Evaluating the Impact of Individual, Social, and Environmental Factors on Bed Net Use for Malaria Prevention

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List of Abbreviations

AIC	Akaike information criterion
ANC	Antenatal care
ASC	Alternative specific constant
CCP	Center for Communication Programs
DCE	Discreet choice experiment
DHS	Demographic and Health Survey
DIC	Deviance information criterion
EPI	Expanded Program on Immunization
GLDAS	Global Land Data Assimilation System
HC3	Health Communication Capacity Collaborative
ICC	Intraclass correlation coefficient
IPTp	Intermittent preventive treatment for pregnancy
IQR	Interquartile range
IRS	Indoor residual spraying
ITN	Insecticide-treated net
LLIN	Long lasting insecticidal net
LST	Land surface temperature
MIS	Malaria Indicator Survey
NIMR	National Institute for Medical Research
NMCP	National Malaria Control Program
PMI	President's Malaria Initiative
RBM	Roll Back Malaria
RC	Reference category
SBCC	Social and behavior change communication
SE	Standard error
TAMSAT	Tropical Applications of Meteorology using Satellite
TNVS	Tanzania National Voucher Scheme
TSH	Tanzanian shilling
UAP	Use access proportion
USAID	United States Agency for International Development
WHO	World Health Organization
WTP	Willingness to pay

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Summary

The number of malaria cases in the world has been declining over the past decade, in large part due to the use of insecticide treated bed nets which have been credited with 55% of this reduction. Population-level access to a net has increased globally from 34% in 2010 to 61% in 2016. Most nets available in households today come from mass distribution campaigns, which provide households with a number of free nets based on a chosen distribution scheme, typically distributing either a fixed number of nets per household or a varying number based on the household size or sleeping spaces. These campaigns are usually conducted every three years to ensure that an adequate level of net coverage is maintained, and that the nets being used are in good condition based on WHO guidelines.

In addition to mass campaigns, nets are distributed in some countries at antenatal care visits (ANC), through expanded immunization programs (EPI), and through school-based distribution. In recent years, the proportion of nets distributed through these systems has increased from less than 25% to over 40%, indicating a shift away from mass campaigns.

To be effective, a net must be hung and slept under. There have been numerous studies evaluating where, when, and why people use nets. Some of the most widely explored factors that influence net use are socio-demographic characteristics including age, gender, and socio-economic status; in response to the implementation of social and behavior change communication about nets, more recent studies have focused on emotional, cognitive, and social predictors of net use. There is also evidence of climatic factors such as rainfall and temperature affecting net use, and qualitative research has reported decreased net use during the dry season due to perceptions of being too hot under a net as well as increased use during the rains due to increases in perceived nuisance biting. However, there is little evidence incorporating quantitative environmental variables when assessing net use behavior.

One of the most important considerations when evaluating net use behavior is whether an individual had access to a net to use in the first place. While an indicator for "access to an ITN" was created by Roll Back Malaria (RBM), some studies aiming to evaluate specific determinants of net use do not limit their analysis to only those with access to a net and instead include an indicator to control for access, which does not achieve the same result.

The objective of this thesis was to evaluate how individual, household, social, and environmental factors impact bed net use. This was done by defining ideational theory in the context of malaria control and modeling how ideation about bed nets can affect net use, in addition to evaluating the role of ideational factors at the individual, household, and community levels. Also important was understanding individuals' propensity to purchase nets, and how particular beliefs and family settings affect this propensity. Finally, this thesis assessed how bed net use was influenced by different ecological factors among individuals with access to a net.

To assess bed net ideation, household surveys were conducted in four countries to examine the relationships between an individual's net-use behavior and their demographic and psychosocial variables. The relationship between the ideational variables and net use tested in this thesis varied by country, indicating a need for context-specific data to inform communication campaigns and SBCC interventions. Madagascar had the largest number of significant ideational variables (six), and these were all positively associated with bed net use. Mali had only three significant ideational variables, all of which were associated with increased net use, while Liberia had two ideational variables positively associated with net use. In Nigeria, two ideational variables were significant, and both were associated with decreased net use. These results underscore the notion that an individual's decision-making process related to bed net usage is complex and multi-dimensional and is an important and significant aspect to keep in mind when studying this issue. Further evidence in this thesis showed that individuals' choice to use a net is heavily dependent on those of the rest of their households; a person's ability to use a net can vary from night to night depending on different circumstances and/or the head of household or primary caretaker could decide to which sleeping spaces the nets are allocated.

Another important finding in this thesis resulted from a discreet choice experiment and short survey conducted in Tanzania. Ninety-two percent of participants chose to purchase a net in any scenario, and 40% chose to buy a net across all seven combinations of net prices and characteristics such as size, shape, and insecticide treatment. A key factor positively influencing demand was whether a participant's household currently owned sufficient nets for all members, with rural participants showing lower net coverage and greater demand than urban participants. Both poor and less poor households showed strong evidence of making purchase decisions based on more than price alone, suggesting that private demand for nets in Tanzania could potentially supplement future coverage campaigns.

A novel method of calculating net access in a household was developed in this thesis. The proportion of household members that used a net out of those that had access, the 'use/access proportion' (UAP), was calculated as the number of household members that slept under a net divided by the number that could have or did use a net (access). This was then used to quantify net use conditional on access using population survey data from Ghana (2014, 2016), Angola (2015-2016), Mali (2015), Nigeria (2015), and Tanzania (2015-2016). The results showed that in Ghana in 2014, message exposure about bed net use for malaria prevention increased net use among those with access, as did living in a rural area in both 2014 and 2016. Humidex (a measure of how hot it feels to an average person), electricity in the household, and IRS were not associated with UAP. In Nigeria, higher wealth quintiles resulted in lower net use, while increased net use was associated with being in the “richer” quintile in Mali, and the “richest” quintile in Tanzania. As the ratio of nets per person increased, so did the UAP in Mali, Nigeria, and Tanzania (this was not significant in either the 2014 or 2016 surveys in Ghana, or the Angola survey). Conversely, as the ratio of rooms used for sleeping in the house per person increased, UAP decreased significantly in Mali and Tanzania. Having electricity was also significantly associated with a decrease in UAP in Mali. Temperature was not significantly associated with UAP in any survey, however in Angola and Tanzania, as rainfall increased so did UAP. These findings suggest that it will likely be necessary in the future to focus studies on net use in rural and urban settings and across wealth status independently, both to better understand predictors of net use in these areas and to design more targeted interventions to ensure universal coverage of vector control methods for the entire population.

While net use is generally high among those with access, to go the last mile to elimination, the malaria community must work with countries and communities to understand how household malaria prevention needs can be addressed, whether that is through nets or other prevention methods. This will require creativity and innovation to ensure the entire population at risk of malaria is covered by the best preventive tools for their given situation, and research into the needs of different population strata should be conducted and considered in the development of future malaria control programs.

Chapter 1: Introduction

1.1 Malaria

According to the World Malaria Report, the number of malaria cases declined by 18% between 2010 and 2016 (World Health Organization, 2017). However, despite these gains, which have been driven by years of intervention and investment (US$2.9 billion was spent in 2015 alone), malaria is still a disease that burdens a large part of the global population, and the decline seen in the number of cases appears to have leveled off since 2014, parallel to the decrease in financial investments (World Health Organization, 2017). Almost half of the world's population, spread over 91 countries, was at risk of malaria in 2016, and there were an estimated 216 million cases of malaria worldwide (Global Malaria Programme, 2017b). Sub-Saharan Africa alone accounts for 61% of the population at risk and 90% of malaria cases (World Health Organization, 2017).

Of the five species of *Plasmodium* that can cause human disease, *P. falciparum* causes most cases in sub-Saharan Africa. The parasite is spread through the bite of an infected *Anopheles* mosquito, which releases sporozoites into the bloodstream when it takes a meal. These sporozoites travel to the liver, where they reproduce and become merozoites. After approximately five days, they emerge from the liver and infect red blood cells. This begins a cycle that takes roughly 48 hours for falciparum malaria, where merozoites mature, replicate, and burst out of the red blood cell to infect new ones, causing the hallmark cyclical fever, along with chills, head and body aches, nausea, diarrhea, and malaise (Crutcher and Hoffman, 1996).

While children under five have the highest burden of illness across all settings, in areas with lower transmission, clinical malaria becomes increasingly dangerous for adults as well, as less acquired immunity is able to develop (Carneiro *et al.*, 2010; Griffin, Ferguson and Ghani, 2014). It has been estimated that adults lose an average of 3.4 days of productivity per case of malaria, and this has a direct household cost of almost US$3 (which is over the average dollar amount per day of about half of the population) (World Health Organization, 2015). Both the high loss of life due to severe malaria infection in children, as well as lost productivity among adults make malaria one of the highest causes of disability-adjusted life-years lost of any infectious disease (Kassebaum *et al.*, 2016), and the amount of money saved from the increase in life expectancy of only 0.26 years due to decreased malaria mortality between 2000–2015 is valued at about US$1810 billion in the WHO Africa region (World Health Organization, 2016).

1.2 Bed Nets for Malaria Prevention

One of the top reasons for the decline in the number of malaria cases has been the use of insecticide-treated bed nets (ITNs) for the prevention of malaria (Bhatt *et al.*, 2015). ITNs[1] alone have been responsible for a 55% reduction in malaria mortality among children under five in sub-Saharan Africa since 2000, and an estimated 54% of the population at risk slept under a net in 2016 (Lengeler, 2004; World Health Organization, 2017).

Bed nets for the prevention of vector borne diseases have been used for decades; insecticide additives were introduced as early as World War II, and the first synthetic pyrethroids were created in the 1970's (Lengeler, 2004; Hill, Lines and Rowland, 2006). ITNs prevent malaria in two ways, first, by providing a physical barrier against mosquito bites, and second, by the insecticide either killing or repelling the mosquito. In addition to protecting the user, ITNs also confer a community-wide benefit by decreasing the mosquito population (Hawley *et al.*, 2003; Teklehaimanot, Sachs and Curtis, 2007). Because of the relative cost effectiveness of ITNs, they became an integral part of global malaria control

[1] In this thesis, "ITN", and "LLIN" (long lasting insecticidal nets) are used interchangeably, as the majority of nets in sub-Saharan Africa have been LLIN since around 2006.

policies in the mid-1990s, with programs targeting the most vulnerable populations, including children under five and pregnant women (Hill, Lines and Rowland, 2006; Galactionova *et al.*, 2017). In 2007, based on guidance from the WHO, countries began to provide ITNs to the entire population in areas at high risk for malaria transmission (Global Malaria Programme, 2007), also known as universal coverage. The WHO defines universal coverage as “universal access to and use of appropriate interventions by populations at risk of malaria”, emphasizing not only the importance of having a net, but also of using one (WHO Global Malaria Programme, 2017). This guidance has dramatically increased the proportion of households owning at least one ITN from 30% in 2010 to 80% in 2016, as well as the proportion of the population with access to an ITN from 34% to 61% over the same time period (World Health Organization, 2017).

