of malaria control efforts in the region; it is important that malaria policy makers continue to monitor and evaluate the effectiveness of these programs. Avenues for improving bed-net coverage including universal coverage campaigns, school and community based approaches should be encouraged to ensure that those most in need of these life-saving interventions benefit most.

Chapter 5

Exploring the linkages between maternal education and childhood malaria infections

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Abstract

Background: Over the last four decades, a plethora of studies have looked at associations between maternal education and childhood nutrition status, vaccination uptakes and general child health. Despite increased global campaign to reduce worldwide child mortality, the mechanism through which maternal education relates to childhood malaria infections which is among the leading causes of child mortality in sub-Saharan Africa (SSA) is less investigated. This study explores the relationship between maternal education and childhood malaria infections using cross-sectional malaria indicator survey data from three countries in SSA.

Methods: Multivariate logistic regression models were fitted to explore the linkages between maternal education and childhood malaria infections. While controlling for individual, household and country level factors, we estimated six different models based on the possible pathways anticipated to determine the relationship between maternal education and childhood malaria infections. Marginal effects for the probabilities of maternal education relating to childhood malaria infections are reported. Additionally, we completed the Oaxaca decomposition analysis to quantify the contribution of maternal education on childhood malaria infections.

Results: The full adjusted model showed significant association between maternal education and childhood malaria. Overall, children-under5 in households with mothers reporting some primary education level had 3.2 percentage points ($p<0.01$) of being less likely to have malaria parasites. The probability for children whose mothers reported having some education level beyond primary school being malaria positive was reduced by almost 5 percentage points ($p<0.001$) compared to children of uneducated mothers. The Oaxaca decomposition analysis of the full adjusted model exhibited about 8% gap in childhood malaria infection between educated and uneducated mothers. Roughly 82% of the gap was largely explained by differences in household wealth, household place of domicile and differences in regional malaria transmission intensities.

Conclusion: Our study found a statistical relationship between maternal education and childhood malaria infections. The magnitude of the coefficients in the final full model was however lower than one established in the base model. These findings emphasize the need for international malaria control programs to support malaria endemic countries by offering enough flexibility in their malaria funding that will allow countries to invest in long term and sustainable malaria control strategies including improving school enrollment and completion for all children and more particularly among girls.

Background

Despite increased interest in the interaction between maternal education and child health, the cognitive pathways through which these two relate to each other are not as straightforward. A number of studies have described various potential linkages which may explain the relationship between maternal education and childhood immunization, nutritional status and mortality rates [142, 143, 157, 266, 267]. While malaria continues to be one of the leading causes of childhood morbidity and mortality in sub-Saharan Africa, efforts to understand the intricate relationship between maternal education and childhood malaria infections have not been vigorously pursued. Nevertheless, considerable efforts have been devoted to understanding the association between malaria in pregnancy and birth outcomes but little has been done to explore the relationships between maternal education and childhood malaria infections [268-273].

Interventions to reduce the burden of malaria in both pregnant women and children aged less than five years (children-under5) have predominantly focused on vector control through use of insecticide treated-nets (ITNs) and presumptive treatment during pregnancy through intermittent preventive treatments (IPTp). While the scaling up of ITNs has substantially increased in the last decade, the use of these ITNs has consistently remained low [136, 274]. Multiple factors including perceived malaria risks, demographic and other intra-household socioeconomics have been associated with low use of ITNs in communities with high malaria prevalence[275-279]. Nevertheless, there are hardly any studies that have explored the role of maternal education in use of these preventive measures and consequently reduce the burden of disease. An investigation onto the role of maternal education on childhood malaria infections will help improve the design and implementation of malaria interventions with the goal to mitigate the burden of the disease in sub-Saharan Africa and other malaria endemic regions. Given the global emphasis to reduce worldwide maternal and child mortality rates, understanding the linkages between maternal education and childhood malaria infections is crucial.

This study investigates the relationship between maternal education and childhood malaria infections in settings with high malaria transmissions. The study uses nationally representative cross-sectional data from Angola, Tanzania and Uganda. The goal of this study is, first to explore the possible pathways through which maternal education may influence childhood malaria infections and, secondly to explore the statistical relationships between maternal education and childhood malaria infections in the three study countries. Literature on the causal relationship between education and health is relatively well established [64, 280-283]. In this study, therefore, the causal relationship between education and health is outside the scope of our proposed analysis. Our analysis is presumptively based on the notion that malaria prevention and treatment choices are largely affected by the level of knowledge individuals possess about the disease. The assumption is reliant on past study evidences about malaria etiology, prevention and control [31, 284]. The study first delves on the possible theoretical pathways through which maternal education may relate to childhood malaria infection rates.

Delineating the pathways

Notwithstanding a growing body of literature demonstrating some strong linkages between maternal education and child health in most developing countries, there are multiple descriptions of these causal relationships[154, 267, 285]. Studies have reported positive relationships between maternal education and childhood nutritional status, survivorship and also uptake of important healthcare services such as vaccinations [66, 153, 161, 286, 287]. A multi-country analysis looking at net education effect on child survival rates by age specific segments concluded that, children survival rates by their mother's education levels were substantially higher among those aged 1-5 years than in neonatal and post-neonatal period [142]. In the same study it was estimated that a one year increment in maternal education could provide as much as 10% decline in under-five mortality rate. The potential benefits societies enjoy through investing in women's education have also been best described in light of the indirect benefits educated mothers enjoy through improved household socioeconomic status[71, 288]. Following these important linkages, it is therefore important to first explore the potential pathways through which maternal education associates with child health and childhood malaria infections in particular.

Improved knowledge encompassing child health: Past studies have argued that education does improve people's knowledge about health and make them more receptive to health messages.[149-151] While specific health messages may not necessarily be covered in all school curricula the overarching goal of education in terms of literacy, academic and non-academic skills have the potential to help women become more receptive to good health messages funneled through different sources including existing health platforms, mass media and other social networks[289]. A study in in Indonesia demonstrated that educated women had greater awareness of correct immunization schedules which enabled them ensure that their children received available vaccines in time[71]. Based on such evidences it is logical to assert that maternal education has the potential to help mitigate childhood malaria infections as educated mothers stand a better chance to protect their children from malaria transmitting vectors than uneducated mothers. Proper knowledge on how malaria is spread can help mothers protect even their unborn children by adhering to effective malaria preventive messages such as use of intermittent preventive treatments during pregnancy, use of mosquito nets as well as use of other vector control mechanisms such as indoor residual spraying.

Furthermore, schooling equips individuals with problem-solving skills that would otherwise be lacking if the individual was uneducated. For instance, a mother who has gone through vocational training may be better prepared to troubleshoot hanging a mosquito-net in her bedroom than one who never had a chance to attend formal education and consequently with less exposure to various problems solving skills. Education encourages individuals to try new things/ideas while bolstering their confidence even when they fail to achieve their primary goals. A study using data from India argued that *'little learning'* in primary schools was beneficial because girls learned to accord teachers with great authority and went on to bestow similar authority on health practitioners as they carefully followed prescribed treatment schedules when they become mothers[68]. In Philippines, a study showed that with each additional year of maternal education, there was increased probability for using preventive services by 4% during any month in the first year of a child's life[141, 288]. Finally, a study conducted in the Democratic Republic of Congo and Southeast Iran concluded that education level of the household head was important factor for increased bed-net use in areas where these nets were distributed for free[290, 291].

Family formation patterns: An analysis of the 1988 World Fertility Survey data plus multiple other studies concluded that differences in the distribution of births by birth order, maternal age at birth, and birth interval length were among the important factors contributing to improved child health[153, 154, 292]. There is a tendency for educated mothers to delay childbearing and avoid the high risk childbearing ages when they are younger[293]. Educated mothers also tend to avoid early marriages which accord them some precious time to grow and mature as they prepare to deal with marriage and childbearing challenges awaiting them. For some countries, cessation of early age childbearing and need to space births at wide intervals enables mothers to deal better with childhood illnesses. In the malaria world, better spaced birth intervals may be critical in helping mothers to attend to their young children's health needs. For instance, the challenges a mother faces when her three children aged below five years have malarial fevers may be more demanding than one she will face if she only had one child to attend to. Birth interval is important for mothers to be able to provide adequate attention to their young children when ill. Use of ITNs may also be hampered when a family expands too quickly as caretakers may fail to provide their children with necessary protection from malaria transmitting mosquito bites. Because of many years spent at school, educated mothers are less likely to marry earlier or reproduce more frequently than those with less schooling years. Adoption of such behaviors has the potential to reduce childhood malaria infection rates.

Economic empowerment: Historically, decision making in most malaria endemic households have been predominantly dominated by men. Gender restrictions can be an obstacle in enhancing women abilities to deal with health challenges their young children may be faced with. Even in circumstances where women are capable of making such decisions as where and when to seek care, how to protect their children from disease infections and others, they may still need help from their husbands or other family members in terms of dealing with the outside world or mobilizing necessary resources to address the problem at hand. Some studies have managed to show the important relationship between maternal education and decision making autonomy as well as health service utilization[156, 157] . Studies have also shown that educated women do enjoy higher autonomy to make independent decisions and socio-economic mobility including where and when to seek healthcare services for their children [158, 159, 294]. One may argue that maternal education not only improves their ability to make autonomous decisions but comes with increased sense of economic security to enhance execution of their decisions. Educated mothers have been shown to earn more than those with less education and their incomes improve household welfare [295-297]. A study from Canada specifically affirmed that households' expenditures are closely linked to traditional gender roles[160]. The study was able to show that expenditures on child care increased only when women's incomes increased and that higher male income was not associated with higher expenditures on child care even when both spouses were full-time and full year paid workers.

Furthermore, evidence from developing countries suggests that educated women tend to marry partners who are also better educated with reliable sources of incomes [298, 299]. Since most women especially in SSA still rely on their male partners to make important decisions about their welfare and their children's welfare, those without some level of education and no reliable source of income of their own are at a disadvantaged position when it comes to health and wellbeing of their children. In societies where male dominance continues to dictate what family priorities should be, uneducated mothers are particularly underprivileged. Educated mothers and/or the partnership between educated couples enable them to live in communities with better healthcare access, better infrastructure including water and sanitation services. With their improved socioeconomic status, educated mothers can afford better healthcare services than those with less education. For childhood malaria control, maternal education may be an important component as it empowers mothers both financially and mentally to make the right decisions regarding the health of their children. An educated mother is less likely to depend on her husband to provide money for malaria prevention and treatment services for the family. Maternal education may also help mothers make right treatment decisions with less reliance on their husbands as it helps break the financial barrier many poor households face when their children fall sick with malaria.

Improved social networking: Education plays an important role in helping students enhance their social networking skills [300]. Educated mothers may have broader social networks that provide knowledge on better child health, where to seek appropriate treatment whenever a child is ill or, good sources of protection against mosquitoes and other disease causing vectors. A study from Gambia reported that mothers in rural areas were influenced by their peers and other women activities like village music groups to attend antenatal clinic days as a group whereas those in urban areas where there was no such support, their attendance to clinic did not improve[161]. Maternal education may for instance, play an important role in helping mothers organize themselves to secure subsidized or free ITNs for their children. In Tanzania social marketing strategy was at one time a bedrock policy for bed-net distribution in rural places. Coverage of ITNs improved substantially through social marketing where comedians and music artists were used to help spread the right message about malaria infections. Through these public health messages, knowledge about protecting children from mosquito bites by use of subsidized ITNs was imparted to public health rally attendants most of whom were mothers[301]. Given these outlined pathways, a better understanding of these relationships will enhance malaria control efforts through implementation of more holistic programs that not only focus on understanding the behavior of malaria vectors and the disease epidemiology but, also relating malaria control to other non-health factors like education for effective and more sustainable malaria control programs.

Data and Methods

This analysis uses cross-sectional malaria indicator survey (MIS) data from Angola, Tanzania and Uganda. The three countries have varied malaria epidemiology and constituted the first cohort of malaria endemic countries in sub-Saharan Africa chosen by the US government to benefit from the President Malaria Initiative (PMI) launched in mid- 2005 and also to initiate the first nationally representative malaria indicator surveys. Data were collected during the period 2006 – 2009 covering a total of over 10,000 households sampled from the three countries. The survey collected information on both years of education and literacy levels for household heads and, for all women of reproductive age (15-49 years old), participating in the interviews. Additionally, the survey collected information on key malaria indicators including childhood malaria infection rates, history of fever and care seeking, household ownership and use of ITNs by children-under5 during the night before the survey was done. Courtesy to local research agencies and with technical assistance from the United States of America research organization, ICF Macro-MEASURE DHS, the survey was successfully completed. Data collection was made possible through financial assistance provided by the United States International Development Agency (USAID). Detailed information on sampling, questionnaires and survey implementation including the survey reports can be freely accessed at www.malariasurveys.org.

Malaria infection rates: A dichotomous variable indicating whether a child tested positive for malaria infection. The test was performed by using histidine-rich protein 2 rapid diagnostic test devices which only detect presence or absence of malaria parasites but does not tell the parasite count load.

Independent Variables

Maternal education level: This was measured as the highest number of self-reported school years completed as reported by interviewed women. Since majority of women had very few years of schooling or no schooling at all, education levels were coded into three categories: no schooling, any primary education, and any secondary or college education. These separate dummy variables enabled us to approximate ceiling effects based on each country's education process pyramid.

Child health knowledge: A total of five indicators were used to capture maternal knowledge on their children's health. These included: (i) Mother's correct knowledge of malaria transmitting vectors, (ii) Treatment for childhood febrile illnesses within 24 hours of fever onset, (iii) Women's use of IPTp in their last pregnancy, (iv) Household ownership and use of mosquito nets and (v) Maternal use of antenatal health services in their last pregnancy. All indicators were binary variables coded 1 if a woman exhibited correct knowledge of malaria transmitting vectors, sought care for a sick child within 24 hours of fever onset, used IPTp or, antenatal care in her last pregnancy, owned and used mosquito nets. Otherwise, the variables were coded as 0 if none of these indicators were observed or reported.

Economic empowerment: The level of women empowerment was measured by a household wealth proxy variable coded into five categories ranging from poorest, poor, less poor, rich and richest coded in ascending order from number 1 to 5. The household wealth/poverty indices were generated using household asset index methods as described in the popular education paper from India which was published in the year 2001[302].

Family formation pattern: First we used the size of households captured by total number of individuals living within a household as one of the indicators for family formation patterns. Secondly, a continuous variable indicating the total number of children-under5 born to a single mother within the household was also used as a proxy for capturing household family formation pattern.

Social networking: MIS did not have any specific social networking data collected. We determined that the only information that could be close to an indication of increased social networking was ownership of mobile phones. Cellphones have increasingly been shown to contribute in various ways to economic development throughout sub Saharan Africa[303]. Studies have also shown that despite majority of cellphone users in most developing countries being poor, they continue to spend money on maintaining them because of their multifaceted benefits including social networking[304-307]. A binary variable coded 1/0 to indicate ownership of a mobile phone was therefore used as a proxy for social networking.

Other Control Variables

Additionally, country level fixed effects were fitted in our estimation models and also controlled for regional differences in malaria transmission intensities, socio-cultural dynamics and also differences physical infrastructures across countries and regions. Moreover, households and individual level factors including demographics and access to public health messages were all fitted in our various models [308]. The outlined pathways linking maternal education and childhood malaria infections formed the four basic pillars fitted in our different models estimated as described in the subsequent study section. The full adjusted model included all four models as envisioned in the pathways linking maternal education and childhood malaria infections.

Estimation Strategy

Multiple logistic regression models were estimated to look at the relationship between maternal education and childhood malaria infections. The analytical techniques were based on a study which looked at the relationship between maternal education and child immunizations in India[143]. We started with a *base model* regressing malaria infection rates against maternal education plus other basic demographic controls. We then incrementally added each of the four pathways hypothesized to mediate the relationship between maternal education and childhood malaria infection rates. Furthermore, we included the sampling cluster fixed effects to hold constant any unobserved community level heterogeneities. The goal of the analysis was to find out the extent to which the magnitude of the education coefficients would diminish/increase after the introduction of each of the hypothesized pathways. Our final-full model included all hypothesized pathways as shown

$$m_{ijk} = \underbrace{ME_{ik}\beta_0}_{Base\ Model\ +C} + \underbrace{CK_{ijk}\beta_1}_{Pathway\ 1} + \underbrace{PF_{ijk}\beta_2}_{Pathway\ 2} + \underbrace{E_{ijk}\beta_3}_{Pathway\ 3} + \underbrace{SN_{ijk}\beta_4}_{Pathway\ 4} + \underbrace{c_{ijk}\,x_{1,\dots,n}}_{C} + \mu_{ijk} \ldots\ldots (1)$$

From the equation, m_{ijk} represents childhood malaria infection rates, ME_{ijk} stands for maternal education level, CK_{ijk} knowledge about childhood health, PF_{ijk} is for family formation patterns, *Eijk* stands for economic empowerment, SN_{ijk} represents social network, C_{ijk} represents all other controls and the μ_{ijk} is for the standard errors. The subscripts *i,j,k* represents individuals *i,* in households *j,* and regional primary sampling units, *k*. Upon production of the odd ratios, we further estimated the marginal effects on the probabilities of maternal education relating to childhood malaria infections. The estimated marginal effects enabled us to succinctly determine and report the direction of these relationships in the results section.