Most nets available in households today come from mass distribution campaigns, which provide households with free nets, the number being dependent on the chosen distribution scheme, typically either a fixed number of nets per household or a varying number depending on the household size or the number of sleeping spaces (Kilian *et al.*, 2010). These campaigns are usually conducted every three years to ensure an adequate level of net coverage is maintained, and that the nets being used are in good condition based on WHO guidelines (World Health Organization, 2011; Global Malaria Programme, 2017a).

The WHO recommended in 2013 that, in addition to distribution through mass campaigns, countries continuously distribute ITNs via antenatal care visits (ANC), expanded immunization programs (EPI), and school-based distribution (which, while classified as “continuous”, are more similar to miniature, targeted mass distribution campaigns). While 75% of ITNs in sub-Saharan Africa came from mass distribution campaigns from 2014 to 2016, 13% were provided through antenatal clinics and 5% through immunization programs (Figure 1.1). These channels target specific populations belonging to “prioritized” groups, primarily pregnant women and children under five, as well as school-aged children who tend to be much less likely to sleep under nets than other family members (Noor *et al.*, 2009; Nankabirwa *et al.*, 2014; Ricotta *et al.*, 2014). In recent years, the proportion of distributed nets allocated to continuous distribution has increased from less than 25% to over 40%, indicating a shift away from mass campaigns (Paintain and Roll Back Malaria, 2011). Many households will at some point during the three years between mass campaigns have a net shortage, and having a household member that belongs into one of these target groups will allow them to receive a net, rather than having to wait for the next campaign.

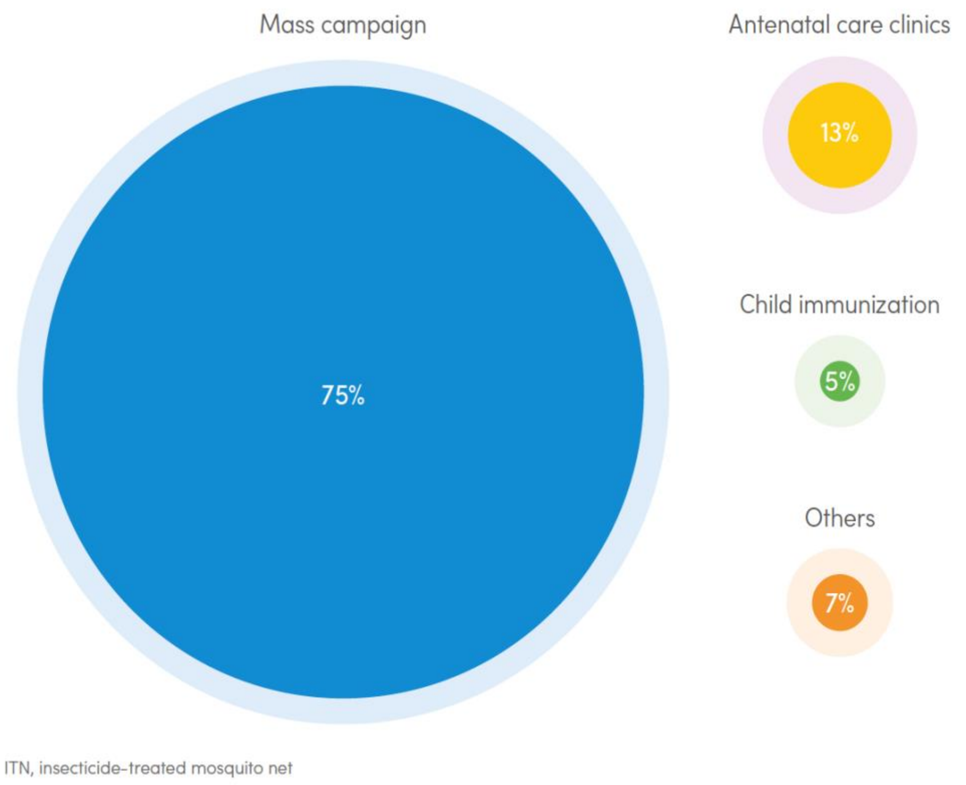

Figure 1.1 Proportion of ITNs distributed through different delivery channels in sub-Saharan Africa, 2015–2016. Source: World Malaria Report 2017.

Continuous distribution is not without its difficulties. A study evaluating the availability of nets through ANC and EPI distribution found that while a high proportion of malaria endemic countries had adopted one or both channels, they accounted for less than 10% of nets distributed and were underutilized in both cases (Theiss-Nyland, Lynch and Lines, 2016). These programs are designed so that every woman on her first visit to ANC or child at an EPI visit between birth and nine months will receive a net. However, in reality, a net is often not received. This can be due to logistical issues such as an inconsistent supply of ITNs distributed by national centers to facilities, or the fact that many women do not use these services (Theiss-Nyland, Lynch and Lines, 2016). A review of four countries' continuous distribution channels discovered stock-outs in every country at some point during the study period, and another study found that 50% of people attending ANC and 60% of EPI attendees did not receive a net (Theiss-Nyland *et al.*, 2016; Theiss-Nyland, Lynch and Lines, 2016). In terms of service utilization, in sub-Saharan Africa, 20% of women do not attend ANC at all during their pregnancy, and vaccine coverage has stalled at 86% (United Nations Children's Fund, 2018; World Health Organization, 2018). A newer "continuous" distribution channel is school-based distribution, where a selection of school-grades are chosen to receive nets every year. This method has been shown to work well in a number of countries (Kolaczinski, 2016; Stuck *et al.*, 2017), however, it does necessitate a well-functioning and well-attended school system for this to be a feasible option for distribution in a country.

In addition to nets distributed freely through mass campaigns and continuous distribution, the private sector has provided to households an alternative means of acquiring nets, and the nets offered in the private sector range from untreated nets to ITNs. Prior to ITN mass distributions, markets were the primary place where households acquired nets (Kilian, 2013). Since the WHO's decision in 2007 to recommend universal coverage of freely distributed or subsidized nets, the private market contributes less than 1% of owned nets, with nets from donor organizations making up the other 99% (Millington, Agboraw and Worrall, 2017). However, the commercial net market meets the need left by campaigns by providing nets in a variety of shapes, sizes, colors, and materials so that the user is able to choose the net that best fits their needs, as well as by providing a place for household to purchase extra nets in between mass campaigns (George *et al.*, 2014). Additionally, as donor funding for campaigns levels off and more of the market relies on alternative means of distribution, the private sector will become an integral part of the effort to maintain net coverage.

Finally, mixed-stakeholder approaches such as distributing subsidized nets via a voucher system have been implemented in a number of countries, most notably Tanzania and Ghana (de Savigny *et al.*, 2012; Kilian, 2013). In this scheme, a voucher is given to an individual that can be used to cover some of the cost of a bed net for sale in the local market. As maybe the best example of a successful voucher program, in the Tanzania National Voucher Scheme (TNVS), pregnant women received a voucher at their first ANC visit that subsidized 70–90% of a net purchase, depending on the type of net selected (Hanson *et al.*, 2008). This program was successful in increasing net coverage and equity throughout the country and was operational for ten years (Kramer *et al.*, 2017), providing a robust and stable alternative for households to acquire nets outside of national campaigns.

1.3 Net Use Behavior

To protect against malaria, it is not enough to simply own a bed net, however, which is why there have been numerous studies evaluating where, when, and why people use nets. Some of the most widely explored factors influencing net use are socio-demographic characteristics including age (Nuwaha, 2001; Panter-Brick *et al.*, 2006; Ng'ang'a *et al.*, 2009; Kulkarni *et al.*, 2010; Rickard *et al.*, 2011; Tchinda *et al.*, 2012), gender (Panter-Brick *et al.*, 2006; Ng'ang'a *et al.*, 2009; Tchinda *et al.*, 2012; Loha, Tefera and Lindtjørn, 2013) and socio-economic status (Nuwaha, 2001; Jombo *et al.*, 2010), which all play different roles in predicting net use within a household.

In addition to these demographic predictors, emotional, cognitive, and social constructs around net use have been evaluated in response to the implementation of social and behavior change communication (SBCC) about nets (Boulay, Lynch and Koenker, 2014; Ricotta *et al.*, 2015). SBCC has been used throughout various health domains to influence health decision making and outcomes (Babalola *et al.*, 2001; Babalola and Vondrasek, 2005; Nguyen *et al.*, 2012), and has been integrated into malaria prevention strategies in an effort to maximize the results of the intervention (Koenker *et al.*, 2014). These concepts and their relationship with bed net use are explored in detail in Chapters 2–4 of this thesis.

There is also evidence of climatic factors such as rainfall and temperature affecting net use, and qualitative research has reported decreased net use during the dry season due to perceptions of being too hot under a net (Pulford *et al.*, 2011; Singh, Brown and Rogerson, 2013), as well as increased use during the rains due to elevation in perceived nuisance biting (Koenker, 2011; Moiroux *et al.*, 2012). However, there is little evidence incorporating quantitative environmental variables when assessing net use behavior. A recent meta-analysis included studies evaluating how the environment influenced malaria outcomes when controlling for various interventions, including ITNs (Sadoine *et al.*, 2018), but these studies did not look at how the environment influenced intervention use. Moiroux and others assessed net use during the dry season in Benin and included remotely-sensed nocturnal land surface temperature (LST) among households with >60% net ownership. They found that the households with the highest mean cluster nocturnal LST compared to those with the lowest had a higher probability of net use (Moiroux *et al.*, 2012). More research exploring these relationships is clearly needed and will be explored in Chapters 5 and 6.

One of the most important considerations when evaluating net use behavior is whether an individual had access to a net to use in the first place. The first step when studying net use behavior is to exclude households that do not own any nets. It is then important to analyze just the population that has access to a net within their household, as those without access cannot use a net. While an indicator for "access to an ITN" was created by Roll Back Malaria (RBM) to evaluate net use for programmatic purposes (MEASURE Evaluation *et al.*, 2013; Koenker and Kilian, 2014), many studies aiming to evaluate specific determinants of net use, be it demographic, social, or environmental, still do not limit their analysis to only those with access. Instead, they include an indicator such as the RBM population access indicator or the nets/person ratio as a way to "control" for access in an analysis (Diabaté *et al.*, 2014; Kateera *et al.*, 2015; Russell *et al.*, 2015). This issue of use conditional on access is addressed in detail throughout this thesis.

1.4 Objectives

The objective of this dissertation is to evaluate how individual, household, social, and environmental factors impact bed net use. This will be done through the following sub-objectives:

1. To define ideational theory in the context of malaria control and to model how ideation about bed nets can affect net use and household universal coverage after exposure to a malaria SBCC campaign.
2. To evaluate the role of ideational factors at the individual, household, and community levels.
3. To understand individuals' propensity to purchase nets, and how particular beliefs and family settings affect this propensity.
4. To assess how bed net use is influenced by different ecological factors among individuals with access to a net.