Blinder - Oaxaca Decomposition

Additionally, we employ Blinder-Oaxaca decomposition technique to better understand the how childhood malaria infections may be explained by inequalities in maternal education rather than other contributing factors such as level of media exposure, household wealth, differences in malaria transmission intensity, differences in household heads' education levels and places of domicile. The technique allows for a division of observed average malaria infection rates between educated mothers and uneducated mothers into both explained and an unexplained portion as described in various economic and social literature especially the gender wage differences studies [309-311]. In this study, the technique provides an objective means of disentangling the effects of true impact of maternal education versus other justified differences. Since the study's primary outcome variable is binary, with coefficients from logistic regression model, the coefficients cannot be used directly in standard Blinder-Oaxaca decomposition equations. We adopt the Blinder-Oaxaca decomposition extension technique for logit and probit models described in past studies [312]. Non-linear decomposition techniques can be useful in identifying the causes of gender, racial, geographical or other categorical differences like malaria infections in binary outcomes in which a logit and probit models are used. Therefore, assuming that a relationship exists between child *i's* malaria infection rate (m_i) and some determinants of childhood malaria infections, X_i (X_i, might be place of domicile, malaria transmission intensity, household income or wealth, bed-net availability etc.). The decomposition for a nonlinear equation such as, $m_i = F(x_i\hat{\beta})$, can be written as:

$$m_i^{edu} - m_i^{noned} = \left[\sum_{i=1}^{N^{edu}} \frac{F\left(x_i^{edu}\,\hat{\beta}^{edu}\right)}{N^{edu}} - \sum_{i=1}^{N^{noedu}} \frac{F\left(x_i^{noedu}\,\hat{\beta}^{edu}\right)}{N^{noedu}}\right] +$$

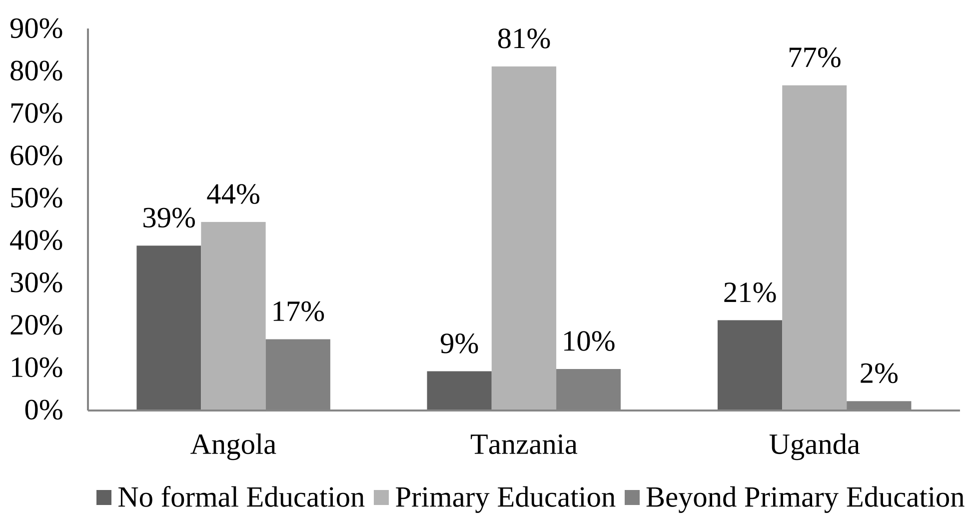
$$\left[\sum_{i=1}^{N^{noedu}} \frac{F\left(x_i^{noedu}\,\hat{\beta}^{edu}\right)}{N^{noedu}} - \sum_{i=1}^{N^{noedu}} \frac{F\left(x_i^{noedu}\,\hat{\beta}^{noedu}\right)}{N^{noedu}}\right] \ldots\ldots\ldots\ldots (2)$$

From equation (2) N^j refers to the sample size for educated and non-educated mothers. This alternative decomposition expression is used because the mean of outcome variable, in our case childhood malaria infection rates, does not necessarily equal the mean of independent variables coefficients. In the equation (2) the first term in brackets represent the part of malaria infections gap that is due to differences in maternal education level whereas the second term represent the part due to differences in group processes determining levels of outcome variable m_i for childhood malaria infections. The second term also captures the portion of malaria infections gap that is due to group differences in un-measurable or unobserved endowments. These are the differences in childhood malaria infections that would result if all children who varied only in their other characteristics not related to their mothers' education levels were cared by mothers of same education level. This is what we also call the 'unexplained' differences in malaria infections by maternal education. Following similar previous studies applying decomposition technique, this study does not focus on the 'unexplained' portion of the gap because of the difficulties in interpreting such results [313-315].

Results

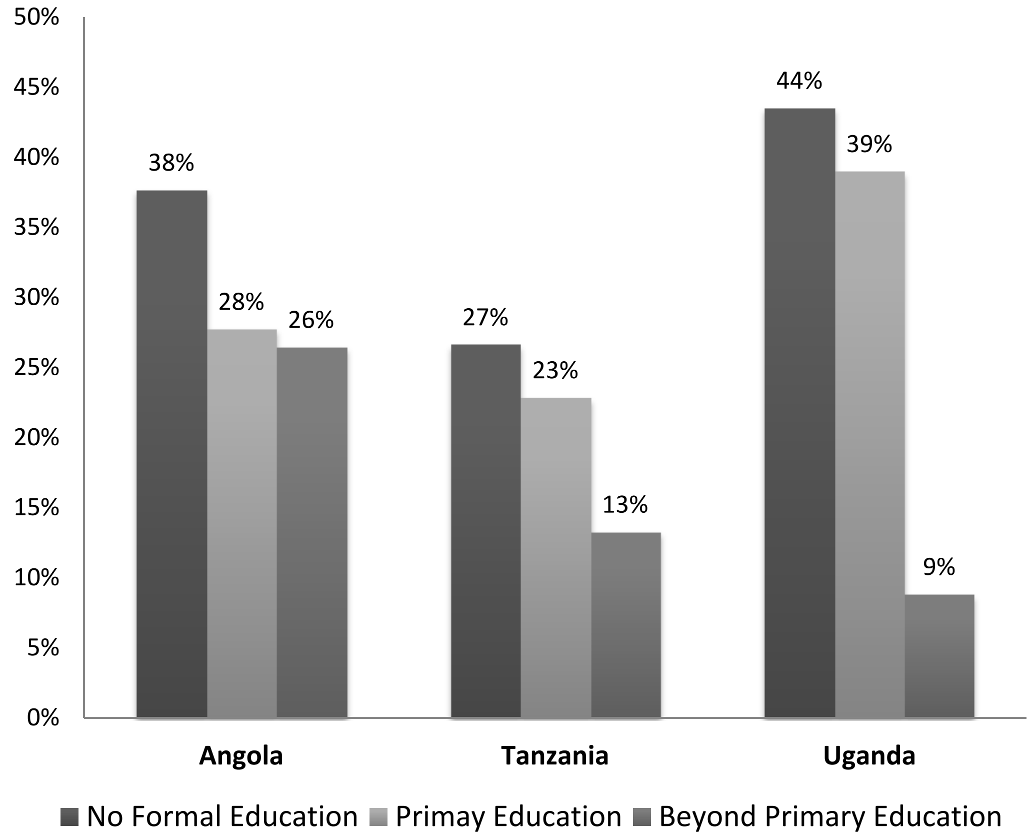
A total of 1,390 (82%) of all women interviewed in Angola, 5,975 (79%) of women in Tanzania and 2,997 (75%) of those in Uganda were eligible for answering survey questions on childhood malaria infections, prevention and treatment practices. Of all eligible women interviewed, Angola had the largest pool of women without formal education, 39%, followed by Uganda, 21%, and in Tanzania only 9% reported having no formal education training.

Figure 5: Distribution of maternal education levels by country of origin



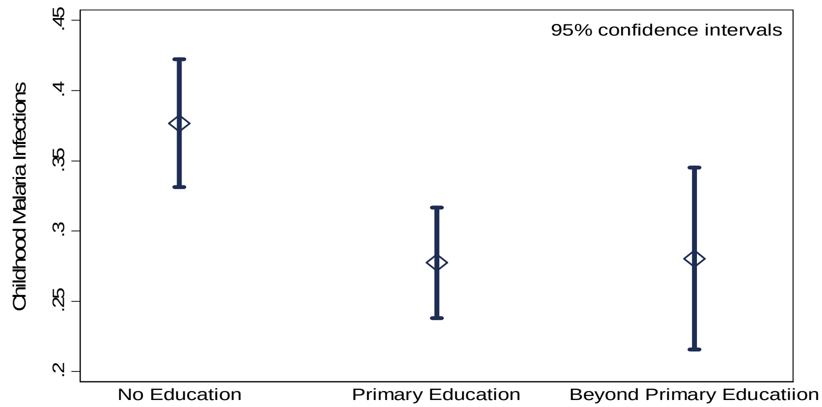
From the descriptive statistics, childhood malaria burden was highest among women reporting no formal education across all three countries. In Angola, childhood malaria burden among women without any formal education was 38% compared to 26% reported among women with more than just primary education. In Tanzania and Uganda, childhood malaria infections were highest among women reporting no formal education 27% and 44% respectively. Childhood malaria infection rates among women reporting only primary education were also high for both Tanzania and Uganda. The difference between having primary education and, not having any formal education in terms of malaria infection rates among children-under5 was not statistically significant in both Tanzania and Uganda. However, there was substantial difference in childhood malaria infection rates for mothers reporting having acquired education beyond primary level to those with/out primary education in both Tanzania and Uganda. For the case of Angola, having some primary education knowledge was associated with about 10% reductions of childhood malaria infection rates. The difference between reporting education level beyond primary level and those with only primary education level was however negligible.

Figure 6: Maternal education and childhood malaria infection rates

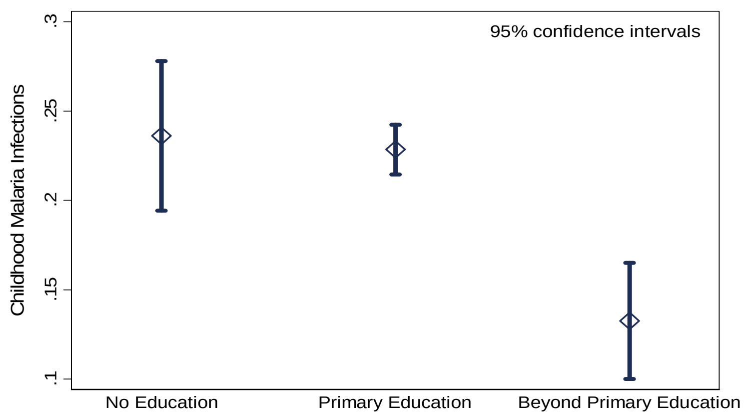


We computed the probability for a child having malaria infections based on their reported mother's education levels at 95% confidence intervals. In each of the three countries, the probabilities for children being malaria infected were highest if their mothers had reported no formal education training. Meanwhile, children of mothers reporting to have post primary education training exhibited the lowest probabilities of being infected with malaria disease. Figure 7 below presents the 95% confidence intervals for childhood malaria infections given their mother's education levels.

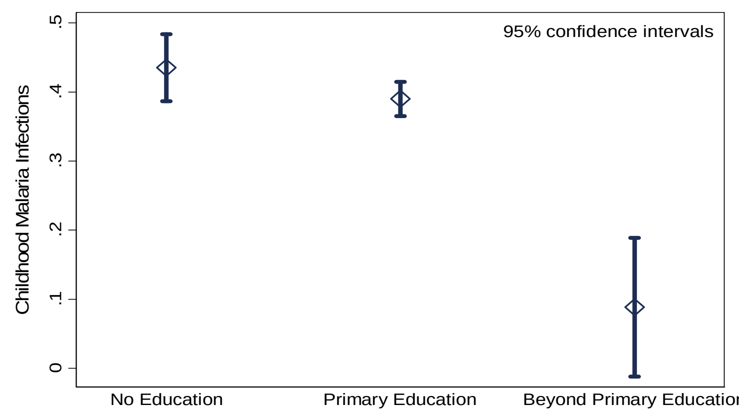
Figure 7: Confidence intervals for maternal education and childhood malaria infection rates



Maternal Education and Childhood Malaria Infections in Angola



Maternal Education and Childhood Malaria Infections in Tanzania



Maternal Education and Childhood Malaria Infections in Uganda

Logistic regression analyses were conducted on pooled data from the three countries. We further estimated the marginal effects to enable us determine the direction of the relationships between variables. The base model (1) exploring the relationship between maternal education and childhood malaria infection rates indicated that children belonging to women with some primary education had lower chance of being malaria positive by 4.2 percentage points ($p < 0.01$). Meanwhile, those with some education level beyond primary school were significantly associated with about 8 percentage points malaria infections reduction in their children-under5 ($p<0.001$). Other important variables with significant effects were place of domicile, media exposure and regional malaria transmission intensity. Education level and gender of the household head exhibited the negative relationship with malaria infection rate but the coefficients were not statistically significant.

Table 5: Relationships between maternal education and childhood malaria infections across the three countries

Malaria Infections N = 6,170	Basic Model (1)	Knowledge on Child Health (2)	Family Formation Pattern (3)	Economic Empowerment (4)	Social Capital (5)	Full Model (6)
Maternal Education						
Primary school (PS)	-0.042* (0.065)	0.033* (0.016)	-0.037*(0.016)	-0.034*(0.016)	-0.026 (0.016)	-0.032*(0.018)
Beyond (PS)	-0.084*** (0.000)	-0.092*** (0.021)	-0.093***(0.020)	-0.050*(0.024)	-0.068**(0.023)	-0.047**(0.021)
Age	0.003 (0.006)	0.002 (0.002)	-0.001 (0.002)	-0.001 (0.003)	-0.003(0.005)	-0.001 (0.005)
Gender of Household Head	-0.018 (0.	-0.018 (0.014)	-0.010 (0.014)	-0.021 (0.014)	-0.026* (0.015)	-0.014 (0.015)
H. head with PS Education	-0.003 (0.013)	-0.002 (0.014)	-0.002 (0.014)	-0.019 (0.014)	-0.011 (0.014)	-0.024 (0.021)
H. head Educ beyond PS	-0.004 (0.033)	0.007 (0.035)	0.010 (0.035)	-0.018 (0.042)	-0.012 (0.037)	-0.009** (0.004)
Rural Domicile	0.060**(0.020)	0.053* (0.021)	0.059** (0.021)	0.034 (0.022)	0.066**(0.021)	0.024* (0.013)
Limited Media Exposure	-0.014 (0.013)	-0.011 (0.014)	-0.011(0.014)	-0.016 (0.014)	-0.011 (0.014)	-0.016 (0.014)
High Media Exposure	-0.032* (0.015)	-0.043*** (0.016)	-0.044**(0.016)	-0.049**(0.016)	-0.037* (0.016)	-0.028* (0.130)
High Malaria Transmission	0.083** (0.028)	0.080**(0.029)	0.078** (0.028)	0.12***(0.029)	0.08**(0.029)	0.093*** (0.028)
Knowledge on Child Health						
Malaria Knowledge		0.001 (0.017)				-0.013**(0.003)
IPTp use		-0.010* (0.005)				-0.010*(0.005)
ITN ownership & use		-0.0.056** (0.021)				-0.076**(0.022)
Birth Spacing		0.038* (0.016)				0.045**(0.016)
ANC Utilization		-0.034**(0.0144)				-0.029* (0.014)
Family Formation Pattern						
Household size			0.007**(0.002)			0.009***(0.002)
#of children<5			0.016* (0.006)			0.010 (0.006)
Total children born			0.003 (0.002)			0.003* (0.002)
Economic Empowerment						
Poor				-0.022 (0.016)		-0.019 (0.017)
Less Poor				-0.041*(0.017)		-0.033* (0.018)
Middle				-0.105***(0.016)		-0.065*** (0.018)
Rich				-0.182***(0.018)		-0.123***(0.019)
Social Capital						
Cellphone use					-0.084***(0.013)	-0.030** (0.015)
Household Controls	No	Yes	Yes	Yes	Yes	Yes
Cluster level controls	Yes	Yes	Yes	Yes	Yes	Yes
Country Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes

In model (2) we included mothers' knowledge on child health while controlling for households, regional and country specific factors and explore how maternal education variables would change. The output results indicated that protection of childhood malaria infections by mothers with primary education only declined by 1 percentage point to 3.3 and remained statistically significant at ($p<0.01$) percent level. The model continued to indicate that secondary education to mothers provided about 9 percentage points of protection to a child from malaria infections at 1% statistical significance level. Living in rural areas continued to inflict more malaria on children by about 5 percentage points at 10% significance level. Meanwhile, media exposure and regional malaria transmission intensity continued to be statistically significant when related to malaria childhood malaria infection rates. While malaria knowledge did not show any positive relationship to childhood malaria infection protection, use of intermittent prevention treatment during pregnancy, antenatal service utilization, and ownership and use of mosquito nets all exhibited the desired negative statistical relationship with malaria infection rates in children under the age of five.