Chapter 2: Associations Between Ideational Variables and Bed Net Use in Madagascar, Mali, and Nigeria

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Abstract

Background: The use of insecticide-treated bed nets (ITNs) is crucial to the prevention, control, and elimination of malaria. Using household surveys conducted in 2014–2015 by the Health Communication Capacity Collaborative project in Madagascar, Mali, and Nigeria, we compared a model of psychosocial influence, called Ideation, to examine how malaria-related variables influence individual and household bed net use in each of these countries. Evaluations of non-malaria programs have confirmed the value of the ideational approach, but it is infrequently used to guide malaria interventions. The study objective was to examine how well this model could identify potentially effective malaria prevention approaches in different contexts.

Methods: Sampling and survey designs were similar across countries. A multi-stage random sampling process selected female caregivers with at least one child under five years of age for interviews. Additional data were collected from household heads about bed net use and other characteristics of household members. The caregiver survey measured psychosocial variables that were subjected to bivariate and multivariate analysis to identify significant ideational variables related to bed net use.

Results: In all three countries, children and adolescents over five were less likely to sleep under a net compared to children under five (OR=0.441 in Madagascar, 0.332 in Mali, 0.502 in Nigeria). Adults were less likely to sleep under a net compared to children under five in Mali (OR=0.374) and Nigeria (OR=0.448), but not Madagascar. In all countries, the odds of bed net use were lower in larger compared to smaller households (OR=0.452 in Madagascar and OR=0.529 in Nigeria for households with 5 or 6 members compared to those with less than 5; and OR=0.831 in Mali for larger compared to smaller households). Of 14 common ideational variables examined in this study, six were significant predictors in Madagascar (all positive), three in Mali (all positive), and two in Nigeria (both negative).

Conclusion: This research suggests that the systematic use of this model to identify relevant ideational variables in a particular setting can guide the development of communication strategies and messaging, thereby improving the effectiveness of malaria prevention and control.

Key words: malaria, ideation, bed nets, insecticide treated nets, health communication, behavior change

2.1 Introduction

As of 2016, sub-Saharan Africa carries the vast majority of the global burden of malaria cases (90%) and deaths (92%); 70% of the deaths were in children under five (World Health Organization, 2016). The use of ITNs has been shown to reduce malaria incidence rates by 50% in children under five (World Health Organization, 2016) and mass ITN distribution campaigns and routine distribution channels have been shown to be effective and cost-efficient ways of increasing household ITN access and reducing malaria morbidity and mortality (Lengeler, 2004; Yukich *et al.*, 2008; RBM Vector Control Working Group (VCWG) Continuous Distribution Workstream, 2011; White *et al.*, 2011; Alba *et al.*, 2014; Ricotta *et al.*, 2015). However, while access to nets remains a barrier to achieving consistent net use in some places (Eisele *et al.*, 2009; Hetzel *et al.*, 2012; Ricotta *et al.*, 2015; Koenker and Ricotta, 2016), the question persists of how to ensure that people obtain and use the nets to which they have access.

At a systems level, access to bed nets is ensured by a country's ability to provide bed nets through mass or continuous distribution, and retail or social marketing channels to achieve universal coverage (Ricotta *et al.*, 2015). The standard Roll Back Malaria indicator of population access to ITN refers to the proportion of individuals that could use a net within a household, assuming one net covers two people. An additional standard indicator is the proportion of households that own enough ITNs to achieve the World Health Organization's universal coverage recommendation of one ITN for every two people (Eisele *et al.*, 2009; Hetzel *et al.*, 2012; Global Malaria Programme, 2014; Ricotta *et al.*, 2015; Koenker and Ricotta, 2016). Recent reports indicate that ITN use and access are strongly correlated (Koenker and Kilian, 2014; Koenker and Ricotta, 2016). Over several recent MIS and DHS surveys, Madagascar and Mali both have very high ratios of ITN use to ITN access (>1.00, indicating more than two people on average share an ITN, and >0.90, respectively), while Nigeria's 2015 MIS documented a ratio of 0.68. In all three countries, the ratio varies at the subnational level and by socioeconomic status and residence (Koenker and Ricotta, 2016). In the few countries where access and use are not strongly correlated, and among groups of people with access who do not use ITNs, social and behavior change communication (SBCC) campaigns offer the most feasible means of closing the ITN access/use gap (Koenker and Kilian, 2014; Koenker and Ricotta, 2016).

SBCC campaigns can help to change or reinforce behaviors necessary to obtain, and/or maintain the appropriate number of ITNs in a household, as well as sleep under a bed net (Bowen, 2013; Owusu Adjah and Panayiotou, 2014; Kilian *et al.*, 2015; Ricotta *et al.*, 2015; Babalola *et al.*, 2016) by focusing on particular psychosocial determinants of behavior. Most behaviors are not driven by a single variable or determinant. For example, preventive health behaviors do not result from a fear of disease alone, but are also—often simultaneously—influenced by such things as concerns about the cost or inconvenience of protective measures, confidence or doubts about the effectiveness of a treatment, and motivation to do what others in the community do (Fishbein *et al.*, 2001). In this study, we conducted a comparison of a particular model of psychosocial influence, known as the Ideation Model of Strategic Communication and Behavior Change (Kincaid, 2000a, 2000b; Health Communication Partnership, 2004; Ricotta *et al.*, 2015), to examine how malaria-related ideational variables influence individual and household bed net use in each of these countries. Evaluations of programs on other health topics have confirmed the predictive value of the ideational approach, but it has not been widely used to guide malaria interventions. The main objective of this study was to determine the degree to which the ideation model was generalizable as a guide to identifying potentially effective malaria prevention approaches in three different countries.

The ideation model (Figure 2.1) is part of a metatheory of strategic communication and behavior change (Kincaid, 2000a, 2000b) that incorporates intermediate cognitive, emotional and social constructs from various behavioral theories and models. Different theories tend to emphasize different factors and variables associated with behavior change. Some emphasize cognitive variables, such as beliefs, values, and attitudes (Fishbein and Ajzen, 1975; Bandura, 1986, 1992; McGuire, 1989; Prochaska, DiClemente and Norcross, 1992); others include emotional variables, such as fear or elation, empathy, and confidence, or self-efficacy (Zajonc, 1984; Clark, 1992; Witte, 1993); while yet others place more emphasis on conative variables, such as social support, social influence, spousal/partner communication, and personal advocacy (Festinger, 1954; Suls, 1977; Latané, 1981; Rogers and Kincaid, 1981; Moscovici, 1986; Kincaid, 1993; Montgomery and Casterline, 1996). These are listed in the central box of Figure 2.1. While many SBCC campaign strategies emphasize social and psychological determinants of behavior, the ideation model described here is unique in that it emphasizes three things: (1) an individual's decision-making process leading up to a behavioral choice is complex and can involve multiple variables simultaneously, (2) ideational variables are behavior-specific, and (3) the influence of those multiple variables is cumulative, that is, the more of the variables that are positive with regard to the behavior, the higher the probability of that behavior occurring. Furthermore, all ideational variables can be influenced by social interaction and a variety of instructive, directive, non-directive and public communication forms, often through mass media exposure (Babalola and Vondrasek, 2005; MEASURE Evaluation *et al.*, 2013; Global Malaria Programme, 2014; Ricotta *et al.*, 2015), which increases the likelihood of population-level change.

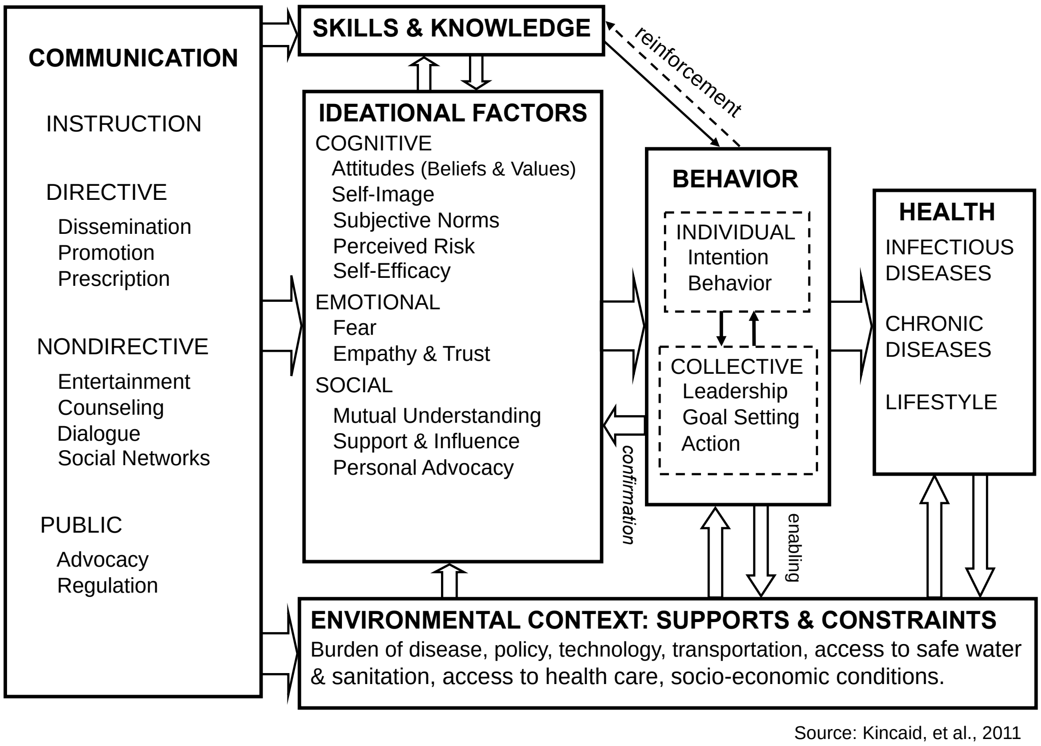

Figure 2.1 Ideation model of strategic communication and behavior change

Furthermore, Figure 2.1 indicates that the ideational change resulting from communication complements other changes in skills and knowledge necessary to perform a particular action, like bed net use, as well as changes in the environmental context, like socio-economic conditions, policies and types of material and technological support for health improvement efforts. When ideational change occurs and is supported by appropriate knowledge and environmental conditions, the behavior of individuals and groups of people is likely to change, resulting in improved health outcomes. The more ideational factors that improve, the greater the probability of behavior change. This model has been used to help guide and explain the effects of a variety of health behavior programs, including contraceptive adoption (Babalola and Vondrasek, 2005; Kincaid *et al.*, 2007; Babalola, Folda and Babayaro, 2008; Krenn *et al.*, 2014), HIV testing (Babalola, 2007), HIV prevention (Bertrand *et al.*, 2006), child survival (Naugle and Hornik, 2014), household treatment and handling of water (Figueroa and Kincaid, 2004, 2010), community support to reduce girls' vulnerability to HIV/AIDS (Underwood and Schwandt, 2015), and Ebola response (Figueroa, 2017). Human-centered design approaches (Norman and Verganti, 2014) in health and other behavioral domains have begun to use the ideation model to understand customer needs and develop client-oriented products that resonate with those needs.

In the case of malaria, one would not expect the same set of beliefs, attitudes, norms, and perceptions to influence, for example, both bed net use and care seeking for fever. Similarly, one would not expect the same set of ideational variables to influence bed net use both in year-round malaria areas and in areas with highly seasonal transmission, because patterns of risk perception and susceptibility are likely to be quite different, thus underscoring the importance of exploring the ideational variables that are relevant for each behavior and in different settings.

Recently in Tanzania, the first malaria-related study to focus on the ideation process found that a particular set of ideational variables mediated the effects of malaria prevention communication campaigns on household-level universal coverage with ITNs (Ricotta *et al.*, 2015). Ideation about bed net use in Tanzania included the following locally specific variables: (1) perceived positive social norms surrounding net ownership and use, (2) belief in one's ability to use nets properly (self-efficacy), (3) belief that net use is an effective way to prevent malaria (sometimes termed 'response' efficacy), and (4) perceived threat of malaria. Exposure to communication campaigns was correlated positively with increased net ideation, that is, the cumulative number of positive ideational variables, which in turn was correlated positively and significantly with household universal ITN coverage, i.e., having enough nets for everyone in the household (Ricotta *et al.*, 2015).

The Health Communication Capacity Collaborative (HC3) conducted household surveys in Madagascar, Mali, and Nigeria, to examine the relationships between an individual's net-use behavior and their demographic and psychosocial (ideational) variables. In this article, we compare the ideational variables of bed net use to prevent malaria in these three countries in order to better understand how differences in ideation can be used to inform strategies to improve the effectiveness of malaria prevention and control interventions wherever bed net use is a public health priority.

2.2 Methods

Study Setting

This study is based on analysis of household survey data collected in Madagascar, Mali, and Nigeria between 2014 and 2015 by the Johns Hopkins Center for Communication Programs (CCP), under the United States Agency for International Development (USAID)-funded HC3 project and with the support of the President's Malaria Initiative (PMI). The surveys were designed specifically for the purpose of comparing ideational influences on the use of bed nets for malaria prevention as part of CCP's mandate under this grant. These countries were chosen for the study because they are PMI priority countries.

CCP designed the questionnaires, but field work was conducted by trained interviewers through a contract with a private research firm in each country, selected through competitive procurement. Questionnaires were translated from the original English into local languages. Depending on respondents' preferences, the interviews were conducted in English, Pidgin English, Igbo or Hausa in Nigeria; French or Bambara in Mali; and Malagasy in Madagascar. Data were collected during the dry season/early rainy season in Madagascar (between September and November 2014), the rainy season in Mali (between July and September 2015), and the rainy season in Nigeria (between July and September 2015).

The three countries have differing levels of malaria parasitemia in children 6–59 months—measured through microscopy—varying from 9% in Madagascar (Institut National de la Statistique (INSTAT) *et al.*, 2013) to 27% in Nigeria (National Malaria Elimination Programme (NMEP) *et al.*, 2016) and 36% in Mali (Programme National de lutte contre le Paludisme (PNLP) *et al.*, 2016). While malaria transmission in Nigeria is stable and perennial, northern Sahelian areas experience increases in transmission during three months or less of seasonal rains (President's Malaria Initiative, no date). Mali's Sahelian belt experiences stable, seasonal transmission while in the northern desert region transmission is low, unstable and epidemic-prone (Programme National de lutte contre le Paludisme (PNLP), MRTC and INFORM, 2015). In Madagascar, the sub-desert and highland zones experience shorter seasons of increased transmission, the latter with pockets of high elevation where autochthonous transmission is rare; the tropical and equatorial zones experience stable malaria transmission most of the year (Kesteman *et al.*, 2014). Cyclones occur between December and April and often result in increased risk of malaria infection. The majority of malaria cases are caused by *Plasmodium falciparum* parasites in all three countries.

Mass bed net distributions took place in each of the three countries prior to survey data collection. While sensitization campaigns accompany most mass distributions, details about SBCC coverage, message exposure, and message recall are only available for a program in Nigeria, namely the Support to the National Malaria Programme (SuNMaP) funded by UKaid, and the NetWorks project funded by the U.S. President's Malaria Initiative (Kilian *et al.*, 2016). In that instance, over half of respondents in ten different states were exposed to multi-channel SBCC and positive attitudes towards nets were positively associated with the number of messages recalled.

Sampling Design and Participant Characteristics

The sampling design was similar across the three surveys. Study participants were selected through a multi-stage random sampling process that involved first selecting—with probability proportional to size—districts, local government areas, or communes depending on the country, then clusters or enumeration areas, and finally households with at least one child under five years old. In each selected household, a child under five years old was randomly selected and the mother of that child was invited to participate in the caregiver survey. In our experience, household heads and caregivers are able to describe not only their own behavior, but that of other members of the family with a fairly high level of reliability. This is especially true for observable behaviors like sleeping under a bed net. We anticipated little additional informational value from multiple interviews in the same household, so opted to interview the caregiver of only one under-five child in each household and distribute the sample across a wider variety of households. In addition, in one third of the selected households, the head of household (if he/she was not the same as the caregiver) was also interviewed to obtain the perspective of the key decision-maker in the household. The multistage sampling design was taken into consideration in calculating the sample size. We applied a design effect of 2.0. Sample weights were not available; so, they were not used in the analyses. The sampling strategy yielded 2,390 households in Madagascar, 3,202 in Mali, and 3,616 in Nigeria. Using a structured household survey questionnaire, information on ownership and use of bed nets was collected on all household members: 12,834 in Madagascar, 19,345 in Mali, and 16,832 in Nigeria. In this manuscript, we merged household-level data with data from the caregiver survey to assess the correlates of household members' net use. Specifically, from the household data, we derived bed net use information and sociodemographic characteristics of individual household members, while data on female caregivers' sociodemographic and ideational variables were derived from the individual caregiver questionnaire.

Variables

In this study, the dependent variable was whether an individual slept under a bed net on the night before the survey, as reported in the household questionnaire. The variable was derived from a question that asked who slept under each net available, as enumerated in a household net roster, following the Roll Back Malaria Monitoring and Evaluation Working Group's recommendations (Roll Back Malaria Monitoring and Evaluation Reference Group Survey and Indicator Task Force, 2013). Net brand was not recorded consistently, therefore determining a net's status as an ITN was not possible; however, the majority of bed nets in each country are ITNs as observed in recent surveys—94% in Madagascar in 2013, 97% in Nigeria in 2015, and 95% in Mali in 2015 (Institut National de la Statistique (INSTAT) *et al.*, 2013; National Malaria Elimination Programme (NMEP) *et al.*, 2016; Programme National de lutte contre le Paludisme (PNLP) *et al.*, 2016). We assessed the predictive value of 25 independent variables measured at the individual, household, and community levels, including household size and the number of nets owned, and the following female caregiver-specific variables:

- education level and religion;
- radio-listening and television-viewing habits;
- exposure to malaria related-information on media or through community sources;
- perceived severity of malaria*;
- perceived susceptibility to malaria*;
- perceived self-efficacy to prevent malaria*, to detect a severe case of malaria*, or to procure enough nets for all members of her household*;
- perceived response efficacy to bed nets*;

- knowledge of fever as a symptom of malaria and of mosquitoes as the cause of malaria*;
- discussion of malaria with friends and family during the last 12 months*;
- participation in decisions about net allocation with in the household*;
- attitudes toward bed nets*;
- perception about bed net use being the norm in their community*;
- awareness of a place to purchase nets*; and
- willingness to pay for nets*.

A cumulative ideation score was then calculated as the sum of the number of ideational variables that are positively associated with bed net use in each country (among the items with * above), producing an ideation score.

In addition to the main models that included the individual ideational variables, other models that substituted a composite core—the sum of the number of positive individual ideational variables for each respondent—were tested to assess the cumulative predictive power of ideation. In addition, we calculated an interaction term between age and sex in the estimated models for all three countries.

Analysis

We used both bivariate and multivariate analytic methods. The bivariate method compares net use across sociodemographic groups and reports the significance of the differences. Logistic regression was the main multivariable analytic method used and was limited to individuals from households with at least one net and at least one child under 5 years old, representing 73% of households in Madagascar, 97% in Mali, and 79% in Nigeria. We report both the odds ratios and the fully-standardized beta coefficients for the regression models to demonstrate both the size of the effect as well as to determine which of the independent variables have the greatest impact on net use.

2.3 Results

In this section, we report the analysis results for each country separately, then summarize findings across all three countries in the discussion section.

Madagascar

Bivariate analysis

Overall, almost three-quarters (73.3%) of residents of households with at least one net slept under a net. Among these households, net use varied significantly by zone of residence: 39.4% in the Highlands compared to 71.4% in Sub-Desert, 72.9% in Tropical, and 82.3% in Equatorial (X^2=447.3; $p<0.001$). Significant differences by age were identified: 79.9% of children under five years old slept under a net compared to 54.5% among children aged 5–17 years, and 80.1% of adults (X^2=469.8; $p<0.001$). Significant differences by gender were also found, with net use being more common among females (75.5%) than for males (70.9%) ($z=4.95$; $p<0.001$).

Multivariate Analysis

Results of the multivariate logistic regression indicate that the significant demographic predictors of net use among household members are the individual's age, zone of residence, household wealth, household size, and number of nets in the household. Also significant were the female caregiver's television viewing and her level of exposure to malaria-related communication messages. There were no significant interactions between age and gender (Table 2.1).

Among males, household members aged 5–17 years were 59% less likely than boys under five years old to sleep under a net. There was no significant difference in net use between adult males and male children under five years old. Among children under five years old, gender did not make a difference in the odds of net use. Additionally, being female did not significantly moderate the relationship between age and net use. The relationship of net use and household wealth was such that the only significant difference was found between those in the lowest quintile and their peers in the fourth quintile. The relationship between net use and household size was negative. For example, people from households with nine or more members were 85% less likely than those from households with fewer than five members. Furthermore, having three or more nets in the household increased the odds of net use almost three-fold compare to having one or two nets.

Whereas female caregiver's regular radio listenership (at least once a week) made no difference in individual member's net use by 15%, regular television viewership (at least once a week) increased the odds by 35%. The female caregiver's low exposure to malaria-related communication messages (one or two messages recalled) did not make a difference compared to no exposure; however, a high level of exposure (three or more messages recalled) was associated with a 45% percent higher likelihood of household member's net use.