Furthermore, we estimated model (3) looking at the impact of maternal education on childhood malaria infections through family formation pathway. The contribution of maternal education in reducing childhood malaria infections continued to remain steady at 3.7 percentage points ($p<0.05$) less malaria infections for children with mothers reporting at least primary education level and around 9.3 percentage points ($p<0.001$) less malaria for children with mothers reporting education level beyond primary school. Household size and total number of children aged less than five years were significantly associated with marginal increase in childhood malaria infection rates ($p<0.05$) and (p<0.01) respectively. Other important covariates with significant impact on malaria infection rates were media exposure, regional malaria transmission intensity and whether household lived in rural or urban domicile.

In models (4) and (5) we explored the economic empowerment and social capital pathways and their relationship to childhood malaria infections given the varying education level of their mothers. Household wealth was strongly associated with childhood malaria infections. Wealth appeared to be the single most important cause for reduction in childhood malaria infections. Children in top quintile households were 18 percentage points (p<0.001) less likely to be malaria infested compared to children in second lowest wealth quintile who were only 2 percentage points less likely to have malaria. Maternal education remained consistently influential in reducing childhood malaria infections by 3.4 percentage points if a mother had some primary education and 5 percentage points to almost 7 percentage points if a mother reported to have education level beyond primary school. On the social networking, cellphone ownership was associated with 8.4 percentage points (p<0.001) reductions in childhood malaria infections. Media exposure and regional malaria transmission intensity also exhibited significant relationship to childhood malaria infections as shown in the table.

Finally, we estimated adjusted full model which included all four maternal education pathways envisioned to impact childhood malaria infections. Overall, maternal education maintained a modest but significant negative relationship with childhood malaria infections despite the model exhibiting significant reductions in the magnitude of the coefficients. A woman with some primary school education level was associated with 3.2 percentage points reduction in childhood malaria infections (p<0.01), whereas those with secondary school education and beyond were associated with almost 5 percentage points reduction in childhood malaria infection rates ($p<0.001$). We also included the interaction terms between maternal education and other pathways identified as manifests for education. The results are not shown in the table but there was a positive and significant relationship between maternal education and mothers' knowledge about malaria disease, their use of IPTp and bed-nets as well as antenatal care services. However, maternal education was not positively associated with birth spacing, total number of children born or the number of children under the age of five years living in a given household. Meanwhile, maternal education was also positively associated with the level of household wealth whereby, mothers belonging to poorest households were up to 35 percentage points less likely to be as well educated as those in wealthier households ($p<0.001$).

We further employed the non-linear Oaxaca decomposition technique to identify the causes of maternal education differences in childhood malaria infections. Estimates from our regression models indicated that there was a gap in malaria infection rates between children of educated mothers of those with mothers without education ranging from 19.6 percentage points in model (1) to almost 8 percentage points in the final adjusted full model (6). In executing the technique, we only focused on the final model (6). Of particular interest was to investigate whether (and the extent to which) group differences in the most likely 'causes' including household head education level, household wealth, place of domicile, the level of media exposure and differences in regional malaria transmission intensity contribute to variations in childhood malaria infections due to their maternal education disparities. Table II reports the findings on individual contributions from maternal education level differences given the suspected causes of malaria infections at household level. Overall, our full adjusted model reports a 7.8 percentage points gap in childhood malaria infection rates due to maternal education level disparities. With malaria being closely associated to poverty, the final adjusted model reports household wealth as the largest factor accounting for 26.9% of childhood malaria infection gap caused by caused by their mothers' education disparity. Residing in high malaria transmission zones takes the second spot explaining 21.7% of the gap while rural dwellers and level of media exposure explains 19.2% and 14.1% of the gaps respectively. Overall, all variables included in the model explains about 81.9 percent of the gap in the full adjusted model as shown on table II.

Table 6: Oaxaca decomposition analysis of different variables in relation to confirmed childhood malaria infections

Oaxaca Decomposition Variables	**Model (1)**	**Model (2)**	**Model (3)**	**Model (4)**	**Model (5)**	**Model (6)**
Infection rates for children of educated Mothers	0.247***	0.247***	0.251***	0.246***	0.234***	0.229***
Infection rates for children of uneducated mothers	0.443***	0.406***	0.387***	0.349***	0.325***	0.307***
Educated/Uneducated gap	0.196	0.159	0.136	0.103	0.091	0.078
Contributions from maternal education differences explained by:						
Household Wealth	NA	NA	NA	0.031***	0.025***	0.021***
Rural Domicile	0.037**	0.042**	0.035***	0.018***	0.015***	0.015***
Media Exposure	0.024*	0.028**	0.025***	0.019***	0.014***	0.011**
Malaria Regional Endemicity	0.039**	0.031***	0.028***	0.022**	0.019***	0.017***
All variables	0.108 (55.1%)	0.101 (63.5%)	0.088 (64.7%)	0.09 (87.4%)	0.73 (80.2%)	0.064 (82.0%)

Discussion

The results also showed that important background variables such as place of residence, demographic and other household characteristics are crucial in explaining some of the association between maternal education and childhood malaria infections. Even after controlling for these background characteristics, children of educated mothers were found to be less likely to have malaria infections than those of mothers without any formal education backgrounds. These results corroborates with studies in other child health fields which have also found strong statistical association between maternal education and child health including survivorship, improved nutritional status and increased immunization uptakes[143, 316].

The incremental inclusion of pathways indicated that knowledge about child health explained almost 5 percentage points of increased bed-net use, and 3.5 percentage points of increased antenatal and postnatal care use. Additionally, economic empowerment was strongly associated with up to 18.2 percentage points' reduction of childhood malaria infections in the top quintile compared to only 2.2 percentage points reduction of malaria infections among children belonging to the second lowest wealth quintile. Perhaps this should emphasize the fact that there are multiple ways through which education may relate to overall health outcomes. Through education, people's incomes may increase and consequently afford them better access to health and non-health related services which overall improves their quality of life. Maternal education can contribute to improvement of access to various health preventive and treatment services. A study in Kenya found that women reporting some higher level of education were more likely to own and use bed-nets obtained from retail sectors than those without any formal education[259]. This could also be an indication that apart from maternal education increasing household incomes it also has the potential to improve their knowledge on best ways to protect their children from various diseases including malaria. Studies have indicated that education does have a direct link to people's incomes and for women in particular, it increases their intra-household bargaining powers and their stake on deciding how household resources should be used[317]. Related to this is the use of cellphones which in this study has been used as a proxy for social networking. While ownership of cellphones was arguably found to have significant negative relationship to childhood malaria infection rates, it is unclear how such interaction works. The likely mechanism may be an indication of increased household wealth. Cellphone use in most of sub-Saharan Africa and other relatively poor regions can be an indication of individual's economic strength. Nevertheless, apart from being seen as an indication of wealth, use of cellphones can open up the whole new range of opportunities for improving child health by providing relevant health information including availability of drugs, ITN distribution campaign, appropriate treatment for children's febrile illnesses and others. Cellphones are increasingly being integrated into public health programs as tools for monitoring disease outbreaks, surveillances and also offer important channels for tailored public health messages to communities across sub-Sahara Africa[303, 318]. While education may accelerate the desire to own and use cellphones because of increased confidence to use modern technology, it also enhances social networks, and information sharing and use of various health services [142, 319].

Our findings raise even bigger question on the extent to which formal education imparts knowledge about disease prevention and treatments. Critics have argued that there is very little if any that formal education offers about child health that is of direct benefit to women or students to merit their families when it comes to improving their knowledge about child health, survival and particularly the transmission, prevention and treatment of diseases like malaria. It is further argued that women with some schooling hardly have any different views about their children's health when compared to those without any formal education. Their perception and understanding of etiology, prevention and treatment of diseases like malaria and others are hardly any different [320, 321]. Malaria researchers may also find this claim interesting because despite high coverage of ITNs in sub-Saharan Africa, maternal or household head's education levels have had very little impact on bed-net use across people of all ages [322-325]. Based on these arguments, conclusive statements on pathway through which maternal education may improve women's knowledge about child health, nutrition, vaccination uptakes and disease preventions should be made with some cautions.

However, it is fair to assert that maternal education can impart some general life skills such as how to search for, and access critical health information that may enhance their children's wellbeing. While school curriculum may not teach child-rearing skills, it has the potential to help women mature in a way that empowers them when dealing with different life challenges including healthy children upbringing. Maternal education can help improve women's knowledge about child health and risky signs which in turn leads to better follow-up on important child health issues including immunization schedules and other disease preventive services. Such meticulous follow-ups to prevention and treatment guidelines may not just be because of doctors' instructions, but also their understanding on the importance of adhering to the messages and treatment algorithms

[143, 316]. Additionally, education broadens women's scope to enable them contextualize, understand and synthesize various public health information [326, 327]. In the malaria community, one may argue that maternal education improves their understanding on causes of malaria, the danger signs of childhood febrile illnesses which may enhance their keenness to preventing their children from contracting the disease. Such prevention and treatment measures can involve use of ITNs, use of intermittent malaria treatment during pregnancy and seeking prompt, effective malaria treatment when a child is sick. Finally, maternal education enhances general life skills instilling confidence to troubleshoot and use various modern technologies including mobile phones that far surpasses those with no formal education training. Educated mothers do therefore exhibit unperturbed advantage over uneducated mothers. Studies have argued that the probability for a woman with some little education to explore treatment options for her sick child at a doctor's office is higher than that for a woman without any formal training. This has also been shown to be true in reproductive health studies where education has been shown to empower women to becoming more autonomous [328].

The results in this study imply that the obstacles facing malaria control efforts in sub-Saharan Africa and other parts of the world may not be limited to intricate malaria epidemiology, fragile health infrastructure and financial barriers alone. The larger implications of this study include the need to adopt radical changes in the way malaria control business is being implemented across countries. Malaria researchers and policy makers ought to look beyond malaria control efforts focusing on clinical and epidemiological trends alone to integrating broader socio-economic, anthropologic and educational issues. While investments in understanding malaria epidemiology and improving clinical outcomes for malaria patients is important, we argue that for successful and sustainable malaria control, countries should contemplate to investing in other indirectly related areas such as improving the number of children enrolling and completing primary education particularly women. In order for such a broader agenda to succeed, international malaria funding agencies must be willing and flexible enough in their funding to allow malaria endemic countries some flexibility in using malaria control resources for improvement of school enrollment and completion rates. This in the long term will enhance community commitment and engagement to sustainable malaria control initiatives. Successful malaria control and elimination will only be achieved by adopting broad embracing goals that spurn across different important sectors including the economic and education sectors[329, 330]. Meanwhile, school curricula and education in general has to be continually tailored to adapt to social-cultural landscapes of communities being served and less maladaptive.

This study relied on MIS cross-sectional data in exploring the underlying relationships between maternal education and childhood malaria infections. With cross sectional data it is always difficult to confidently ascribe causal relationships between variables. The existence of multiple confounding factors which are difficult to control given the nature of cross-sectional data makes the task even daunting. It is also fair to say that the study was retrospective and could not collect or use any additional data not contained in the survey. As a result of these limitations, the analysis had to improvise and use proxies which may have misrepresented some of our key variables of interest. Additionally, it is important to note that the pathways outlined in this study may have not been exhaustive enough in fully explaining the interactions between maternal education and childhood malaria infections. Perhaps a more interesting question could also be to explore how societal preferential treatments for educated mothers may play a key role in benefiting such women as they strive to ensure that their children are offered the best health and nutritional services available. An interesting question might focus on exploring whether societal preferential treatments enjoyed by educated mothers play any significant role in improving their children's health relative to the skills acquired through existing education system.

Conclusions

This study found a significant statistical relationship between maternal education and childhood malaria infections. The study further identified and discussed critical pathways through which maternal education associates with childhood malaria infections. Knowledge about child health and economic empowerment offered through education, were key to alleviating the rate of childhood malaria infections to mothers with some primary education or, education level beyond primary school. The Oaxaca decomposition technique showed that there was a gap of roughly 8 percentage points between educated and uneducated mothers leading to increased childhood malaria infections. In the full adjusted model almost 82% of this gap was explained by differences in household wealth, dwelling in rural places, malaria transmission intensity and the level of media exposure.

The findings suggest that investments in malaria control should go hand in hand with encouraging school attendance and completion of at least primary school by all children and more particularly for girls. As shown in this analysis, there is a significant relationship between maternal education level and child hood malaria infections. Malaria control funding agencies should contemplate giving malaria endemic countries enough flexibility to decide how to invest in long term and sustainable malaria control programs. Such flexibility could allow countries to invest in programs like improvement of education and school enrollment and completion which would indirectly enhance malaria control efforts through creating more aware and engaged communities for sustainable malaria control. Much as understanding the epidemiology of malaria remains key for better malaria policy design and implementation, so too, should malaria control programs strive to include non-clinical and epidemiological related issues like incorporating basic malaria control messages in school curricula.

Chapter 6

A comparative study on cost-effectiveness analysis for adopting universal malaria rapid diagnostic tests (mRDT) for children under-five years of age: With Evidence from Malaria Indicator Survey Data in three sub-Sahara African Countries.

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Abstract

Background: In 2010, the World Health Organization issued a new guideline for malaria treatment worldwide. Among others, the guideline calls for universal testing of malaria parasites prior to treatment in patients of all ages. Over the last decade, debates on whether malaria testing should be adopted for children under5 have divided malaria researchers. Economic evidence to support such a strategy especially in settings where donor agencies play a critical role in ensuring successful implementation of such policies remains sparse. This study explores whether adoption of Rapid Diagnostic Tests (mRDT) for malaria treatment in children under-five years of age would be a cost effective strategy given the variations in malaria epidemiology across sub-Saharan Africa and also the culture of clinical practice which oftentimes ignores test results even in cases where such tests are accurate.

Methods: We used Malaria indicator survey (MIS) data from three countries with varied malaria epidemiology to determine the prevalence of malaria in children under5. Additionally, we used drug and mRDT cost data from each of the three countries. Furthermore, additional secondary clinical data on mRDT and antimalarial effectiveness as well as clinical practices were gathered from existing literature. In cases where data were missing we relied on experts opinions. Data were uploaded in TreeAge decision tree software to determine the costs and cost-effectiveness of using mRDT relative to presumptive malaria treatments.

Results: Adoption of mRDT strategy for malaria treatment in children under-five years of age was found to be cost effective across the three study countries relative to presumptive treatment strategy. However, the threshold for mRDT effectiveness was variable across the three countries. For instance, adoption of mRDT strategy in Angola was found to be cost effective from as low as 5% under5 malaria prevalence to as high as 78% prevalence level. In Uganda, the strategy was only effective up to around 65% of under5 malaria prevalence whereas in Tanzania adoption of mRDT strategy was only effective as long as the under5 malaria prevalence did not exceed the 36% threshold.

Conclusion: mRDT strategy was variably cost-effective relative to presumptive malaria treatment strategy across all three study countries. Our findings also established that local factors, including malaria prevalence, cost of testing supplies, the volumes of patients seeking care at primary health facilities and clinician's compliance were critical in determining the level of cost-effectiveness mRDT strategy could achieve. Efforts to evaluate mRDT strategy with particular focus on appropriate storage, use and compliance to the test results should continue to be pursued for effective resource use.

Introduction

In the year 2010, the World Health Organization (WHO) issued a new malaria treatment guideline with bold recommendation for universal malaria testing to patients of all ages prior to administering any treatments[24, 182]. Despite issuance of these guidelines, malaria endemic countries have been slow to adopt universal malaria testing especially in young children. Reactions to the new policy guideline by researchers and malaria policy makers have been ambivalent because of programmatic and technical policy implementation challenges [77, 78, 331, 332] .