Significant ideational variables for female caregivers included perceived self-efficacy to prevent malaria, perceived self-efficacy to detect malaria, perceived self-efficacy to obtain enough nets for members of her household, perceived response efficacy of nets, descriptive norm about nets, awareness about where to procure nets, and level of participation in decisions regarding net allocation within the household. Residents of households where the female caregiver demonstrated perceived self-efficacy to prevent malaria were 57% more likely to sleep under a net than those in households where the female caregiver did not demonstrate such belief. Similarly, the female caregiver's self-efficacy to detect a severe case of malaria was associated with a 16% increase in the odds of household member use of net while the caregiver's perceived self-efficacy to obtain enough nets for her household was associated with a 34% increase in the odds. Female caregiver's belief that net use was the norm in her community increased the odds of household member's net use by 39% while her awareness of where to procure a bed net increased the odds by 28%. Finally, members of a household in which the female caregiver participates in net allocation decisions were 34% more likely to sleep under a net than those in households where the woman did not participate in such decisions.

A look at the magnitude of the fully standardized beta coefficients reveals that the most important predictors of household members' net use were the individual zone of residence, number of nets in the household, and household size and age, in order of importance. Among the female caregiver's ideational variables, the most important were descriptive norms (perceptions about how other people behave), perceived self-efficacy to procure enough nets for the household, participation in household net allocation decisions, perceived self-efficacy to prevent malaria, and awareness of where to procure nets.

Figure 2.2 shows a graduated, dose-response relationship of net use with ideation score, controlling for all other non-ideational variables. The percent who slept under a net on the night before the survey increased from 54.5% in households where the female caregiver had zero positive ideational variables (out of six) to 83.2% in households where the female caregiver had all six positive ideational variables. When the composite ideation score (mean=4.13, SD=1.18) was substituted for the individual ideational variables in a logistic regression, the results indicate a strong positive relationship, controlling for all other non-ideational variables. Specifically, a one-point increase in the caregiver's ideation score increases the household member's odds of sleeping under a net by about 37%.

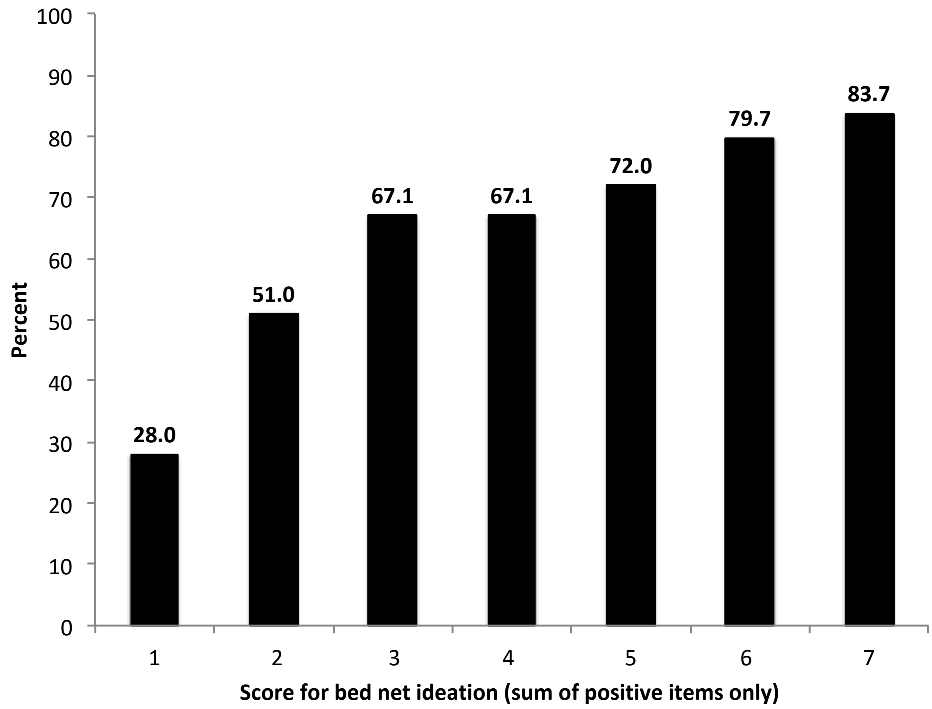

Figure 2.2 Percent of household members who slept under bed net by female caregiver's malaria ideation score, Madagascar, 2014.

Mali

Bivariate Analysis

In Mali, possession of nets was almost universal in 2014-2015: only 3.1% of the households in the study regions did not have at least one bed net. Net use information was available for 19,345 household members (9,436 males and 9,909 females). The majority of household members (82.1%) slept under a net on the night preceding the survey. Differences by gender, age group, and region of residence were significant. More than four-fifths (85.3%) of females compared to 78.7% of males slept under a net on night before the survey ($z=14.2$; $p<0.001$). Net use was less prevalent among older children aged 5–17 years (76.2%) compared to children under five (88.4%) and adults (84.1%) ($X^2=298.3$; $p<0.001$). Variations by region of residence were also noticeable, varying from 78.5% in Koulikoro to 87.3% in Sikasso ($X^2=155.4$; $p<0.001$).

Multivariate Analysis

Results of the multivariate logistic regression revealed that the predictors of net use in Mali operate at various levels and include age, gender, number of nets in the household, and region of residence (Table 2.1). Other significant demographic predictors include household wealth, household size, and level of education of the female caregiver.

Among males, the odds of net use were significantly lower among boys aged 5–17 years (67% lower) and men (63% lower) compared to children under five. Among children under five, there was no difference between boys and girls in the odds of net use. The association of age with net use depended on gender: being female attenuated the negative relationship of bed net use with age. There was a graduated reduction in the odds of net use across wealth quintiles such that the odds of net use were about 35% less in households in the highest quintile and 15% less in households in the middle quintile compared to the poorest households. The relationship of net use with household size was negative: each additional household member decreased the odds of net use by 17%. In contrast, the relationship with the number of nets was positive: people in households with three or four nets were almost three times as likely and those in households with five or more nets were almost six times as likely to use a net compared to their peers in households with one or two nets. Whereas there was no difference between Koulikoro and Bamako, the residents of Sikasso and Mopti were significantly more likely to use a net compared to their peers in Koulikoro.

The association of net use with caregiver's education was negative in Mali, with members of households where the woman has post-primary education being about 15% less likely to use a net compared to their peers in households where the woman had primary education or less. Female caregiver's regular radio listening was not associated with net use, but regular television viewing increased the odds of household members' net use by 23%. The caregiver's exposure to malaria-related messages made no significant difference in net use independently of what was attributable to general media habits.

In terms of ideational variables, there was a strong positive association with caregiver's awareness of fever as a symptom of malaria and mosquito as the cause of malaria. Similarly, the relationship with caregiver's perceived self-efficacy to obtain enough nets for members of her family was positive and significant. Rather surprisingly, household members' net use was negatively associated with the female caregiver's perceived self-efficacy to detect a severe case of malaria.

Examination of fully standardized beta coefficients revealed that the most important determinants of household members' net use were age, household size, and number of nets. The most important caregiver's ideational variables were her malaria-related knowledge and her perceived self-efficacy to obtain enough nets for members of her.

The multivariable logistic regression that included the overall ideation score (mean=2.73, SD=1.08) in place of the individual ideational variables revealed a dose response relationship between caregiver's ideation score and household members' net use. For example, the odds of household member net use was more than twice (2.06) as high in households where the female caregiver scored three out of three on the positive ideation score compared to households where the female caregiver scored zero out of three.

Nigeria

Bivariate Analysis

In Nigeria, only one-third (33.7%) of residents of households with at least one net slept under a net. Among these households, net use varied significantly by state of residence: 32.1% in Akwa Ibom compared to 38.2% in Kebbi and 29.9% in Nasarawa (X^2=92.6; p<0.001). There were also significant differences by age: 44.7% of children under five years old slept under a net compared to 24.4% among children age 5–17 years and 32.9% of adults (X^2=463.3; p<0.001). There were also significant differences by gender with net use being more common among females (36.2%) than males (31.1%) (X^2=48,1; p<0.001).

Multivariate Analysis

Results of the multivariate logistic regression indicate that the significant predictors of net use among household members are household size, age, state of residence, number of nets, and being of Christian faith, in order of magnitude. Among males, compared to children under five, 5–17 year olds (50.2% lower) and adults (55.2% lower) were significantly less likely to have slept under a net. There was no significant sex difference among children under five. When looking at the interaction between age and gender, being female significantly improved the odds of adult net use. Unsurprisingly, as household size increased, odds of using a net decreased. For example, the likelihood of net use was about 79% lower for people from households with ten or more members compare to those from households with fewer than five members. There was a negative dose response association between net use and number of nets (a 12% decrease in likelihood), which is opposite of what we found in Madagascar and Mali. The odds of using a net were significantly higher in Kebbi (49%), but not in Nasarawa or Akwa Ibom. Respondents of Christian faith were 15% less likely to use a net than those practicing other religions.

Use of radio or television and reported level of exposure to malaria messages by the female caregiver were not significant predictors of net use in Nigeria. In terms of ideational variables, there was a negative relationship between net use and caregiver’s perceived severity of malaria, with the odds of net use being 12% lower among members of households where the caregiver has a higher level of perceived severity of malaria compared to their peers in household where the caregiver has a lower level of perceived severity. There was also a negative relationship between caregiver’s perceived response efficacy of nets and household members’ net use. No other ideational variables were significant in Nigeria.

Table 2.1 Results of logistic regression of household members' net use by selected sociodemographic, ideational, and household variables in Madagascar, Mali, and Nigeria.

	Madagascar		Mali		Nigeria	
Predictor	**Odds Ratio**	**Beta[1]**	**Odds Ratio**	**Beta[1]**	**Odds Ratio**	**Beta[1]**
Age group						
Under-5 (RC)	1.00	--	1.00	--	1.00	--
5 – 17	0.41***	-0.19	0.33***	-0.26	0.50***	-0.16
Adult	0.93	-0.02	0.37***	-0.24	0.45***	-0.20
Gender						
Male (RC)	1.00	--	1.00	--	1.00	--
Female	1.16	0.03	0.84‡	-0.04	1.04	0.01
Age group/Gender Interactions						
Under-5 X Male (RC)	1.00	--	1.00	--	1.00	--
5 – 17 X Female	0.98	-0.00	1.46***	0.07	1.08	0.02
Adult X Female	1.28‡	0.05	3.30***	0.25	1.67***	0.11
Household wealth quintile						
Lowest (RC)	1.00	--	1.00	--	1.00	--
Second	0.97	-0.01	0.91	-0.02	0.96	-0.01
Middle	0.85‡	-0.03	0.85*	-0.03	0.96	-0.01
Fourth	0.80**	-0.04	0.71***	-0.06	0.95	-0.01
Highest	0.99	-0.00	0.65***	-0.09	0.88‡	-0.03
Household size[2]			0.83***	-0.32		
Household size[2]						
2 – 4 (RC)	1.00	--				
5 – 6	0.45***	-0.17				
7 – 8	0.25***	-0.27				
9 +	0.15***	-0.34				
Household size[2]						
2 – 4 (RC)					1.00	1.00
5 – 6					0.53***	-0.15
7 – 9					0.36***	-0.23
10 +					0.21***	-0.31
Number of nets in household[3]						
1-2 (RC)			1.00	--		
3-4			2.72***	0.240		
5 or more			5.93***	0.415		
Number of nets in household[3]						
1 – 2 (RC)	1.00	--				
3 or more	2.79***	0.22				
Number of nets in household[3]						
0-1 (RC)					1.00	--
2					0.89***	-0.03
3 or more					0.65***	-0.10

Predictor	Madagascar		Mali		Nigeria	
	Odds Ratio	Beta[1]	Odds Ratio	Beta[1]	Odds Ratio	Beta[1]
Zone of residence						
Highlands (RC)	1.00	--				
Sub-desert	3.60***	0.28				
Tropical	2.38***	0.23				
Equatorial	5.07***	0.35				
Region of residence						
Koulikoro			1.00	--		
Sikasso			1.79***	0.13		
Mopti			1.23***	0.04		
Bamako			0.95	-0.01		
State of residence						
Akwa Ibom (RC)					1.00	--
Kebbi					1.49***	0.10
Nasarawa					1.10‡	0.02
Caregiver’s education						
Primary or less (RC)	1.00	--	1.00	--	1.00	--
Post-primary	0.92	-0.01	0.85**	-0.03	0.96	-0.01
Caregiver’s religion						
Non-Christian (RC)	1.00	--			1.00	--
Christian	0.89‡	-0.03			0.86*	-0.04
Caregiver’s radio listening habits	1.00	--	1.00	--	1.00	--
Fewer than once a week (RC)	0.91	-0.02	0.98	-0.01	1.02	0.01
At least once a week						
Caregiver’s television watching habits						
Fewer than once a week (RC)	1.00	--	1.00	--	1.00	--
At least once a week	1.35**	0.04	1.23***	0.05	1.03	0.01
Caregiver’s exposure to messages on malaria						
No exposure (RC)	1.00	--	1.00	--		
Low	0.98	-0.01	0.96	-0.01		
High	1.45***	0.07	0.90	-0.02		
Heard messages on malaria					0.96	-0.01
Caregiver’s perceived severity of malaria						
Lower (RC)	1.00	--	1.00	--	1.00	--
Higher	0.97	-0.01	0.97	-0.01	0.88**	-0.03
Caregiver’s perceived susceptibility to malaria						
Lower (RC)	1.00	--	1.00	--	1.00	--
Higher	1.00	-0.00	1.00	-0.01	0.93‡	-0.02

	Madagascar		Mali		Nigeria	
Predictor	**Odds Ratio**	**Beta[1]**	**Odds Ratio**	**Beta[1]**	**Odds Ratio**	**Beta[1]**
Caregiver's perceived self-efficacy to prevent malaria						
Lower (RC)	1.00	--	1.00	--	1.00	--
Higher	1.57***	0.06	1.07	0.02	1.03	0.01
Caregiver's perceived self-efficacy to detect a serious case of malaria						
Lower (RC)	1.00	--	1.00	--	1.00	--
Higher	1.16**	0.03	0.94	-0.01	0.99	-0.00
Caregiver's perceived response-efficacy of nets						
Lower (RC)	1.00	--	1.00	--	1.00	--
Higher	1.14	0.02	1.06	0.01	0.92*	-0.02
Caregiver's awareness that fever is a symptom of malaria						
Not aware (RC)	1.00	--	1.00	--		
Aware	0.98	-0.00	1.16***	0.04		
Caregiver's awareness that mosquito is the cause of malaria						
Not aware (RC)	1.00	1.00	1.00	--	1.00	--
Aware	0.98	-0.00	1.36***	0.05	0.93	-0.01
Caregiver's perceived self-efficacy to purchase enough nets						
Lower (RC)	1.00	--	1.00	--		
Higher	1.34***	0.07	1.20***	0.04		
Discussed malaria with friends/relations	1.06	0.01			1.00	-0.00
Participates in decisions about net allocation	1.34***	0.06			1.00	-0.00
Attitudes towards nets						
Negative (RC)	1.00	--			1.00	--
Positive	1.02	0.01			0.97	-0.01
Perceived net use as the norm among in community	1.39***	0.07			1.02	0.01
Knows where to buy nets	1.28***	0.06			1.02	0.01
Willing to pay for nets	1.02	0.00			1.04	0.01
Pseudo-R^2	17.1%		9.9%		8.6%	
Hosmer-Lemeshow GOF[2] (X^2/p)	15.3/0.08		15.5/0.08		14.9/0.09	
Number of Observations	9,260		19,345		15,463	

	Madagascar		Mali		Nigeria	
Predictor	**Odds Ratio**	**Beta[1]**	**Odds Ratio**	**Beta[1]**	**Odds Ratio**	**Beta[1]**

Notes: ‡ p<0.1; * p<0.05; ** p<0.01; *** p<0.001.

[1] Fully (XY) standardized beta coefficients.

[2] Household size was not normally distributed in Madagascar and Nigeria. The variable was differently categorized in the two countries in a way that helps to ensure model fit

[3] Number of nets was not normally distributed in any of the study countries. The variable was differently categorized in the three countries in a way that helps to ensure model fit

[4] GOF = Goodness of Fit

RC = reference category

X = interaction term

2.4 Discussion

The ideation model of communication and behavior change has been used effectively in a number of health domains to guide the strategic design and evaluation of health communication interventions, but it has received relatively little attention in malaria prevention efforts. This study attempted to compare the dynamics of ideation and behavior in three countries in order to determine how it differs by context. Results indicate that a more diverse set of ideational factors play a role in household bed net use in Madagascar compared to Mali or Nigeria, and that the strongest ideational predictors of bed net use vary from one country to another, although efficacy-related variables appear to be important in all three settings. In our view, this demonstrates the usefulness of ideation as a conceptual tool that can help researchers and program planners identify common psychosocial variables and systematically examine how they influence malaria-related behavior in a particular programmatic context, controlling for prevailing local conditions.

The role of independent demographic variables

In terms of demographic predictors of bed net use, there were more similarities than differences across the three countries analyzed in this study, even though Madagascar and Mali had much higher rates of bed net use (73% and 82%, respectively) compared to Nigeria (34%). In all three countries, children under five years old were more likely to sleep under a bed net compared to older children aged 5–17 years (and adults, except in Madagascar). Also in all three countries, the odds of bed net use were lower on average in larger households. The documented relationships with age and household size are consistent with what other studies have found in Africa and elsewhere (Nuwaha, 2001; Panter-Brick *et al.*, 2006; Ng'ang'a *et al.*, 2009; Biadgilign, Reda and Kedir, 2012; Babalola *et al.*, 2016). Also in Madagascar and Mali, bed net use was higher in the poorest households compared to wealthier households. Only in Mali were families whose caregivers had lower levels of education significantly more likely to use bed nets than families whose caregivers had more education. In Nigeria, Christians were less likely to use bed nets than Muslims. Findings of this nature can help programmers to target subgroups that are at higher risk.

In Madagascar and Mali, households with caregivers who regularly watched television were more likely to report bed net use. Consistent with findings from other studies, in Madagascar, caregivers' higher malaria message recall was associated with higher rates of bed net use (Jombo *et al.*, 2010; Kilian *et al.*, 2015; Ricotta *et al.*, 2015; Babalola *et al.*, 2016). The reasons for the lack of significant association between caregiver's exposure to malaria messages and bed net use in Mali and Nigeria were not clear; we know little about the intensity or content of malaria messages except in Nigeria, so it is hard to attribute the findings to the reach or quality of the information provided. The overall lower use of bed nets in Nigeria may result in lower salience of malaria messaging, which would reduce motivations to pay attention to and process malaria information, even though communication campaigns were underway.

Effects of independent ideational variables

In terms of ideational predictors of bed net use, multiple factors were positively correlated with net use in Mali and Madagascar. Counterintuitively, in Nigeria, the higher the caregiver's perceived severity of a malaria infection or her perceived response efficacy of nets (i.e., belief that bed net use can prevent infection), the lower the reported bed net use. Some conceptual frameworks that focus on threat and efficacy as predictors of behavior see high perceived risk as potentially debilitating—a frightened person may not take action to counter a disease threat if there is no accompanying belief in one's ability to manage the threat (Rogers, 1975, 1983; Witte, 1993; Rogers and Prentice-Dunn, 1997). Sometimes self-efficacy can result in lower rates of behavior if it takes the form of overconfidence to control threats and achieve health outcomes (Stone, 1994; Pajares, 1997; Vancouver and Kendall, 2006; Moore and Healy, 2008). This may be the case in Nigeria, where there was no evidence that self-efficacy perceptions—self-efficacy to detect or prevent malaria or self-efficacy to obtain bed nets—were associated with bed net use. People may feel so confident in their ability to detect and treat a severe case of malaria that they feel less threatened by the disease, and are therefore less motivated to sleep under a net.

In Mali, consistent with findings from many previous studies, knowledge about malaria played a role in motivating behavior: people who knew that fever is a symptom of malaria and who knew that mosquitoes spread malaria were more likely to report bed net use (García-Basteiro *et al.*, 2011; Biadgilign, Reda and Kedir, 2012; Esimai and Aluko, 2014). This finding was in contrast to what we found for the other two study countries. Without more information about existing malaria communication in Mali, it is difficult to know why these differences exist. Some malaria programs in sub-Saharan Africa emphasize rapid careseeking in response to fever as part of large scale “test and treat” campaigns. Such programs would draw attention to information about malarial fever caused by mosquitos versus non-malarial fever and the importance of being tested to know the difference. In such a case, a stronger association between mosquitos and fever could result in greater interest in bed net use to prevent both. Future analysis of how malaria campaigns with different emphases may reinforce (or interfere with) each other would be useful.

In Madagascar, self-efficacy to prevent malaria and self-efficacy to obtain bed nets were associated with higher reported net use, echoing findings from other studies, including a similar study conducted in Liberia (Babalola *et al.*, 2016). Unlike Mali, in Madagascar self-efficacy to detect a severe case of malaria was positively associated with net use. Also in Madagascar three additional ideational variables were positive predictors of bed net use: the belief that bed net use was the community norm, knowing where to obtain a bed net, and participation at the household level in decision-making about who would sleep under a bed net. Why more ideational variables were significant in Madagascar compared to Mali or Nigeria is not clear. One the one hand, greater familiarity or experience with an issue is often associated with greater cognitive elaboration; if malaria communication (whatever its content) is more intensive or far-reaching in one place compared to another, that could explain more nuanced perceptions about disease threat and prevention. On the other hand, where exposure to information has been low, the introduction of an information campaign can have novelty effects—people learn a lot very quickly—whereas familiarity with an issue sometimes results in more counter-arguing and rejection of new information. More research on the history and content of malaria communication in these countries would be needed to determine which explanation is more likely.