Critics of universal malaria testing argue that the strategy is difficult to implement and would put lives of those intended to be saved in more vulnerable situations[78, 184]. The capacity for malaria endemic countries to effectively use microscopy at every point of care is inexistent and the newly deployed malaria Rapid Diagnostic Tests (mRDT) have been shown to have low sensitivity rates which could potentially lead to higher mortality rates especially among children-under5[76, 333, 334]. Studies have also reported low adherence to malaria test results by clinicians which in turn may result to the strategy being less cost-effective relative to presumptive treatments strategy[335-337]. Moreover, most malaria endemic countries have relied on external sources of funding for improvement of malaria case management programs including the rollout of artemisinin-based combination drugs and also implementation of mRDT. Over dependency on external funding for malaria control activities have resulted into some donors cherry-picking malaria programs they prefer to support. Such practices have resulted to delays in implementation of the new treatment guideline package. There is also some concern that there is limited information on cost-effectiveness of mRDT use and other program implementation challenges especially in children-under5[331] . This study aims to address this gap by exploring the cost-effectiveness of mRDT use relative to presumptive treatment for malaria in children-under5 in three sub-Saharan Africa countries with varying degrees of malaria prevalence. The rest of the study is organized into background literature review, description of the study countries, analytical methodology, presenting study results and discussions of the results, and finally conclusion and policy recommendations.

Despite multiple studies which indicate that a significant proportion of febrile patients are treated for malaria in the absence of parasitemia, presumptive treatment of malaria based on a history of fever in all patients was the bedrock policy for malaria management in virtually all malaria endemic countries[27, 173, 186]. Historically, there was little opposition to this treatment strategy and complacency to this policy was enhanced given that antimalarial drugs were cheap whereas, malaria diagnostic tools were unaffordable, nonexistent or too difficult to implement. Critics of the strategy argued that presumptive malaria treatment policy resulted in adverse economic and clinical consequences especially in many poor families living in areas with high malaria burden [26, 30, 167, 338]. Presumptive strategy resulted to unnecessary use of antimalarial drugs especially when febrile illnesses were unrelated to malaria parasites[81]. It also resulted to delays in getting appropriate treatment as patients were misdiagnosed and treated for malaria when they actually had none. Moreover, because of delayed treatment, many patients especially young children were dying for diseases that could have been properly treated if appropriate and timely diagnosis was completed.

Following the clinical and economic shortfalls of presumptive malaria treatment, the endorsement of the new WHO policy is widely seen as a necessary step to improve malaria case management[339, 340]. The new policy's calls for a more restrictive use of newly introduced antimalarial combination drugs has the potential to mitigate the spread of drug resistance problem as it aims to ensure that inappropriate antimalarial drug use is abated. Importantly, patients with non-malarial fevers are better placed to receive improved and more accurate diagnoses and consequently appropriate treatments [24, 341, 342]. Improved malaria case management has an indirect benefit in terms of better management of non-malarial illnesses which otherwise may not be appropriately addressed under a presumptive treatment strategy and consequently lead to poor outcomes, especially in terms of child survival. Finally, it is important to also mention that the technology to appropriately diagnose malaria has substantially improved over the last decade with cheap and easy to use new technologies like one relying on use of malaria rapid diagnostic tests (mRDT).

While the new policy has the potentials for superior clinical and economic benefits to both households and governments [26], its implementation process has been slow with mixed response from clinicians and policy makers. The mixed response has been partly because of the limited evidence available to guide decision makers on the relative cost-effectiveness of presumptive treatment and existing diagnostic tools, and also poor policy implementation strategy on by malaria endemic countries[167, 343]. Given the continued reliance on international donors and the magnitude of infectious disease burden experienced in most malaria endemic countries, information on program cost-effectiveness is vital for policy makers when allocating the competing public health needs.

In this study we propose to use a decision tree model and probabilistic sensitivity analyses to explore whether the adoption of universal mRDT would be a more cost-effective strategy than the traditional presumptive treatment strategy for children less than five years (Children-under5). We are specifically focusing on children in this age group because of their elevated risk for contracting malaria and disproportionate burden of malaria-specific morbidity and mortality that they bear. The study uses malaria prevalence benchmarks based on the household malaria indicator survey (MIS) data from three sub-Saharan Africa countries of Angola, Tanzania and Uganda. The advantage of analyzing MIS data from the three countries is in their malaria epidemiological differences and also their varied populations reflected by their diverse socioeconomic, political and health systems. Moreover, given the wide variations of malaria epidemiology across the study countries, places with low level of malaria infections will still have many patients associated with clinical malaria in children under-5. In such situations, implementing a cost-effective strategy with better malaria diagnosis may result not only in saving lives but also saving resources which otherwise, would be wasted. Details on the MIS survey are provided in the subsequent methods section.

Methods

Study Area

This study is based on MIS data obtained from three countries in sub-Saharan Africa which include; Angola, Tanzania and Uganda. The countries constitute the first cohort of countries with high malaria burden funded by the US government's President

Malaria Initiative launched in the year 2005. According to United Nations Population Fund, the combined total population for the three countries was approximated at 98 million people in 2010. Approximately 1/3 of this total population consists of children under-5, with nearly 50% of the total population under the age of 18. It is estimated that 95% of the populations in each of the three countries are at risk of contracting malaria disease as they experience moderate to high malaria transmissions. Indeed, it is estimated that malaria is responsible for approximately 30% of all deaths in children under-5 in these three countries [18, 202]. Prior to issuance of the 2010 World Health Organization guideline on malaria diagnosis, almost 90% of all fevers in children under-5 were treated presumptively in all three countries. Following the diverse malaria epidemiologic backgrounds shared by these countries, the presumptive malaria treatment strategy resulted into some malaria misdiagnoses as well as misuse of antimalarials whenever children did not have any malaria fevers.

Description of study design and data

The study compares the use of mRDT versus presumptive malaria diagnosis and treatment strategy in children aged 6 -59 months in the three study countries. The decision tree charted in figures 1 to 4 below follows an individual patient from diagnosis and treatment of malaria to the final health outcomes shaped by the sensitivity and specificity of each strategy and level of malaria prevalence. The incremental costs and health outcomes in each of the two strategies are calculated according to this structure and according to all possible levels of prevalence of malaria parasites among febrile outpatients (children-under5) presenting at facilities. Rather than describing all possible parameters affecting the choice of a given diagnostic strategy, this study aims at capturing the influence of key variables on cost-effectiveness and the relationships between them. Such variables as cost of drugs, cost of mRDT kits, prevalence of malaria and clinicians compliance to mRDT test results are decisive in establishing either strategy's cost-effectiveness.

For the malaria prevalence data, the study used the national MIS data from the three countries. To ensure national representation, MIS data are based on three stage cluster sampling approach. In the first stage communities are selected based on administrative and population sizes, the second stage selection focused on rural and urban populations mix and finally the third stage involved a systematic random sampling of households from a list based on previous national census surveys. All eligible individuals within the households and consenting to the interview were interviewed and blood tests for malaria infections were taken from all eligible children under-5. A histidine-rich protein 2 (HRP2) Rapid Diagnostic Test (mRDT) for malaria was used to perform the tests in both Angola and Tanzania whereas in Uganda mRDT malaria test results were further validated and parasites quantified by use of laboratory microscopy. For the purpose of this analysis, mRDT diagnostic strategy is believed to be the most feasible strategy that can achieve universal access to parasite-based diagnosis for populations at risk of malaria as recommended by WHO official document outlining guidelines for malaria diagnosis[24]. The complexities and logistics necessary for accurate and reliable use of microscopy makes it difficult to use the strategy in large scale in any foreseeable future given the weak and fragmented health systems in the sub-Saharan Africa. Therefore, the cost-effectiveness model in this study only considers the use of mRDT relative to presumptive treatment strategy and we did not make any considerations for use of light microscopy in malaria diagnostic.

Malaria Infections: From the MIS data, results on malaria infection rates in children under-5 were used to model the cost-effectiveness of mRDT diagnostic and treatment strategy relative to presumptive treatment. In addition to malaria infection rates, household response to a child with fever in the past two weeks was used as a proxy to determine prevalence for assumed malarial fevers and care seeking patterns. In this analysis, we make a simplistic assumption that children reported with fevers are either malaria positive or, do have bacterial/viral infections[344]. In line with previous studies and for simplicity purposes, we did not assume any co-infections for both malarial and bacterial/viral caused illnesses[186]. Patients with fever are treated for malaria under presumptive treatment strategy whereas; under mRDT diagnostic and treatment strategy, only malaria infections confirmed cases are treated with antimalarials. Otherwise, they are given antibiotics for treatment of bacterial/viral caused fevers. In this analysis, the malaria infection rates for each country were estimated at 25% in Angola, 18% in Tanzania and at 42% in Uganda. These estimates are based on numbers obtained from households Malaria Indicator Survey data. All other fevers were assumed to be non-malarial fevers and prescribing antibiotics to treat these fevers was assumed to be the correct prognosis [78, 339] .

Costing: The costing of this study was undertaken from provider's perspective (government ministry or donor agency) at the health facility level and restricted to only two visits, assuming incorrect or treatment failure on their first visit to healthcare provider. The perspective is adopted because of the fact that governments and international partners continue to be heavily involved in providing care to majority of the people in sub Saharan Africa. Most of the costs of providing care are therefore solicited from governments and donors and for this reason; the policy implications are more relevant to health care providers than to end users of the services. The costs provided are only incremental costs incurred for purchase of drugs and the mRDT kits and are all from the provider perspective. Other costs such as infrastructure, supervision, training, and health workers salaries were assumed to be fixed. Technically, health workers would require some training on the use of mRDT but the implementation of Integrated Management of Childhood Illnesses (IMCI) under presumptive treatment also required training and retraining over long periods of time. Following these trainings, we assumed that both components would equally require some training and since most costs associated with such training were unavailable, we assumed them fixed and equally distributed across the two diagnostic strategies. Training is also tied to improvement of quality of care across different programs and sometimes would occur concurrently.

For the cost of purchasing mRDT kits, antimalarial and antibiotic drugs, both manufacturers' cost and those relating to distribution of these supplies were included in the costing model. Following the drug distribution costs, there were wide variations across the three countries based on the strength of country-specific drug distribution infrastructure. Typically, drug costs per child dose for malarial or non-malarial fevers were obtained from official national malarial control programs in each of the three study countries. However, because of unreliable government financing for most health programs, most primary health facilities experienced drugs and supplies stock outs. Donor partners including Global Fund to Fight AIDS, Tuberculosis and Malaria (Global

Fund), PMI and other bilateral agencies had to assist with the purchase and distribution of antimalarials and mRDT in each of the three study countries[†††]. In Angola where the government drug delivery system was unreliable, a parallel system has to be put in place to ensure that both drugs and mRDT were safely delivered at primary health facilities. This is also part of the reason why this analysis focuses on provider perspective and remains relevant especially to external program funding agencies.

While the artemisinin-based combination drugs manufacturers have reduced the prices of these antimalarials to an average of $1.00 per adult dose, the pharmaceutical companies have included some penalties/incentives to encourage countries to place their orders at least 3 months in advance to expected delivery dates. Therefore, the level of logistic efficiency exhibited by governments in placing these orders determines the prices paid by these countries for purchase of antimalarial drugs. Because of country differences, antimalarial drug purchase prices for Angola were averaged at $1.50 per child dose while in Tanzania and Uganda the average prices were $0.95 and $1.10 respectively. Meanwhile, each of the three countries had their own drug and medical supplies distribution challenges. For instance, following the country data obtained from the three study countries respective ministries of health and/or donor agencies, Angola had the most expensive drug distribution mechanism resulting to the cost of a dose of antimalarial averaging at $ 12.50 whereas in Tanzania and Uganda, the national medial stores departments charged an additional margin of 10-15% of the drug value as storage and distribution cost. However, oftentimes non-government organizations have been used

[†††] Discussions with PMI Resident Advisors in Angola, Tanzania and Uganda indicated that PMI assisted with procurement and distribution of mRDT at the beginning of the implementation of the policy in each of the three countries. PMI also purchased Artemisinin-based combination drugs for all three countries at one time or several occasions to help curb the antimalarial drug stock out problem experienced in all three countries.

by donors to accelerate drug distribution to health facilities in remote districts. Because of this, the drug distribution costs in Uganda were estimated at 20% of the original drugs and mRDT kits purchase price.

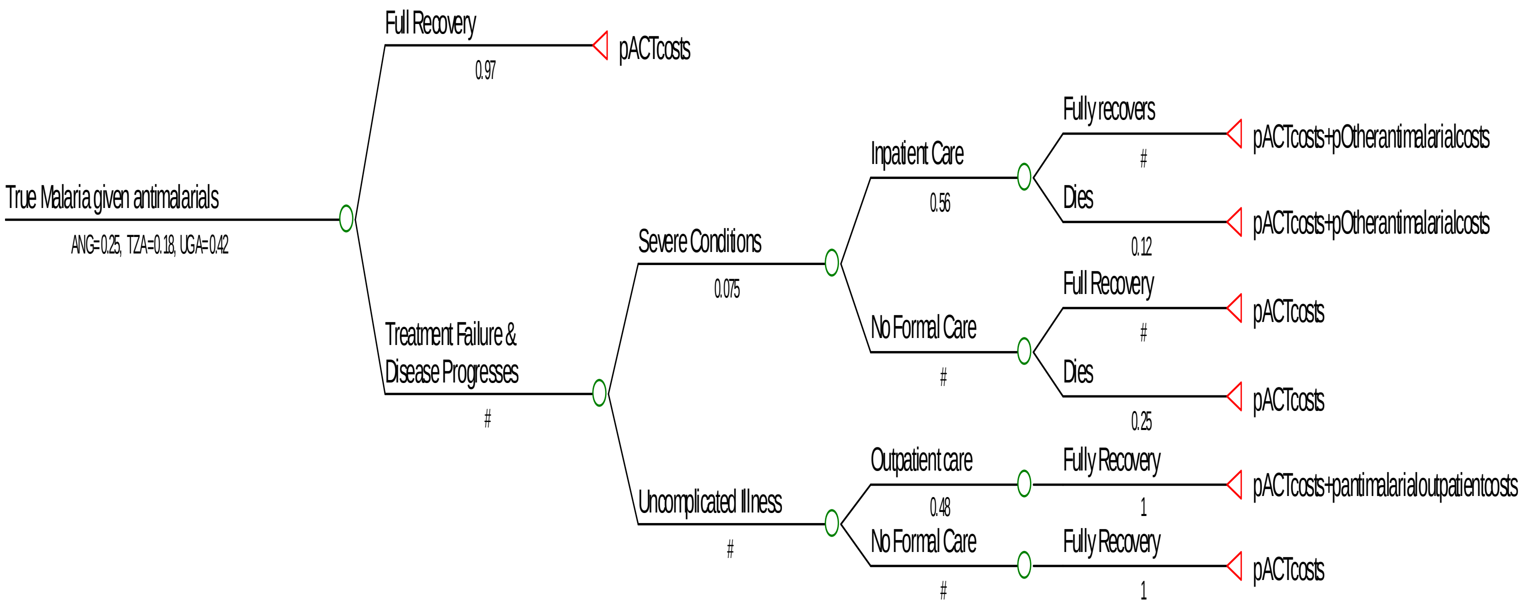
Analytical Approach

We used TreeAge Pro suite 2009 decision tree software: *(Copyright©1988-2009 TreeAge Software, Inc., 1075 Main Street Williamstown, MA 01267)* to develop malaria diagnosis and treatment decision pathways. The decision tree begins with ambulatory care at health facilities for all children under-5 with history of fever. We assume that upon arrival at the clinic children are diagnosed and treated for their disease by either presumptive diagnosis or by use of rapid diagnostic malaria test. The decision tree outlined in figures 1 – 4 below follow individual patients from diagnosis and treatment to outcomes based on the assumptions, sensitivity and specificity of either of the two strategies and the level of malaria prevalence. The incremental costs and proper case identification and treatment under each strategy are calculated according to the outlined structure that is according to all possible levels of prevalence of parasitemia among outpatient pediatric children with febrile illness presenting at health clinics. Rather than describing all possible parameters affecting the choice of diagnostic strategy, the study model aims to capture the influence of key variables on cost-effectiveness, and the relationships between them. The analysis uses retrospective cost effectiveness in exploring the use of mRDT versus presumptive malaria treatment in pediatric children.

For the completion of the decision tree pathways, variable needed included: (i) the prevalence of all cause fevers in children under5 for each of the three study countries, (ii) prevalence of malaria infections adjusted for each country's transmission intensities, (iii) proportion of ambulatory childhood fevers presumptively treated for malaria, (iv) proportion of ambulatory childhood fevers with actual malaria parasites, (v) proportion of childhood fevers correctly treated for malaria presumptively and also those correctly treated for malaria under the mRDT strategy (vi) proportion of children recovering fully after they receive their first treatment, (vii) proportion of treatment failures progressing to severe conditions, (viii) proportion of children being admitted because of their fevers progressing to severe conditions, (ix) proportion of children with severe conditions dying after receiving treatment, (x) proportion of children with severe conditions dying before they seek additional treatment, (xi) proportion of childhood fevers not progressing to severe condition but seeking additional care and receive proper treatment, and finally, (xii) proportion of children with uncomplicated fevers not seeking additional care but still fully recover from their ailments. The variables with their baseline values and the original source of the values as used throughout the decision tree pathways are attached in the end of the document as appendix 1.

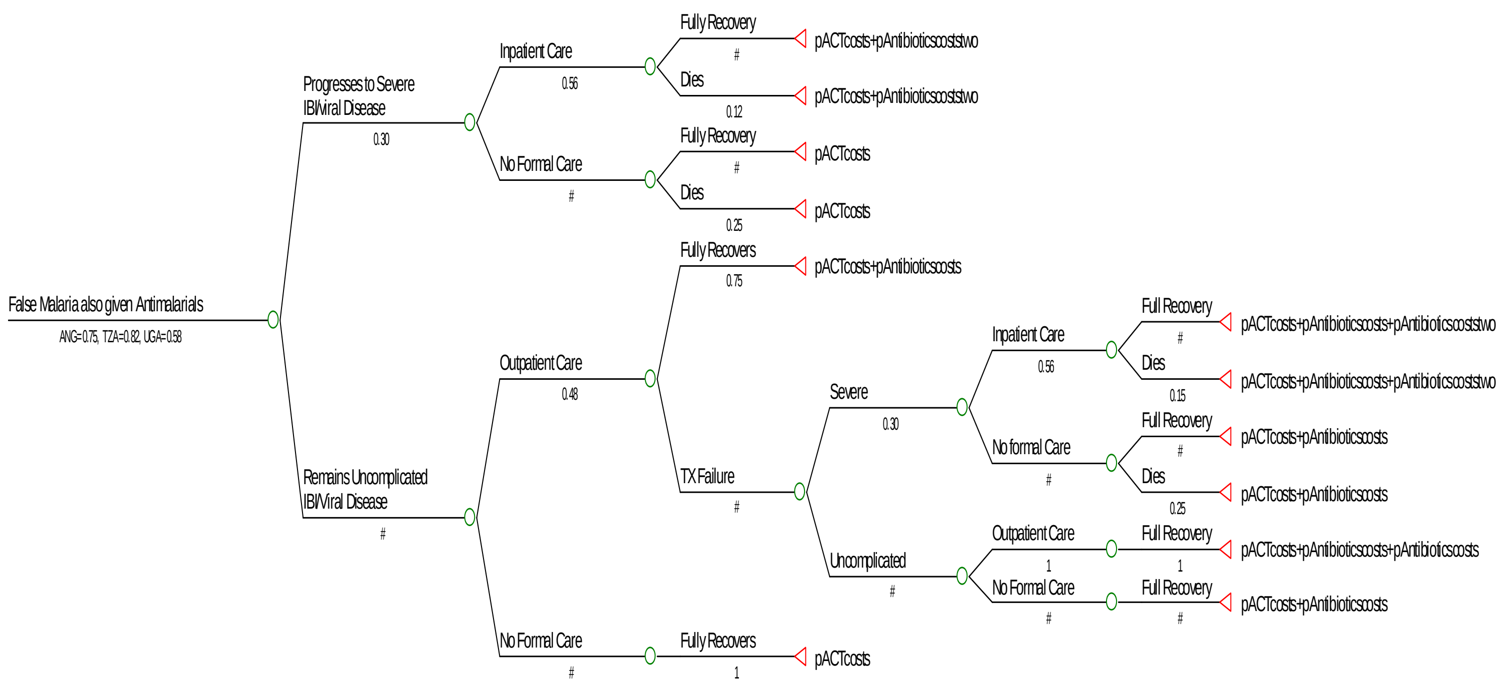
We imputed these values in the decision trees described in figures 1 – 4 below. Figure 8 outlines the decision pathways for all children with malaria parasites given antimalarials after presumptive diagnosis strategy. Important to mention is also the fact that upon visiting the health clinic for the first time, all children diagnosed with malaria either through presumptive or mRDT were assumed to receive effective artemisinin-based combination drugs as their first treatment option. Artemisinin-based combination drugs were also assumed to be 97% effective in clearing malaria parasites in children [345, 346].

Figure 8: Decision pathways for pediatric fevers correctly treated for malaria



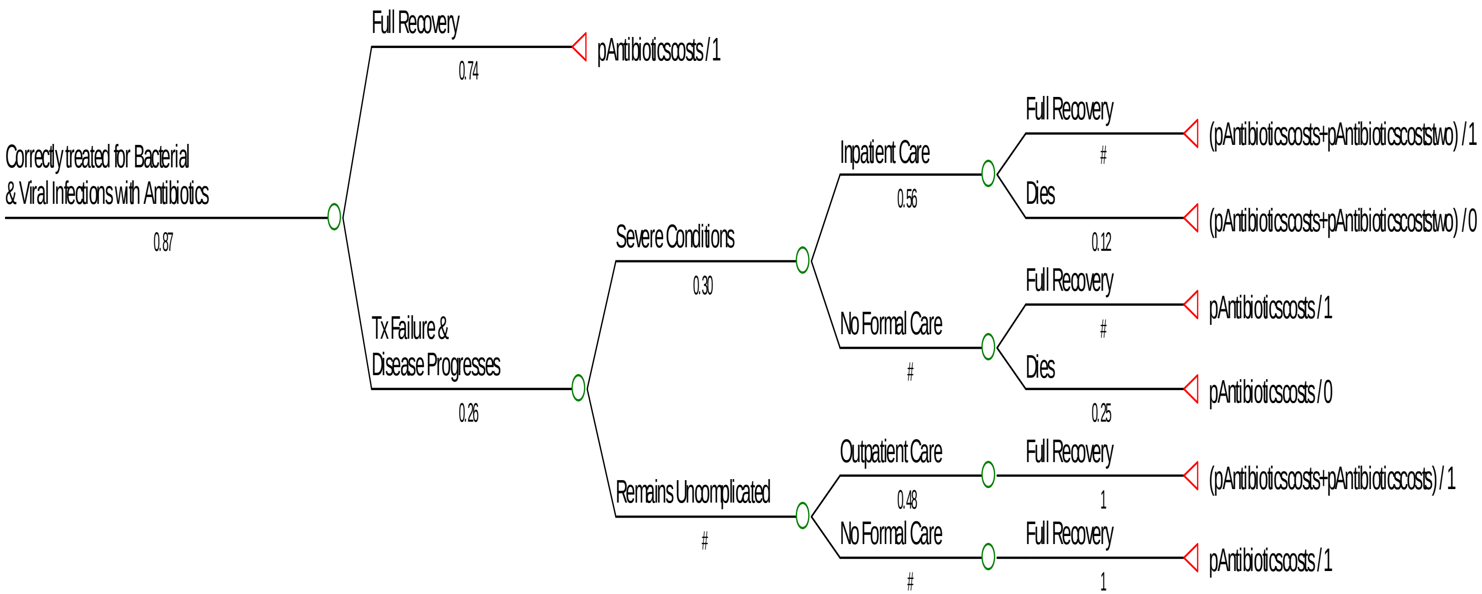
We further assumed that of those children incorrectly treated with antimalarials at least 30% of them would exhibit signs of the disease progressing to severe condition. 56% of them will seek care and be admitted [32, 347]. Of those whose conditions did not progress to severe illnesses, only 48% were assumed to seek additional care at formal health clinics. Based on past studies and expert opinions, we assumed that 12% of inpatients in this group will die and the rest will completely recover [347, 348]. Following limited information on proportion of children recovering with neurological sequelae, we excluded such options in our final decision tree model. We also assumed that 75% of children under-5 receiving antibiotics will completely recover while the remaining 25% will endure treatment drug failures as outlined in figure nine[186].

Figure 9: Decision pathways for pediatric non-malarial fevers treated with antimalarials



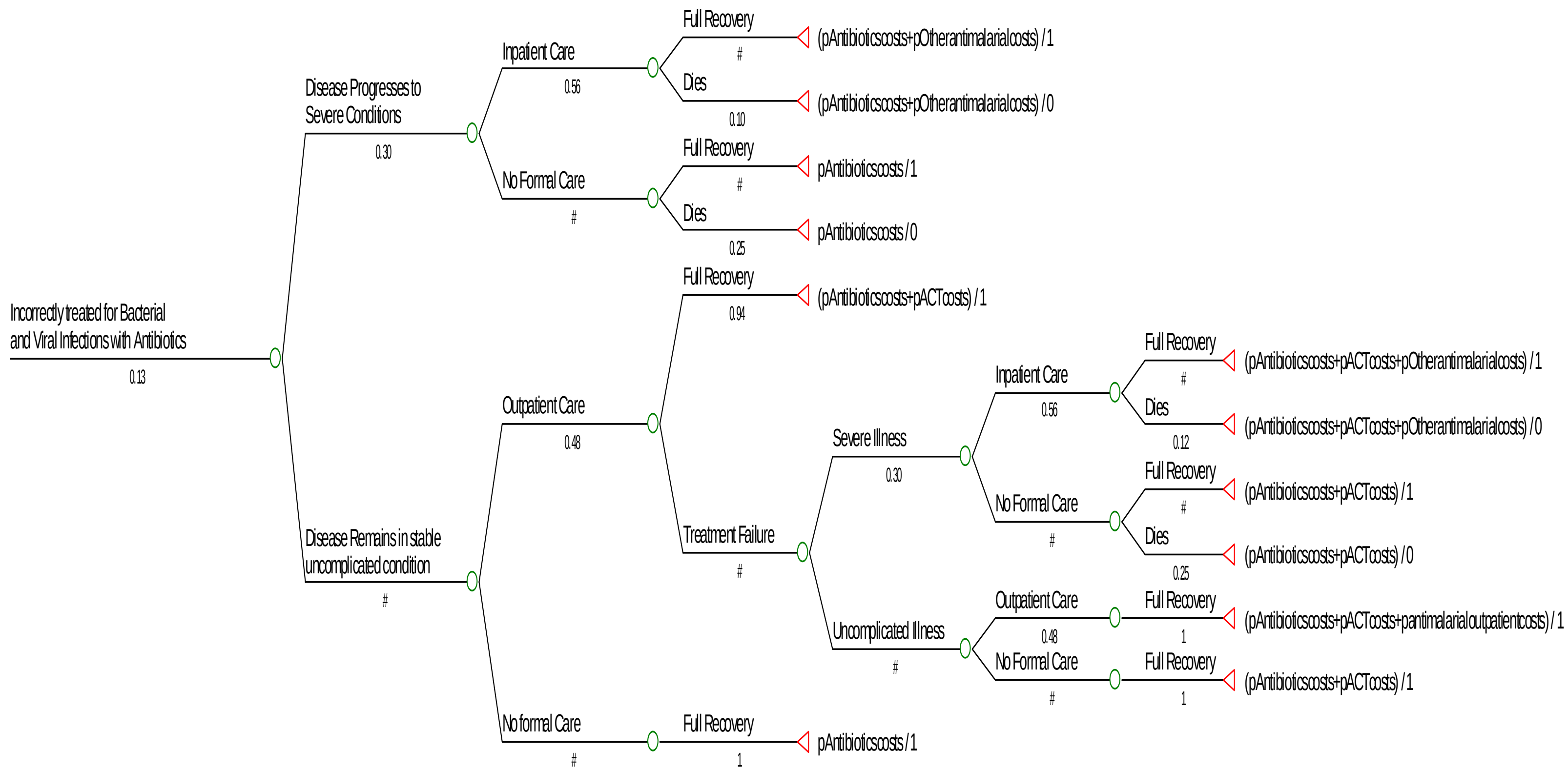
We assumed that less 11% of children presenting with fever at health facilities will be treated for bacterial and/or viral illnesses under presumptive malaria treatment strategy [349, 350]. For those under the mRDT diagnostic strategy, up to 96% of children with fever will correctly receive antibiotics for treatment of bacterial and/or viral infections. Based on past studies, the efficacy of antibiotics was assumed to be much lower than that for first-line antimalarial drugs of choice (assumed to be artemisinin-based combination therapy). Antibiotic efficacy rate was therefore assumed to be 74% resulting to 26% treatment failure[186]. We also assumed that the proportion of children under-5 seeking care for the second time to be less than 50% as exhibited in figure three below.

Figure 10: Decision pathways for pediatric non-malarial fevers correctly treated with antibiotics



While we assume that health workers incorporate the diagnostic test results in their clinical decision making, we also make a realistic assumption that a fraction of children presenting with fever but receiving negative mRDT malaria infection results may still receive antimalarial drugs. We also assumed that at least 4% of positive mRDT tests may actually contain no malaria parasites even though they will be prescribed with antimalarial drugs. We explored the decision tree pathways for such malarial and non-malarial fever patients as outlined in figure four. The probabilities for being treated with effective antimalarial drugs, adherence to prescribed drugs as well as that for disease progression to severe illnesses plus adverse outcomes are obtained from various published and unpublished studies as well as expert opinions from renowned malaria researchers.

Figure 11: Decision pathways for pediatric malaria fevers incorrectly treated with antibiotics



Effectiveness Indicator and cost-effectiveness measure*:* The effectiveness of either strategy is measured through the ability for each strategy to properly identify and treat any pediatric malaria case presented at the clinic. Therefore, treatment outcome was assumed to be proper malaria case diagnosis and treatment resulting to *survival* or *death* of the child as an effective outcome. These outcomes were based on estimated fatality probabilities established from past childhood malaria and bacterial infections literature [347, 351, 352]. Presumptive treatment on the basis of fever history was assumed to have perfect sensitivity and zero specificity whereas, mRDT was assumed to be 94% effective in detecting *plasmodium falciparum* malaria parasites with a specificity and sensitivity of 95% and 96% respectively [353-356]. Therefore by proper malaria diagnosis we simply referred to correct detection of malarial fevers or sensitivity and also correct exclusion and treatment of non-malarial fever cases or specificity. For the cost-effectiveness, the study estimated the average cost effectiveness ratio (ACER) and the incremental cost-effectiveness ratio (ICER). In calculating for ACER, the total cost of diagnosis and treatment under either strategy was divided by the probability of correctly treating and saving lives of children under-5 with reported malarial and non-malarial fevers. The rationale for this analysis is that national malaria control programs would wish to identify less costly malaria treatment options than the comparator as long as these interventions yield better health outcomes (dominant) over those that are less effective and more costly (dominated).

Sensitivity Analysis*:* Following the relative strength of some of our variables on the performance of the model, we identified six important variables to test for their sensitivities upon parameter variations. For instance increasing the proportion of children exhibiting severe health conditions after their first visit to clinic for treatment of febrile fever could affect child survival outcomes. Changes in the proportion of children with febrile with positive malaria tests may also impact the model outcomes. Also, the variations in the prices of antimalarial drugs and mRDT further affected the model outcome as well as changes in the clinicians' practices in terms of adherence to mRDT test results were determined to have huge impact on the model outcomes. Moreover, the proportion of patients deciding to make a second visit to any healthcare provider was considered an important driver of overall costs of treatment. For instance, an increase of the proportion of patients seeking additional care from 48% to say 60% could see a rise in average treatment costs dependent on how accurate the initial disease diagnosis was performed.

After conducting multiple sensitivity tests, we settled on fewer parameters with larger and more responsive impact on the cost-effectiveness model outcomes. The variables selected for final sensitivity tests include; changes in mRDT prices, changes in prices of antimalarial drugs, clinicians' adherence to malaria test results, changes in the proportion of children with non-malarial fevers and improvements in care seeking behaviors for pediatric fevers. We conducted both one way and, two-way sensitivity analyses and monitored the behavior of the model based on performance of the tests. Prices for mRDT were varied widely to establish the lower and upper thresholds upon which adoption of the strategy would be cost effective.

Results

Overall adoption of mRDT strategy for malaria treatment was cost-effective or dominant over presumptive malaria treatment strategy at relatively lower levels of malaria prevalence in all three countries. Owing to differences in the prices of antimalarial drugs and mRDT kits, adoption of mRDT diagnostic strategy relative to presumptive treatment was variably cost-effective across the study countries. For instance in Angola, adoption of mRDT was found more cost effective as it yielded the strategy effectiveness of 0.987 at the average cost of US$7.30 while adoption of presumptive malaria diagnostic strategy cost an average of US$14.00 with a lower 0.956 effectiveness assuming no child with fever tested positive with malaria parasites. In Tanzania the average cost of implementing mRDT strategy was US$1.42 with estimated 0.993 effectiveness rate whereas, presumptive malaria diagnostic strategy cost slightly more at US$ 1.52 with estimated 0.953 rate of effectiveness. Finally, in Uganda, the adoption of mRDT strategy cost an average of US$ 1.10 with estimated effectiveness rate of 0.987 compared to use of presumptive malaria treatment strategy which on average cost almost US$ 2.00 to yield a relatively lower effectiveness rate of 0.962.