As summarized in Table 2.2, of the 14 ideational variables examined in this study, six were significant predictors of bed net use in Madagascar (all positively), four were significant predictors of bed net use in Mali (one negatively), and only two were significant predictors in Nigeria (both negatively).

Madagascar and Mali share only one of the ideational predictors: self-efficacy to obtain enough bed nets for your household. Self-efficacy to detect malaria was also a significant predictor in those two countries, but positively in Madagascar and negatively in Mali. In Nigeria, perceived severity of malaria and perceived response efficacy of nets were the only ideational variables associated (negatively) with bed net use. This finding suggests that structural and demographic barriers as well as psychosocial influences may need to be addressed as determinants of bed net use in that country.

It is important to note that another study in Nigeria that included measures of female caretakers' malaria-related ideation (Babalola, Okoh and Berg, 2016) found it to be significantly associated with the caretaker's own use of a bed net, rather than bed net use by members of her household. Other factors may also explain why household bed net use is more weakly correlated with caretaker's ideation in Nigeria. For example, it may be that female caregivers in Nigeria have less agency to influence bed net use by other members of the household compared to female caregivers in Mali and Madagascar, thus weakening the causal link between caregiver ideation and household member behavior.

Table 2.2 Summary of ideational predictors of bed net use, by country.

	Country		
Predictor	**Madagascar**	**Mali**	**Nigeria**
Perceived severity of a malaria infection	ns	ns	–
Self-efficacy to detect severe case of malaria	+	ns	ns
Self-efficacy to prevent malaria	+	ns	ns
Self-efficacy to obtain enough nets for the household	+	+	ns
Response efficacy (belief that nets are effective)	ns	ns	–
Perceived community norm of bed net use	+	na	ns
Knowledge of where to get bed nets	+	na	ns
Knowledge that fever is a sign of malaria	ns	+	ns
Knowledge that mosquitos are the malaria vector	ns	+	ns
Participating in decision-making about net allocation	+	na	ns
Number of positively significant ideational predictors of bed net use	6	3	0

Key: + (positively relationship), − (negatively significant), ns (not significant), na (not measured)

Implications for effective malaria social and behavior change strategies

It is essential to note that age, region, household size, and number of nets in the household were the strongest predictors of bed net use, demonstrating that families are prioritizing younger children, consistent with recent studies (Ricotta *et al.*, 2014), and that the primary barriers to bed net use are still largely due to access. Controlling for these structural barriers permits SBCC programs to then isolate pertinent ideational variables. Of all the ideational variables examined in these three countries, those that were the most consistently significant predictors of bed net use were related to efficacy perceptions: self-efficacy to obtain bed nets for your household and self-efficacy to detect malaria. This suggests that efficacy-based communication strategies are likely to produce desirable results. Programs should emphasize increasing and reinforcing the head of household’s and caregiver's confidence in responding to the threat of malaria and their correct and consistent net use as a preventive measure. The widely validated social learning approach of modeling effective behavior (Bandura, 1992) could be used to show or describe locally acceptable and identifiable examples of effective net use and other preventive behaviors in an effort to build local self-confidence in malaria prevention. Showing how nets can be obtained and used may be particularly important in places like Nigeria where net use and the access to use ratio are low to begin with, and might complement expanded distribution efforts and accelerate uptake. Finally, while we cannot confirm the relationship between female agency and decision making using the current datasets, it may be important in settings where caregivers have less household authority to influence decision makers or other female caregivers in the same household. In such settings, modeling efficacious communication in the household about bed net use could be beneficial.

This study also provides support for the hypothesis of a cumulative impact of ideational variables. In Madagascar and Mali, where multiple ideational variables were significant predictors of bed net use (controlling for the effect of household and sociodemographic variables), bed net use was higher when more ideational variables were positive. This suggests that it may be effective to bundle more than one ideational variable into program messaging, for example, by addressing multiple aspects of self-efficacy and malaria knowledge in an integrated communication strategy.

Limitations of this study

The use of bed nets by household members was determined through an enumeration of household residents, of the nets available in the household, and through subsequent questions about who slept under each of those nets on the night prior to the survey. This produced an outcome variable representing whether an individual slept under a net the night before the survey. Yet, data on ideational variables were collected only from the female caregivers of a selected child under five years old in each household. Our analysis assumes that what a particular female caregiver—who may be only one of several caregivers in the household—knows, thinks, and feels about malaria and bed net use will have an impact on the bed net use patterns of the entire household. Ultimately, bed net use is a volitional behavior, particularly for older children and adults who may have the power to make their own choices and are therefore influenced by their own individual attitudes, beliefs, and preferences as opposed to those of the female caregiver who was interviewed. While our data indicate that can be a positive relationship between female caregiver ideation and household net use, controlling for numerous other household and demographic variables, the actual causal pathways are undoubtedly more complicated. Future studies may wish to collect ideational data from more than one individual in a household or, perhaps, include more questions about the content of interpersonal discussion of malaria prevention and net use among household members, in order to better understand the broader household context of net use decisions.

2.5 Conclusions

While the strongest predictors of net use among households with at least one bed net were age, region, household size, and number of nets, this study has demonstrated the importance of controlling for these variables when trying to identify the ideational variables that influence caregiver bed net use in three African countries, because the relevant ideational variables varied across countries. In Madagascar, the two most significant ideational predictors of bed net use were the caregiver's descriptive norm about bed net use and her awareness of where to procure a bed net. In Mali, the most important caregiver's ideational variables were her perceived self-efficacy for obtaining bed nets and her malaria-related knowledge. While no ideational variable was positively linked with bed net use in

Nigeria, this finding calls for additional study to identify other possible social, structural, and supply-side explanations for bed net use.

In short, this research suggests that integrating more than one ideational variable—such as malaria knowledge and one or more aspects of self-efficacy—into program messaging, could result in a more effective integrated communication strategy.

Ethics approval

Ethical clearance for all three surveys was obtained from The Johns Hopkins Bloomberg School of Public Health Institutional Review Board (IRB) and local IRB in Madagascar (Ministry of Health), Mali (Institut National de Recherche en Santé Publique), and Nigeria (National Health Research Ethics Committee). In all three countries, interviewers obtained oral informed consent from participants prior to the interviews. Written consent is uncommon for minimal risk studies in all three countries for two reasons: (1) literacy levels are generally low and (2) no personal identifiers were collected for the survey, so a participant's signature on a consent form would represent an unnecessary identifier that could link a participant to her/his data. All three local IRBs approved this process.

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Chapter 3: Correlates of Intra-Household ITN Use in Liberia: A Multilevel Analysis of Household Survey Data

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Abstract

Background: Malaria is a major cause of morbidity and mortality in Liberia. At the same time, insecticide-treated net (ITN) ownership and use remain low. Access is a key determinant of ITN use but it is not the only one; prior studies have identified factors that affect the use of ITNs in households with at least one ITN. These factors operate at the individual, household, and community levels. However, studies have generally not assessed the psychosocial or ideational determinants of ITN use.

Methods: Using 2014 household survey data, this manuscript examines the socio-demographic, ideational, household, and community factors associated with household member use of ITNs in Liberia. Multilevel modeling was used to assess fixed effects at the individual, household, and community levels, and random effects at the household and cluster levels.

Results: The data showed significant residual clustering at the household level, indicating that there were unmeasured factors operating at this level that are associated with ITN use. The association of age with ITN use was moderated by sex such that men, older children, and teenagers were less likely to sleep under an ITN compared to women and children under five years old. Female caregivers' perceived severity of malaria, perceived self-efficacy to detect a complicated case of malaria, and exposure to the "Take Cover" communication campaign were positively associated with ITN use by members of her household. The association with household size was negative, while the relationship with the number of ITNs was positive. **Conclusions:** Programs should seek to achieve universal coverage (that is, one ITN for every two household members) and promote the notion that everyone needs to sleep under an ITN every night. Programs should also seek to strengthen perceived severity of malaria and educate intended audience groups on the signs of malaria

complications. Given the significance of residual clustering at the household level, interventions that engage men as heads of household and key decision-makers are relevant.

3.1 Introduction

Malaria is endemic in Liberia, representing a major cause of morbidity and mortality, and a leading cause of outpatient attendance and in-patient deaths in 2014 (Ministry of Health and Social Welfare Republic of Liberia, 2014). Children and pregnant women are the most affected by the disease. Rapid diagnostic testing conducted as part of the 2011 Malaria Indicator Survey revealed that 45% of children aged 6–59 months had malaria; microscopy revealed a lower prevalence (28%) (National Malaria Control Programme Republic of Liberia *et al.*, 2011). The microscopy test results indicated that malaria prevalence increased monotonically with age from 9.6% among children aged 6–8 months to 35.4% among those aged 48–59 months. Other factors associated with variations in malaria prevalence among children included rural residence, county of residence, mother's education, and household wealth quintile.

Insecticide-treated nets (ITNs) provide a physical barrier between humans and mosquitoes; the insecticide used on the nets also repels and kills mosquitoes. ITNs have been shown to lead to significant reductions in parasite rates in children under five years old and all-cause child mortality (Lengeler, 2004; Fegan *et al.*, 2007; Eisele, Larsen and Steketee, 2010). Additionally, there is evidence that ITN use by a majority of the community provides some level of protection even to those who are not using them, as it helps to reduce overall malaria transmission (Killeen *et al.*, 2007).

The government of Liberia is committed to reducing the burden of malaria in the country as evidenced in the 2010–2015 National Malaria Strategic Plan, which is the most recent national guidance available for Liberia (Ministry of Health and Social Welfare Republic of Liberia, 2014). The strategic plan builds on the two previous national malaria strategic plans and articulates strategies designed to reduce malaria morbidity and mortality, and reduce the incidence of malaria by 2015. The strategic plan has specific targets and strategies focused on each of the following four strategic areas: malaria case management, intermittent preventive treatment in pregnancy (IPTp), integrated vector control (including use of ITNs and indoor residual spraying (IRS)), and behavior change. Additionally, the plan recognizes the need to strengthen the capacity of the National Malaria Control Program in the development, management, and evaluation of malaria programs. The strategies articulated in the strategic plan are geared towards increasing prompt and effective treatment of malaria in children under five years old, increasing the uptake of IPTp for pregnant women, increasing access to IRS and ITNs in households, and increasing ITN use by children and pregnant women. Regarding ITN use, one of the key objectives of the National Malaria Strategic Plan seeks to increase the use of long-lasting insecticide-treated nets (LLINs) to 80% among children and pregnant women by 2010 and sustain this level of use through 2015.