Table 7: Input parameters considered in choosing the most cost-effective strategy between RDTs and Presumptive malaria diagnosis and treatment - Baseline and Sensitivity analyses

Choice of RDT over Presumptive Diagnostics in the three countries given their malaria epidemiology			
General Input Parameters	*MIS Baseline*	*Lower Limit*	*Upper Limit*
Treatment seeking for uncomplicated illnesses	48%	35%	80%
Treatment seeking for severe illness	56%	45%	88%
Clinicians' Compliance to test results	75%	50%	90%
ANGOLA			
Country specific parameters	*MIS Baseline*	*Lower Limit*	*Upper Limit*
Malaria Prevalence	25%	05%	78%
Cost of RDT (US$2.00 – 7.00)	2.70	$2.00 or less	3.00 or less
Treatment seeking for uncomplicated illnesses	48%	38%	Any level
Non-Malarial febrile illness-NMFI (50-95%)	75%	Any level	<87%
Malaria infection progressing to severe (0.05-40%)	7.5%	Any level	Any level
NMFI progressing to severe (15 – 50%)	17%	Any level	<40%
Clinician compliance to test results (50 – 100%)	75%	64%	Any level
TANZANIA			
Country specific parameters	*MIS Baseline*	*Lower Limit*	*Upper Limit*
Malaria Prevalence	18%	05%	36%
Cost of RDT (US$ 0.20 – 2.00)	$0.50	$0.65 or lower	$0.65 or less
Treatment seeking for uncomplicated illnesses	48%	34%	Any level
Non-malarial febrile illnesses –NMFI (0 – 95%)	82%	Any level	<81%
Malaria infection becoming severe (0.07 – 40%)	7.5%%	Any level	<37%
NMFI (bacterial) becoming severe (20 – 50%)	17%	Any level	Any level
Clinicians compliance to test results (0 – 100%)	75%	>75%	>93%
UGANDA			
Country specific parameters	*MIS Baseline*	*Lower Limit*	*Upper Limit*
Malaria Prevalence	42%	05%	65%
Cost of RDT (US$ 0.30 – 2.00)	$0.70	$1.30 or less	$1.30 or less
Treatment Seeking for uncomplicated illnesses	48%	45%	Any level
Non malarial febrile illness – NMFI (0 – 95%)	62%	Any level	<82%
Malaria infection becoming severe (0.07 – 40%)	7.5%	Any level	<32%
NMFI (bacterial) becoming severe (20 – 50%)	17%	Any level	Any level
Clinicians compliance to test results (0 – 100%)	75%	>72%	>90%

Following the incremental cost-effectiveness analysis, indicated that adoption of mRDT strategy was more cost effective relative to presumptive strategy across all three countries. In each of the three countries, adoption of mRDT strategy was cost effective as long as the proportion of children diagnosed through mRDT was less than 78%. In Angola adoption of mRDT strategy relative to presumptive malaria treatment was more cost-effective from 0% up to 78% of malaria infection rates in children under-5. In Tanzania mRDT strategy was more cost-effective relative to presumptive treatment of malaria up to childhood malaria infection rate of 36% only. Meanwhile in Uganda, the adoption of presumptive malaria treatment was more attractive relative to mRDT strategy after malaria infection rates in children under-5 crossed the threshold of 65%.

Figure 12: Average Cost for Diagnosis and Treatment of Malaria and Non-Malarial Fevers by Use of Either of the two Strategies

Malaria Prevalence	Diagnostic Strategy	Cost	Incr. Cost	Effect	Incr. Effect	Average C/E	Incr C/E (ICER)
ANGOLA							
0%	RDT	$7.30		0.99 Case		7$/Case	
	Presumptive	$14.60	$7.30	0.96Case	0.03 Case	15$/Case	230$/Case
25%	RDT	$10.50		0.99 Case		10$/Case	
	Presumptive	$14.55	$4.05	0.96 Case	0.03 Case	15$/Case	135$/Case
50%	RDT	$12.00		0.99 Case		12$/Case	
	Presumptive	$14.70	$2.70	0.96 Case	0.03 Case	15$/Case	56$/Case
75%	Presumptive	$14.70		0.96 Case		15$/Case	
	RDT	$14.93	$0.18	0.99 Case		15$/Case	(Dominated)
100%	Presumptive	$14.80		0.96 Case		15$/Case	
	RDT	$17.40		1.00 Case		17$/Case	(Dominated)
TANZANIA							
0%	RDT	$1.30		0.99 Case		1$/Case	
	Presumptive	$2.50	$1.20	0.95 Case	0.03 Case	2$/Case	3$/Case
25%	RDT	$2.00		0.99 Case		2$/Case	
	Presumptive	$2.50	$0.08	0.95 Case	0.04 Case	2$/Case	1$/Case
50%	Presumptive	$2.38		0.95 Case		2$/Case	
	RDT	$2.60	$0.22	0.99 Case		2$/Case	(Dominated)
75%	Presumptive	$2.20		0.95 Case		2$/Case	
	RDT	$2.75	$0.55	0.99 Case		2$/Case	(Dominated)
100%	Presumptive	$2.10		0.95 Case		2$/Case	
	RDT	$3.00	$0.70	1.00 Case		2$/Case	(Dominated)
UGANDA							
0%	RDT	$1.50		0.986 Case		1$/Case	
	Presumptive	$3.00	$1.50	0.963 Case	0.023 Case	3$/Case	32$/Case
25%	RDT	$1.82		0.989 Case		1$/Case	
	Presumptive	$2.77	$0.85	0.963 Case	0.026 Case	3$/Case	17$/Case
50%	RDT	$2.10		0.992 Case		2$/Case	
	Presumptive	$2.00	$0.10	0.963 Case	0.029 Case	2$/Case	5$/Case
75%	Presumptive	$2.15		0.963 Case		2$/Case	
	RDT	$2.40	$0.05	0.995 Case		2$/Case	(Dominated)
100%	Presumptive	$2.30		0.963 Case		2$/Case	
	RDT	$2.75	$15.00	0.998 Case		2$/Case	(Dominated)

We performed two simple analyses to look at the effectiveness of either of the two strategy given one outcome variable, that is survival outcome or average cost per properly identified and treated case. Looking at survival outcomes, the probabilities for improvement of child survival rates after adoption of mRDT strategy were higher when compared to adoption of presumptive diagnostic treatment strategy. In all three countries, mRDT strategy yielded higher survival probability than presumptive malaria treatment strategy which consistently exhibited inferior survival probabilities of about 0.95 compared to mRDT strategy which had survival probabilities of above 0.985. In terms of the average cost of either strategy given proper case diagnosis and treatment, there were some cost variations and cutoff points for adoption of either of the two strategies across the three countries. The results showed that in Angola, mRDT strategy was cheaper relative to presumptive malaria diagnosis and treatment from 0% parasitemia level in pediatric fevers up to 70% of positive malaria parasites found in all pediatric fevers presenting at primary health care facilities. Meanwhile, in Tanzania the adoption of mRDT strategies relative to presumptive strategies was cheaper given that the rate of pediatric fevers with positive malaria parasites ranged from 0% to 40%. Finally, adoption of mRDT strategy in Uganda was preferred relative to presumptive malaria treatment as long as confirmed malaria parasites in all pediatric fevers did not exceed 63% among children seeking care at primary healthcare facilities.

Results from the sensitivity analyses

We performed additional analyses exploring various real-world scenarios to test the strength of our findings on the cost-effectiveness of mRDT strategy relative to presumptive treatment strategies. We conducted multiple sensitivity analyses which included multiple parameters such as increasing the proportion of children with severe malaria or non-malaria fevers, changes in under-5s mortality rates caused by severe malaria and non-malaria fevers, increased proportion of children with malaria positive results, variations in prices of mRDT, improved healthcare seeking behaviors as well as improved adherence to treatment regimen by both patients and clinicians. Based on the potential impact of the findings, we hereby present results for increased level of proportion of children reporting positive malaria results, improvement of health care seeking behavior and also mRDT price variations.

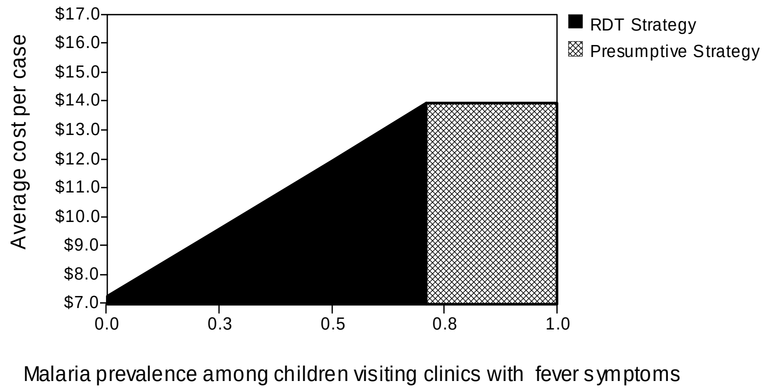
Proportion of children under5 fevers with positive malaria infections: Our estimates showed that the probability of a child with fever at 95% confidence intervals as follows: Angola at 0.247 [with [CI: 0.270 – 0.415], in Tanzania the probabilities were 0.183 [CI: 0.341 – 0.406] and finally in Uganda the probabilities were 0.418 [CI: 0.352 – 0.414]. Following these baseline malaria prevalence, we assumed a scenario with two extremes of having very low level of malaria positive rates and relatively higher level of children with malaria positive rates. We began with a lower bound scenario where malaria positive rates for all children with fever visiting at health facilities was only 5% and tested whether mRDT strategy would be cost-effective relative to presumptive treatment strategy. Assuming all other factors were held constant, the adoption of mRDT strategy at a given 5% malaria prevalence level was highly cost-effective relative to presumptive malaria treatment strategy across each of the three countries. Meanwhile on the upper bound, adoption of mRDT strategy for malaria treatment given a 95% level of malaria positive rates in children under5 with fever was not economically attractive. In

Angola, adoption of mRDT strategy was not cost-effective after crossing the 78% malaria prevalence level. In Tanzania the mRDT strategy was less attractive once malaria prevalence rates crossed the threshold of 40% level whereas in Uganda the strategy was dominated by presumptive strategy at above 65% of malaria positive infection rates among children under5s**.**

Table 8: Cost-Effectiveness for Indicating Preference for RDT Strategy at lower Malaria Prevalence levels over Presumptive Treatment across the study countries

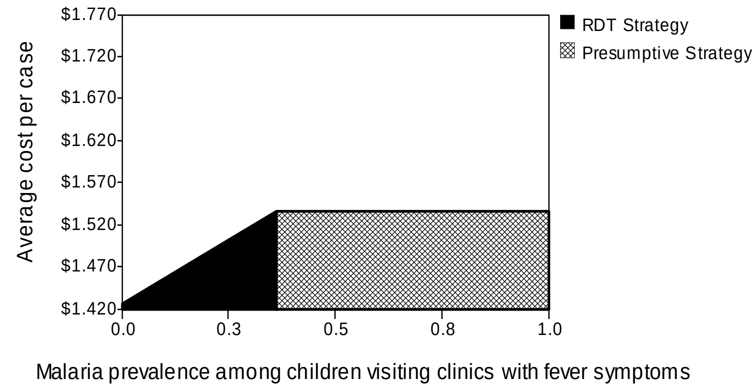
Strategy Graph on Average Treatment Cost for Malaria and

Non-Malarial Fevers by mRDT or Presumptive Treatment Strategies in Angola



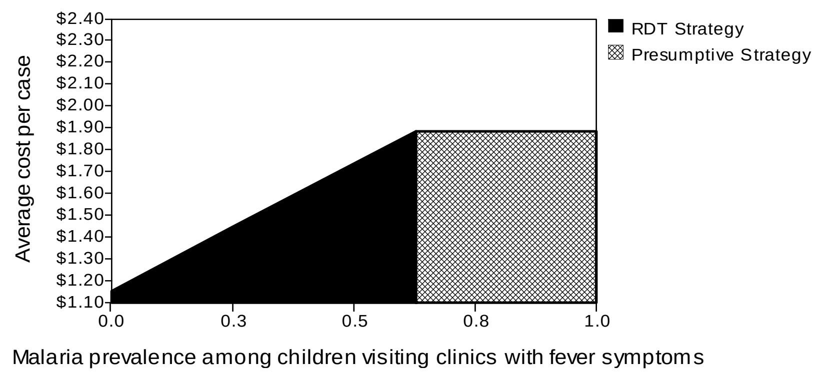
Strategy Graph on Average Treatment Cost for Malaria and

Non Malarial Fevers by mRDT or Presumptive Treatment Strategies in Tanzania



Strategy Graph on Average Treatment Cost for Malaria and

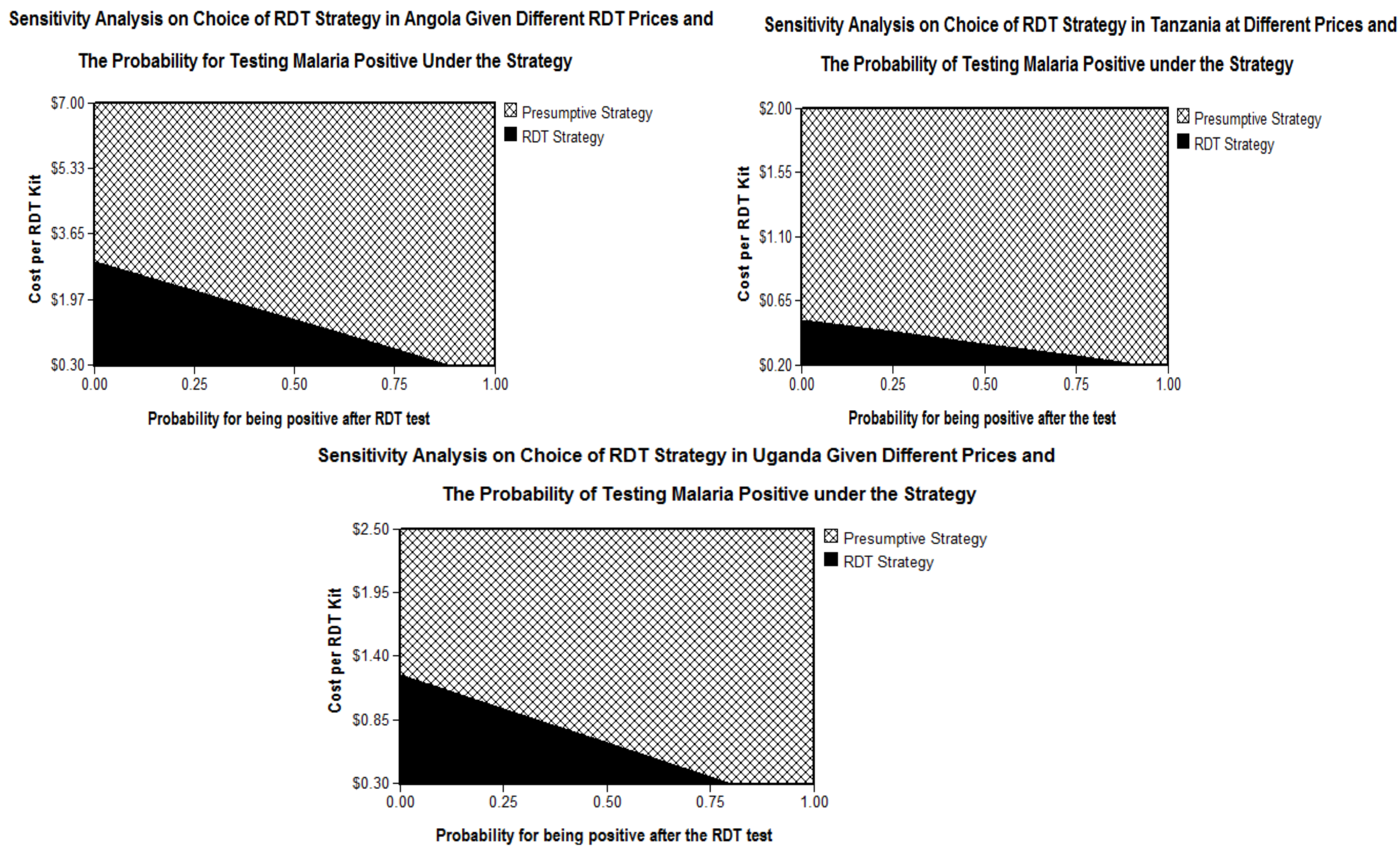
Non-Malarial Fevers by mRDT or Presummptive Treatment Strategies in Uganda



Improvement of care-seeking among children with fevers: Revisiting health clinics for proper diagnosis and treatments add important cost and clinical outcome magnitudes relevant for determination of effectiveness of either malaria treatment strategy adopted. From the existing literature on care seeking behavior in sub Saharan Africa, we first assumed that 48% of children with treatment misdiagnosis on their first visit to health facilities would return to clinics for further treatments. We tested a scenario where more than 48% of children initially reporting to health clinics would return for further treatment after completion of the first visit. For both Angola and Uganda, improved health care seeking above the initial rate of 48% was found to be cost effective up to 99% of all children with fever who already had made at least one prior visit to the health facility. However, the mRDT strategy only remained cost-effective if malaria prevalence remained at 30% or lower and continued to decline with each increase in the proportion of children with fever seeking care at health facilities. In Tanzania, the mRDT strategy was only cost effective as long as care seeking for children with fever and testing positive for malaria did not did not exceed 73% and with overall malaria prevalence of less than 45%. In the sensitivity analysis we tested a scenario where care seeking could surpass a 90% level for all children with fever and with at least one prior visit to the health facility for treatment.

Changes in the prices of mRDT: As would be anticipated, cost-effectiveness of the mRDT strategy relative to presumptive treatment is sensitive to the costs of initial diagnostic test kits. The mRDT strategy is likely to become more cost-effective relative to presumptive treatment as long as prices for purchasing these test kits are at least lower than the price for antimalarial drugs. At the time this analysis was being performed, mRDT kits were sold at the competitive market price of around US$1.50 or less. However, following WHO policy recommendation of 2010, many countries have rapidly started to deploy large scale use of these tests. The increased demand may lead to rise in prices but may also lead to increased production and supply and therefore a decline in prices. We explored a scenario where the price of mRDT could fall to the lowest price levels reflective of each study countries' economies. We assumed a lowest mRDT price of US$0.30 for Angola, US$0.20 for Tanzania and US$0.30 in Uganda. Additionally, we tested a scenario whereby mRDT prices could be as high as US$7.00 in Angola, US$2.00 in Tanzania and US$2.50 in Uganda. Given these price ranges, adoption of mRDT Strategy was cost-effective in Angola as long as prices were less than US$3.00 and the proportion of children with malaria positive rates was lower than 80%. In Tanzania, for the mRDT strategy to be cost-effective, prices for mRDT had to be equal or less than US$0.50 at a malaria prevalence rate of less than 85% for children-under5. Meanwhile in Uganda, mRDT strategy was preferred relative to presumptive treatment as long as mRDT prices were US$1.30 or less and malaria prevalence rate was less than 78% for children-under5**.** It is also important to note that the cost of a child's antimalarial dose had a strong correlation to the level at which adoption of mRDT strategy given its price would be cost effective relative to presumptive treatment. For instance adoption of mRDT was more cost-effective in Angola where antimalarial drugs costs were highest followed by Uganda and finally Tanzania wherein the strategy was marginally cost-effective.

Figure 13: Sensitivity Analysis on Price Variations for RDT Test Kits and their Impact on Choice of the Strategy



Finally, while clinician adherence to malaria test results and prescribe correct treatment regimen would be clinically and economically important, our results on adherence showed little impact on cost-effectiveness. Perhaps this is because in our assumptions we already assumed a relatively higher adherence to treatment by both patients and clinicians. The other reason is possibly because in most cases, the costs of drugs for first line treatment for both malaria and non-malarial fevers in this study were technically assumed to be higher than second line treatments leading to lower impact on cost-effectiveness of the either treatment strategy.

Discussion

Our analysis has shown that adoption of mRDT strategy over presumptive treatment for malaria and non-malarial fevers in children-under5 can be clinically and economically attractive strategy contingent on a number of factors. Based on the MIS data from Angola, Tanzania and Uganda, mRDT strategy was cost-effective relative to presumptive treatment as long as overall proportion of children with malaria positive results did not exceed 78%. Because of high drug prices per a child’s dose of antimalarial in Angola, adoption of mRDT strategy was highly cost-effective in Angola than either Tanzania or Uganda. The difference in incremental cost-effectiveness of mRDT relative to presumptive treatment strategy was up to US$7.30 in Angola whereas in Uganda and Tanzania it was less than US$1.50.

For the sensitivity analyses, we reported three parameters yielding highest impact on the cost-effectiveness of adopting mRDT strategy. These included changes in the proportion of children with positive malaria results, improvements on care-seeking for children with malaria and non-malarial fevers and finally changes in the price of mRDT kits. In this study, we found any proportion of children with malaria positive results below 30% to be generally attractive for adoption of mRDT strategy relative to presumptive treatment. Countries with high antimalarial drug prices like Angola were more likely to be more cost-effective by adopting mRDT strategy relative to presumptive treatment even at relatively higher rates (78%) of children with malaria positive results than those with low antimalarial prices. In Tanzania for instance where a first line dose of antimalarial for a child was estimated at about a dollar, adoption of mRDT strategy was marginal cost-effective at 35% rate of children-under5 with malaria positive rates. Improvement of health care seeking behavior for children with both malarial and non-malarial fevers had a positive impact on cost-effectiveness of mRDT strategy relative to presumptive treatment as long as at least 30% of children in Angola were seeking care at health facilities, 48% of children in Tanzania and 45% of children with fever in Uganda sought care at formal health facilities. Of those seeking care though, malaria prevalence had to be at least less than 80% in order for the mRDT strategy to be cost effective in each of the three study countries. Finally, with the variation of MRDT prices, adoption of mRDT strategy was cost effective as long as their prices did not exceed US$3.00 in Angola, US$ 0.50 in Tanzania and US$ 1.30 in Uganda. Any mRDT price beyond these limits would make the strategy less cost-effective.

Perhaps it is important to note that at lower levels of malaria prevalence, the likelihood of having malaria over-diagnosis through presumptive strategy is higher because most patients with non-malarial fevers will still be prescribed with antimalarials. In addition to poor diagnosis and incorrect prescription of antimalarial drugs, the likelihood for these patients to return to clinics for further treatment is even higher leading to their average treatment costs being higher than in situations where mRDT strategy is adopted. In this study's model, adoption of mRDT strategy enabled over 95% of childhood fevers to be correctly treated with antimalarials and antibiotics for those children with non-malarial fevers. However, with high malaria prevalence, the adoption of mRDT strategy proved to be of less economic benefit in terms of cost savings but had the potential for being clinically effective through ensuring correct diagnosis under-5 malarial and non-malarial fevers. The strategy was also shown to save more lives when compared to presumptive treatment strategy. Additionally, under such circumstances, the adoption of mRDT strategy exhibited the potential to limit antimalarial drugs misuse which in the long-run could as well, play a crucial role in halting antimalarial drug resistance problem.

This study is the first of its kind to explore whether adoption of mRDT strategy for diagnosis and treatment of malarial and non-malarial fevers in children-under5 is cost-effective relative to presumptive treatment strategy. Past studies have relied on mixed data for both adults and children and also relied heavily on expert opinions [186, 357]. In contrast to past studies in this area, our study only compared two malaria diagnostic (mRDT vs. presumptive) strategies and deliberately did not include microscopy diagnostic strategy because it was considered practically unattainable for at every health facility in a typical malaria endemic setting in sub-Saharan Africa. Despite these differences, our findings corroborate with those established in other studies that adoption of mRDT strategy is highly cost-effective relative to presumptive malaria treatment strategy. Two studies looking at cost-effectiveness of mRDT strategy relative to presumptive and microscopy malaria diagnostic and treatment in sub-Saharan Africa established that adoption of mRDT strategy was highly cost-effective [185, 186]. In fact in one of these studies, the use of mRDT in high malaria transmission settings was cost effective relative to presumptive treatment as long as malaria prevalence did not exceed 60% a finding similar to some of our findings[185]. Country specific studies in Tanzania, Zambia and Nigeria also found adoption of mRDT strategy being more cost-effective or yield more savings relative to microscopy or presumptive malaria treatment strategies [358-361].

A good number of studies have found mRDT strategy to be more cost and life savings as the strategy reduces unnecessary antimalarial drug use and therefore realizes some savings and also leads to better and accurate disease diagnosis[167, 362]. A study in Zanzibar Tanzania found that use of mRDT reduced health facility re-attendance because the disease was successfully diagnosed and treated on patients first visit and diagnosis by mRDT[332, 363]. In Zambia, the use of mRDT was found to have the potential for reducing the consumption of antimalarial drugs and therefore reduce malaria treatment costs especially in low transmission settings[364]. The study did also find that in areas with relatively high transmission settings, the relative advantage of using mRDT was lower since clinicians were less likely to adhere to mRDT test results and therefore the strategy had little or no cost-benefit impact.

Study limitations

This evaluation was conducted from the provider perspective not societal as it did not include any of household or malaria patient related cost. However, had the analysis adopted a full societal perspective to capture the distributional impact of using either strategy; the epidemiological and economic advantages of using mRDT strategy might have been even higher. The second limitation to the study relates to paucity of data especially on clinicians compliance to test results. There have been reports of many health practitioners continuing to prescribe antimalarial drugs regardless of negative test results [185, 277, 331, 332, 336, 354, 363, 365, 366]. Because of data limitations we had to heavily rely on secondary data sources and in few cases we used estimates obtained from ‘expert opinions’. Some of these estimates may have potentially over/under-estimated some numbers leading to our findings being less robust. Data limitation was also one of the reasons we could not complete a more sophisticated analysis to incorporate disability adjusted life years (DALY’s) as the primary measure of either strategy’s effectiveness. Furthermore, studies have shown that a big proportion of patients often do self-diagnosis and self-treatment at home or through private retail markets where malaria tests are unavailable[356]. There is limited information on the actual number of children under-5 treated at private drug outlets and therefore this evaluation is incomplete as long as we did not explore the option of having mRDT at private drug outlets. Finally, our analytical approach did not measure wastages resulting from inappropriate use of mRDT. Such wastage could result from poor mRDT storage which might be perverse in most of rural clinics in Africa, poor mRDT reading skills by health workers which could result to unnecessary repetitiveness of mRDT tests. We argue that while measuring such wastages would be important, it may prove to be extremely difficult to execute. Nevertheless, the study conclusions remain robust and informative to malaria policy makers. This is the first study to look at the cost-effectiveness of mRDT use for treatment of malaria in children under-5 relative to presumptive treatment strategy.

Conclusions

This study has shown that adoption of mRDT diagnostic strategy for malaria treatment in children under-5 is cost-effective relative to presumptive treatment strategy in all three study countries. However, the threshold at which the mRDT strategy was cost-effective varied across countries; in Tanzania the mRDT strategy was cost effective as long as malaria infection rates were less than 36%. Adoption of mRDT strategy for Angola and Uganda was cost effective relative to presumptive treatment only if malaria infections did not exceed 78% and 65% respectively. While adoption of mRDT strategy was cost-effective, local factors, including malaria prevalence, cost of testing supplies, the volumes of patients seeking care at primary health facilities and clinician's compliance must be considered. The potential for malaria case management to improve after the implementation of mRDT strategy compared to the presumptive strategy is promising. As more malaria endemic countries continue to adopt mRDT as a national strategy, efforts should continue to evaluate the operational aspects of mRDT use in children under-5 especially with regard to appropriate use these diagnostic tools to avoid wastages and also compliance to test results. Any meaningful economic evaluation on mRDT use has to address these important determinants for successful implementation of the malaria treatment strategy.

Chapter 7

Discussions Policy Implications and Overall Conclusions

Introduction

This study was completed at an exciting time for global malaria control efforts. The excitement has mainly been generated by increased global attention and funding for malaria control with the goal to reduce morbidity and mortality particularly in young children and pregnant women. Following this renewed interest, malaria researchers are currently full of optimism that finally this old scourge can be controlled and ultimately eliminated worldwide [367, 368]. Despite this optimism, researchers have to be cautious because of the enormous challenges that lay ahead to finally reach the goal of global malaria elimination. The main challenges include reported emerging artemisinin combination drugs and insecticide resistance to malaria parasites and vectors respectively [369-373]. Other challenges such as poor access to effective antimalarials, existence of fake antimalarials in Africa and Southeast Asia are also posing serious threats to the global efforts to control and consequently eliminate malaria[60, 374-377]. Additionally, there is a growing skepticism on the ability of malaria endemic countries to sustain the substantial gains already achieved because of weak and fragmented health systems, low research capacity and poor community commitment and engagement in malaria control efforts [378, 379]. This last chapter delves to discussing the main conclusions of the study and make policy recommendations to national malaria control programs in endemic countries and global malaria control program. In this chapter we also discuss our study limitations and potential areas for further research.

General Discussions

The goal of this dissertation was to investigate whether large scale malaria control programs currently being implemented in three countries in sub-Saharan Africa with substantial international funding support since the launch of the PMI program in mid-2005 are effective in reducing inequities as well as being cost-effective. Each of the three papers comprising this dissertation responded to one of the challenges related to global efforts to scale up malaria interventions. The first paper, using data from malaria indicator survey conducted in three countries aimed to establish whether large scale targeted free bed-net distribution mediates the relationship between household socioeconomic status and a set of childhood malaria control indicators. Therefore, malaria infections in children-under5, household ownership of bed-nets and use of bed-nets by children-under5 were investigated as outcome variables while household wealth was the main independent variable. The main conclusion of the paper was that despite increased funding and free distribution of bed-nets, children in poorest households continued to be disproportionately affected by malaria. Children-under5s in poorest households were more susceptible to malaria infections than those in wealthier households. Access and use of effective malaria control tools such as mosquito nets was also much better among wealthier households than found among children-under5 belonging to the poorest households.

In the second paper, we investigated the linkages between maternal education and childhood malaria infections. The study also showed that maternal education was significantly associated with low childhood malaria infections. Children-under5 whose mothers or care-takers reported to have attained some primary education or beyond, were up to 4.7 percentage points less likely to be malaria positive. Improved child knowledge, economic empowerment and social networking were identified as some of the important pathways through which maternal education impacted childhood malaria infections rates.

Finally, the third paper examined the cost-effectiveness of recently World Health Organization endorsed policy of universal malaria testing among patients of all ages. We specifically looked at whether mRDT was cost-effective relative to presumptive malaria treatment and compared results across the three study countries. Our results indicated that adoption of mRDT strategy was cost-effective across all three countries but the level at which the strategy would be cost-effective varied by the level of malaria transmission intensity and local costs of implementing the mRDT policy strategy.

These findings reaffirm results published in many other studies arguing that malaria disease disproportionately affects the poorest and socio-economically marginalized populations[7, 42, 48, 49, 93, 380, 381]. However, in contrast to past studies most of which were small localized projects, our findings are based on nationally representative MIS data which only started to be collected after increased international initiatives for global malaria control. Also uniquely important is the fact that this study was conducted after implementation of strategies thought to address the perverse inequities in accessing effective malaria control packages. The design and implementation of various programs to improve access to effective malaria control tools such as bed-nets and antimalarial drugs through subsidized voucher systems or free distribution was believed to be remedial to inequity problem[50, 56, 97, 253]. Unfortunately, our findings indicate that targeted free bed-net distribution did not eliminate inequities in access and use of bed-nets in the three study countries. While there was substantial increase in the number of households reporting ownership and use of bed-nets, the poorest households remained disproportionately underserved and experienced more childhood malaria infections than relatively wealthier households.

Meanwhile, children whose mothers were uneducated were also more susceptible to malaria infections than those whose mothers had some primary education or those with education level beyond primary school. Such findings expose our limited understanding of the barriers poor populations encounter when needing effective and lifesaving health-services and interventions. The design and implementation of the interventions have mainly been biased towards addressing financial barriers that underserved communities experience when in need of various health services. However, it does seem that there are other non-financial barriers that we've not been able to address or adequately deal with. Such non-financial barriers include, but not limited to, distance to health facilities, poor physical infrastructure like housing, roads and health facility building, weak health systems often exhibited by lack of competent health care providers in poorest communities and stock out of important malaria control supplies.

For effective malaria and other disease control strategies, public health experts ought to do a better job at understanding the types and nature of barriers poor populations encounter when needing public health services. While financial barriers may be important to address, the non-financial barriers like those mentioned above as well as the psychological barriers may be as devastating and life threatening as the diseases themselves. Only a few studies have reported physical distance to health facilities as one of the main reasons for low level of access to malaria control and other health services[98, 125, 228, 234, 252]. Unfortunately, the nature of MIS data did not allow us to adequately explore the non-financial barriers such as distance to health facilities and strength of the health systems saving poor communities in the study countries. Additionally, environmental factors and terrain challenges may also play critical part in improving or limiting access to life saving interventions [55, 251]. Study evidence has shown that poor people tend to cluster and live in difficult hard-to- reach places or in areas where social services are unavailable because they are unable to afford them [382-385]. The design of public health policy devoid of any considerations to such segments of the population is prone to fall short in effectively delivering vital public health services to these marginalized populations.

Moreover, poor people may endure mental and psychological barriers in accessing effective public health services. Studies have shown that poverty and marginalization erodes individuals' self-confidence and instills in them the feeling of helplessness, incompetence and depression [386-388]. Following these trends, underserved populations often tend to see themselves as undeserving and therefore have a self-limiting obstacle to even access some services that may be freely and readily available to them. In the study exploring the relationship between maternal education and childhood malaria infections, we argued that one of the possible pathways through which maternal education interacts with childhood health was through increased maternal confidence to handle her child's health and other nurturing related issues. By virtue of being uneducated, these mothers are already marginalized; the fact that most of them are poor increases their chances of feeling helpless with that becoming a strong psychological barrier to their access of various public health services including those related to malaria control. We therefore argue that the design of malaria control programs has to be broad enough to be able to identify such people in the community and reach out to them for successful program implementation. Typically, poor people tend to cluster together and they feel bound by their shared destiny of a miserable life. Outreach programs specifically aimed at reaching out to these clusters of population should easily identify them and provide them the services they need as long as the goal of such programs are clear from the design stage of the intervention.

The third paper demonstrated that the universal use of malaria rapid diagnostic tests for children-under5 is variably cost-effective. The level at which the mRDT strategy was cost effective relative to presumptive malaria treatment strategy varied in each of the three study countries. Following the one way and two-way sensitivity analyses, the variations in the costs of the drugs and mRDT kits were important policy drivers for the cost-effectiveness of either strategy. The costs of implementing mRDT strategy varied widely across countries because of differences in socio-economics, malaria transmission intensity, expected clinician adherence to the test results and also whether or not the strategy would be extended to the private sector to include retail drug outlets[79, 365, 389]. Adoption of mRDT strategy will probably not be equally cost-effective in all malaria endemic countries. For the successful malaria control agenda, the design and implementation of malaria control policies have to be tailored to reflect country specific needs rather than global or regional needs. To make this point clear, one may consider how intermittent prevention and treatment of malaria in pregnancy (IPTp) policy strategy has been implemented across countries. While the policy has the potential to save thousands of pregnant women and their children’s lives, the cost-effectiveness of the strategy is highly variable across countries. In countries like Uganda where malaria transmission is high and stable throughout the year, implementation of IPTp policy continues to be highly cost effective. However in Zanzibar and Rwanda, where malaria transmission is currently at very low levels, their public health policy makers are beginning to question whether continuing with implementation of IPTp strategy is any longer cost-effective. The spread of the antimalarial drug resistance problem was also a gradual process and the cost-effectiveness of antimalarial policy change was different across countries even though the global malaria control bodies never acknowledged or encouraged countries to tailor their control policies based on their needs at the time. This study highlights the importance of investigating country specific needs with the aim of designing malaria control policies that are tailored to address those needs.

After the failure of the first global malaria elimination strategy in 1969, malaria control strategies prioritized disease control through malaria chemotherapy and downplayed efforts to sustainably interrupt and control malaria infections [35, 378]. With the establishment of the World Health Organization’s Roll Back Malaria (RBM) program in 1998, malaria control strategy slightly shifted to include four standard pillars applicable in all malaria endemic countries. These are: early diagnosis and prompt treatment, planning and application of selective and sustainable preventive measures, early detection or prevention of epidemics and their containment, and continual monitoring and evaluation of malaria situation. Based on the findings of this study, we argue that, for successful malaria control and consequently its elimination, there can be no single strategy applicable everywhere. Of critical importance is the long term commitment with flexible strategy that includes community involvement, integration with health systems and development of active surveillance systems for effective malaria control. The expansion of malaria control initiatives to include non-clinical/epidemiological indicators such as including and making compulsory the teaching of malaria preventive measures into primary and secondary school curricula is necessary. Such necessary steps will enhance sustained commitment from local communities, civil society, policy leaders and scientific community residing in all malaria endemic countries.

Policy Implications

There are three important policy implications that can be drawn from the three papers. First, the targeted free bed-net distribution to reach out to underserved population did not yield the desired outcomes. While there was substantial increase in overall ownership and use of bed-nets across households, the poorest households continued to disproportionately exhibit lower ownership and use of bed-nets across all three countries. This means that the policy was unsuccessful in reaching those most in need. A number of reasons might have accounted for the undesired outcomes including poor choice of bed-net delivery channels to reach those most in need, poor strategy in identifying the underserved populations and poor communication by bed-net delivery program implementers that resulted in low enthusiasm to access and use of the free bed-nets by the neediest populations. In order for the program to reach out to the underserved populations, new bed-net distribution and also delivery strategies have to be designed and implemented.

Secondly, children whose mothers had some primary or beyond primary level education were less susceptible to malaria infections than children-under5s whose mothers were uneducated. Therefore, it is important for global malaria funding agencies to recognize this fact and allow malaria endemic countries to have some flexibility in using malaria control resources to strengthen their local education programs. Such investments could be used to increase the number of children particularly girls to school enrollment and completion, improve their teaching curricula to include malaria prevention and control skills which are currently not taught at most of the schools in these countries. Perhaps such investments will give some guarantees on successful and sustainable long-term malaria control programs.

Finally, while adoption of mRDT relative to presumptive treatment is generally cost-effective, there are huge variations regarding the extent to which these strategies would be cost-effective across countries. Adoption of mRDT strategy in Angola may be an attractive and very cost-effective but the same strategy may be less cost-effective in Tanzania or Uganda because of a number of factors as discussed earlier in the study. To maximize gains, malaria control policies should be tailored to reflect specific country needs and challenges. There can be no uniform regional and global malaria control policies that are cost-effective in all malaria endemic countries. Multilateral and bilateral malaria funding agencies should strive to allocate malaria resources in a manner that gives enough flexibility for malaria endemic countries to investigate and implement malaria control policies that are reflective of their public health needs. Meanwhile, malaria endemic countries should have clear strategies and well defined goals upon which decisions on funding allocation will be built around. For effective implementation of funding flexibility, donor countries should demand some level of performance that will be required from the endemic countries as a warranty for continual program support.

Overall Study Limitations

The major limitation of this study is on the source and nature of data used in the analysis. The study heavily relied on cross-sectional malaria indicator survey data from Angola, Tanzania and Uganda. Any analysis relying on cross-sectional data is limited in that it cannot make any causal inferences for lack of control of other confounding factors. This particular MIS data was the first attempt to obtain nationally representative malaria indicator surveys from sub Saharan Africa. The challenges for undertaking such ambitious data collection for the first time in history can be overwhelming. The quality of data may also have not been the best considering the fact that the local capacity for these countries to collect such data was extremely limited. Our study was retrospective as it was designed after data were collected. One major disadvantage of such studies is inability to precisely measure some of the variables of interest. In our case, we had to improvise and use some variables like ownership of cellphones to explore the relationship of social networking and childhood malaria infections. Also, some of the analysis like exploring non-financial barriers to accessing effective malaria control packages such as distance to health facilities could not be completed because the dataset did not have these variables. However, the rationale for improvising some of the variables used was based on reasonable assumptions to ensure that the findings remained valid and with valuable policy implications.

This dissertation relied on additional published and unpublished data sources for completion of modeling the mRDT cost-effectiveness study. Resources were unavailable for us to invest in primary data collection for use in this modeling exercise. Important country specific data on parameter inputs such as clinician compliance to test results, health seeking behaviors and also the proportion of non-malarial childhood fevers that are caused by invasive bacterial or other viruses were obtained from past studies. The cost-effectiveness analysis also was conducted from the provider or service delivery perspective and not the societal perspective. Nevertheless, we believe that these data limitations would not change the main conclusions of the study as discussed above.

Areas for further Research

The dissertation focused on few indicators including effectiveness of targeted bed-net distribution in reducing socioeconomic inequalities, maternal education and childhood malaria infections as well as the cost-effectiveness of adopting mRDT strategy in children-under5. There are further areas that need to be investigated in order to be able to initiate productive discussions on the direction of future malaria control policies. Since these MIS data were collected, a number of malaria control policy changes have been initiated including implementation of universal free-bed net distribution in most of the SSA. While targeted free-bed net distribution did not achieve the desired equitable access of bed-nets, it will be interesting to analyze more recent MIS data to find out if universal bed-net distribution has been able to overcome bed-net ownership inequalities seen in earlier surveys as reported in this dissertation.

On the relationship between maternal education and childhood malaria infections, it may be interesting to explore the role maternal education plays in raising the profile of a mother within the community. Some scholars have argued that education may improve a woman's access to various services as her persona is changed by the way the community sees her for her education and gives her some preferential treatments. These may be education spillovers interesting to measure to be able to quantify the non-skill based impact of education in improving child health in these settings.

Finally, our evaluation of mRDT cost-effectiveness strategy took a government and programmatic implementation perspective. With increased donor funding for malaria control initiatives, it is necessary to conduct these evaluations based on a programmatic implementation perspective because such costs will be reflective of real world malaria program implementation. The government costing perspective however, sometimes undermines the significance of well-funded programs often implemented by donor resources. Donor funded programs are often better furnished and able to hire best logistic personnel to ensure better supply chain management. As a result, the notorious supply stock-outs problem often experienced in government run programs due to poor stocking forecasts and leakages is minimized. Moreover, the study did not conduct a cost-effectiveness analysis from the societal perspective. It may be important for future studies to undertake such a task in order to better understand the cut-off points for the strategy being cost-effective.

Conclusions

This dissertation explored the economic and socio-behavioral effectiveness of large scale malaria control programs in three sub-Saharan Africa countries. Our results indicated that targeted free bed-net distribution failed to reduce inequalities in access to effective malaria prevention tools like mosquito-nets. Children in poorest households were also more susceptible to malaria infections and less likely to use mosquito-nets than those from relatively wealthier households. The study further established that childhood malaria infections were higher in children whose mothers were uneducated than in children whose mothers had at least a primary education level. Moreover, the use of mRDT strategy was found to be variably cost-effective across the three study countries relative to presumptive malaria treatment strategy.

These findings suggest that in order to have equitable access to malaria prevention tools, malaria control programs should not rely on targeted free-bed net distribution strategy alone. Programs should also rely on different mechanisms to properly identify underserved segments of the population in order to adequately address their malaria control needs. Our findings further suggest that maternal education might play a key role if sustainable malaria control and consequently its elimination, is to be achieved. The education pathways through which maternal education reduces childhood malaria infection rates include improvement of child health knowledge and also economic empowerment among educated mothers. Malaria endemic countries should adopt education policies that encourage children and more specifically girls to attend and complete at least primary school education level. In order for such policies to be effectively pursued, international malaria funding agencies should support malaria endemic countries efforts to improve their number of school enrolment and completion rates by affording them some flexibility in their funding for malaria control. Such policies have the potential to solicit members of the younger generation and other community members' commitment to sustainable malaria control efforts. Finally, while some malaria control strategies like adoption of mRDT may be cost effective, economic effectiveness may vary across countries. In light of this realization, global malaria control bodies should support and encourage malaria endemic countries to investigate their respective country needs in terms of cost-effective malaria control initiatives. For malaria control programs to be cost effective, they should be tailored to reflect country specific malaria epidemiology and socio-economic needs.

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Appendix 1: CEA Model Parameter Inputs and Data Sources

Name of the Variable	Rate or $	Source
Correct Presumptively diagnosed Malaria	0.650	Barat A et al (1999), AJTMH, Jun; 60(6): 1024-30
Malaria patients treated with ACTs	0.690	NMIS (Tanzania, Uganda & Angola): 2006 - 2009
Malaria cases treated with other Antimalarials	0.310	NMIS (Tanzania, Uganda & Angola): 2006 - 2009
Patients' adherence to effective drugs	0.780	Shunmay Y & Nicholas White (2005), TMIH Vol 10:2
Patient Adherence to less drugs	0.580	Shunmay Y & Nicholas White (2005), TMIH Vol 10:2
Expected ACT treatment Efficacy	0.970	Thwing J et al BMC Public Health, 2011, 11 (Suppl3)514
Expected Efficacy of other Antimalarials	0.726	Baird Kevin J. (2005), NEJM 352: 1565 - 1577 April 2005
Expected Antibiotic drugs efficacy rate	0.740	Shillcutt et al 2008, Bull World Health Organ, February, 86(2) 101 -110
Children with Invasive Bacterial Infections	0.172	Walsh AL et al (2000), PIDJ, Volume 19(4): 312 - 319
Children with IBI severe conditions	0.120	Evans J. A et al (2004) QJM Volume 97(9):591 - 597
Children diagnosed with Viral Infections	0.870	Mosha J.F et al 2010
Pneumonia & Measles case Fatality Rates	0.030	Mnyika SK & Caroline A (2005), EAJ of Public Health, Vol 2:2, 2005
Fatality rates due to Bacterial Infections	0.121	Berkley JA et al (2005) NEJM 352:1 & Rayburn H et al (2004) BMJ
Outpatient case Fatality rates	0.059	Lepage P et al (1987), The Lancet, Vol 329 (8548):1458 - 1461 & Obaro, S et al (2011), BMC Infectious Diseases, May 2011; 11:137
Care seeking patterns for febrile illness		NMIS (Tanzania, Uganda & Angola)
Children with Positive mRDT results	0.260	NMIS (Tanzania, Uganda & Angola)
RDT Sensitivity	0.950	Abba K et al, (2011), Cochrane Review, 2011, Issue 7
Child fatality due to delayed care seeking	0.119	De Savigny D et al (2004), Malaria Journal, Vol. 3:27
Non-Malarial fevers given antibiotics	0.065	NMIS & Expert opinions
Care seeking behavior for malarious children	0.530	McCombie S (1996), S.Science & Medicine Vol.43:6, Gething, P.W et al, (2010), PLoS Med 7(7)
RDT and Facility Costs	$ 0.60 - 5.50	Yukich J et al (2010), AJTMH 83(1), Country specific data
Other non-mRDT facility cost	$ 0.59 – 3.60	Yukich J et al (2010) adjusted for specific country cost of living
Under five Drug costs (CoArtem dose)	$ 0.45 – 12.50	International Drug Price Indicator Guide & Country specific delivery costs
Price for other Antimalarials	$ 0.25 – 3.50	International Drug Price Indicator Guide & Country specific delivery costs
Antibiotics (Amoxycline)	$ 0.90 – 1.50	International Drug Price Indicator Guide & Country specific delivery costs

Appendix 2: Baseline Malaria Country Profiles

Basic Malaria Indicators	**Angola 2007**	**Tanzania 2007/08**	**Uganda 2008**
Ownership of Mosquito Nets			
Households with at least one insecticide-treated net (ITN)	27.5%	39.2%	15.9%
Use of Mosquito Nets			
Children-under5 years old who slept under an ITN the previous night	17.7%	25.7%	9.7%
Children-under5 years old who slept under an ITN the previous night or in a house sprayed with IRS in the last 12 months	19.4%	27.2%	14.5%
Pregnant women 15-49 years who slept under an ITN the previous night	22.0%	26.7%	10.0%
Pregnant women 15-49 years who slept under an ITN the previous night or in a house sprayed with IRS in the last 12 months	23.0%	28.2%	14.3%
Indoor Residual Spraying			
Households reporting that their dwelling was sprayed with a residual insecticide in the last 12 months	1.5%	3.4%	6.0%
Use of Intermittent Preventive Treatment (IPT) during pregnancy			
Women who have received 2+ doses of a recommended antimalarial drug treatment during ANC visits for their last pregnancy in the last 2 years	2.5%	30.1%	16.2%
Treatment of Children with Fever			
Children-under5 years old with fever in the last 2 weeks preceding the survey, who received any antimalarial drugs	29.3%	56.7%	61.3%
Children-under5 years old with fever in the last 2 weeks preceding the survey, who received any antimalarial drug the same or next day	18.2%	33.6%	28.9%
Prevalence of Anemia			
Children 6-59 months old with a hemoglobin measurement less than 8 g/dl	3.8%	7.7%	13.5%
Prevalence of Malaria			
Children 6-59 months old with malaria infection	19.2%	17.7%	NA

Source: *Malaria Corner Country profiles web: - http://www.measuredhs.com/topics/malaria-Corner/country-profiles.cfm*

Appendix 3 Malaria Indicator Survey (MIS) Questionnaire Modules

3.1 **MIS Introduction and Overview**

3.2 **MIS Household Questionnaire**

3.3 **MIS Woman's Questionnaire**