Results of the 2013 Demographic and Health Survey showed that 55% of households in Liberia had at least one ITN while only 22% of households had universal coverage (Liberia Institute of Statistics and Geo-Information Services *et al.*, 2013). Only 38% of children under five and 37% of pregnant women slept under an ITN on the night preceding the survey. In households owning at least one ITN, 63% of both groups slept under an ITN the previous night.

In order to provide optimum protection, ITNs must be used regularly by all members of a population. Reasons for ITN use differ, but include the protection they offer from nuisance mosquitoes, perceived density of mosquitoes in one’s surroundings (Yohannes *et al.*, 2000; Beer *et al.*, 2012; Moiroux *et al.*, 2012; Koenker *et al.*, 2013), and quality of the ITN (Batisso *et al.*, 2012). The reasons often provided for non-use of ITNs include perceived heat, perceived discomfort of sleeping under an ITN, perceived low mosquito density, torn or worn ITNs, perception that the ITN was not needed, and unavailability of ITNs (lack of access) (Pulford *et al.*, 2011; Beer *et al.*, 2012; Allen and Shuford, 2014; Kilian *et al.*, 2015).

Access is a key determinant of ITN use but not the only one. Studies that have focused on the factors associated with ITN use have highlighted the roles of age (Nuwaha, 2001; Panter-Brick *et al.*, 2006; Ng'ang'a *et al.*, 2009; Kulkarni *et al.*, 2010; Rickard *et al.*, 2011; Tchinda *et al.*, 2012), sex (Panter-Brick *et al.*, 2006; Ng'ang'a *et al.*, 2009; Tchinda *et al.*, 2012; Loha, Tefera and Lindtjørn, 2013), and pregnancy status (Kulkarni *et al.*, 2010). Other factors found to be associated with variations in ITN use include household size (Ng'ang'a *et al.*, 2009; Biadgilign, Reda and Kedir, 2012), and socio-economic status (Nuwaha, 2001; Jombo *et al.*, 2010). Studies have also found a positive relationship between exposure to social and behavior change communication (SBCC) messages and ITN use in various settings (Biadgilign, Reda and Kedir, 2012; Bowen, 2013; Boulay, Lynch and Koenker, 2014; Owusu Adjah and Panayiotou, 2014; Kilian *et al.*, 2015; Ricotta *et al.*, 2015). In addition to these socio-demographic and program exposure variables, it is important to understand the cognitive, emotional, and social interaction factors that influence health behaviors. In the case of ITNs, these factors include knowledge, personal beliefs in one's ability to obtain and use ITNs properly, perceived threat, perceived ITN efficacy, interpersonal communication, perceived social support, and social norms. For example, possessing accurate malaria knowledge has been found to be a strong predictor of ITN use in some settings (Nganda *et al.*, 2004; Macintyre *et al.*, 2006; García-Basteiro *et al.*, 2011; Biadgilign, Reda and Kedir, 2012; Esimai and Aluko, 2014). Similarly, beliefs that malaria is not a serious problem (low threat) and that the ITN is not effective in preventing malaria (low response efficacy) can contribute to low ITN use (Baume, Reithinger and Woldehanna, 2009; Banek, Kilian and Allan, 2010; Beer *et al.*, 2012).

The combination of these cognitive, emotional, and social interaction concepts is called "ideation." Ideation is a concept frequently used in the family planning and HIV community as a way to understand people's readiness to adopt health protective behaviors (Kincaid, 2000a; Babalola and Vondrasek, 2005; Nguyen *et al.*, 2012). Ideation has only recently been explored in the malaria literature as a way to understand how mass media campaigns and community mobilizers influence the number of ITNs per person in a household (Ricotta *et al.*, 2015).

Objectives

Using household survey data collected between March and April 2014, this study evaluates the role of socio-demographic characteristics, caregiver ITN ideation, household characteristics, and community factors in ITN use among household members. The tested hypothesis is that the factors affecting ITN use operate at individual, household, and community levels. What differentiates this study from most previous studies is its focus on the role of ideational characteristics and unmeasured factors operating at the household and community levels in intra-household ITN allocation.

3.2 Methods

Study Setting

The study took place in four counties of Liberia in 2014, just prior to rainy season: Bong, Cape Mount, Grand Kru and Rivercess. Malaria prevalence among children under five years old (measured by rapid diagnostic test) was generally high in these counties and varied from 41.6% (95% CI: 33.9–48.7) in Bong to 69.5% (CI: 50.9–83.3) in Grand Kru (secondary analysis of MIS 2011 data performed by lead author). The four counties represented two endemicity strata in Liberia: Bong and Rivercess which have a malaria prevalence below the national average, and Grand Kru and Cape Mount which have a malaria prevalence above the national average.

Study Design and Procedures

The data presented were derived from a cross-sectional household survey conducted in Liberia in 2014 by the Johns Hopkins Center for Communication Programs. A total of 1200 households were randomly selected from the four counties. The sample size was adequate to detect a 10-percentage point difference in ITN use between the two malaria endemicity strata. Households were selected through a multistage process that involved randomly selecting enumeration areas (clusters) with a probability proportional to size and then households from each study county. Only households with at least one child under the age of five years were eligible for participation in the survey. In selected households, a woman with a child aged less than five years old was randomly selected for interview. Through the household questionnaire, ITN use information was collected for 6,463 household members. The data analyzed in this manuscript combined ITN use information for individual household members derived from the household questionnaire with female caregivers' socio-demographic and ideational characteristics derived from the individual questionnaire.

Data Analysis

The dependent variable evaluated in this study is defined as sleeping under an ITN on the night before the survey. We limit the analysis to individuals from households with at least one ITN, representing only a little over one third of the households.

We assessed the predictive value of fifteen independent variables measured at the individual, household, and community levels and defined as follows:

- Age: Household members were divided into three age groups: 0–4 years, 5–17 years, and adults aged 18 years and above;

- Sex of household member: Male or female;
- Education level of the female caregiver interviewed in the household, assessed as none, primary, or post-primary;
- Female caregiver's perception about ITN use being the norm in their community: An ideational variable assessed through a question that asks respondents in how many households in their community do people sleep under an ITN. The response options were: All households, most households, at least half of the households, fewer than half households, or hardly any households. We distinguished between the women that responded "all" or "most" households and those that gave other responses;
- Female caregiver's perceived susceptibility to malaria: Another ideational variable assessed through seven Likert-scale attitudinal statements related to the likelihood of getting malaria. For example, "During the rainy season, I worry almost every night that someone in my family will get malaria"; and "Nearly every year, someone in this community gets a serious case of malaria". We scored each of the seven items between -2 and +2, computed a total score which we then split it at zero to denote low versus high perceived susceptibility;
- Female caregiver's perceived severity of malaria: Measured through five Likert-scale attitudinal items. For example: "When someone I know gets malaria, I usually expect them to completely recover in a few days" (reverse-coded); and "Every case of malaria can potentially lead to death". We scored each of the five items between -2 and +2, computed a total score which we then split it at zero to denote low versus high perceived severity of malaria;
- Female caregiver's perceived self-efficacy to recognize a complicated case of malaria;

- Female caregiver’s knowledge about malaria prevention: Measured as mentioning at least one correct malaria prevention method while not mentioning any incorrect prevention methods;
- Female caregiver’s perceived self-efficacy to prevent malaria in self and children.
- Female caregiver’s exposure to the “Take Cover” malaria communication campaign. The “Take Cover” campaign used radio spots, print materials and community mobilization to promote ITN use. It was first launched in 2009; the radio materials were periodically rebroadcast until the time of the survey in 2014. We defined high level of exposure to the campaign as having heard of the program from two or more media or community sources;
- Number of ITNs in household: Classified as one, two or more than two;
- Household size: The number of usual residents of the household;
- Household socio-economic status: Derived from household assets through principal components analysis and divided into quintiles;
- Number of under-five children within the household: We divided the number into one, two, or three or more; and,
- County of residence: That is, Bong, Cape Mount, Grand Kru or Rivercess.

Multilevel modeling is the main analytic method used in this manuscript. The survey data analyzed in this manuscript reflect a hierarchical nature with individuals nested within their household, which are, in turn, nested within their clusters or neighborhood. In nested data, individuals within the same units tend to be more similar than those from other units. Ordinary regression methods do not account for this clustering and tend to underestimate the standard errors of regression coefficients (Guo and Zhao, 2000). When survey data are nested, multilevel modeling is the indicated analytic approach as it helps to adjust for clustering. To further justify the use of multilevel modeling, we computed the design effect. A design effect greater than 2.0 indicates violations of the independence assumption (Maas and Hox, 2005). The design effect in our data was 11.4. In other words, clustering in the data results in over eleven-fold reduction in effective sample size compared to what would have occurred with simple random sampling.

We estimated three-level mixed effects models with fixed effects at the individual, household, and county levels, and random effects at the household and cluster levels. We estimated two models: an empty model without covariates to assess if there was significant group-level variation in ITN use, and the full model that included variables measured at the individual, household, and county levels. In multilevel models, a small number of groups and small group sizes have been documented to bias the efficiency of multilevel random parameter estimates downwards (Maas and Hox, 2004, 2005; Clarke and Wheaton, 2007). Some studies have also found that having a large number of groups compensates for the negative effects of small group sizes (Maas and Hox, 2005; Clarke and Wheaton, 2007). For example, Clarke and Wheaton (Clarke and Wheaton, 2007) found in their simulation study that when number of groups is greater than 150 the bias resulting from even extremely small group sizes is considerably reduced. In our data, we have a total of 60 clusters with size varying from 3 and 80 individuals, with a mean of 38. To minimize bias in the random components of the estimates, we follow Clarke and Wheaton (Clarke and Wheaton, 2007) and limit the analyses in this manuscript to respondents residing in clusters with at least ten individuals. This approach resulted in a loss of five groups and 29 individuals. The final sample used for the analysis comprised 2,269 individuals. We estimated the models using the *gllamm* command in Stata 13 (College Station, Texas, USA).

Ethical approval and informed consent

The Johns Hopkins Bloomberg School of Public Health Institutional Review Board (IRB) and the University of Liberia, Pacific Institute for Research and Evaluation IRB approved this survey. Only adults were enrolled into the study. Interviewers obtained verbal informed consent from all participants prior to the interviews. The researchers opted for verbal consent due to the low literacy level of a significant proportion of the study participants. The person obtaining the consent signed the consent document to attest that consent had been obtained. The two ethics committees approved this procedure.

3.3 Results

Socio-demographic characteristics of households and members

Table 3.1 provides information on the socio-demographic and ideational characteristics of the population in households with at least one ITN. Almost half (47.3%) of the population were adults, and household members were equally divided between males and females. In terms of female caregiver’s characteristics, most of the study population came from households where the female caregiver had little or no education. The ideational characteristics of the female caregivers revealed that fewer than one third (29.8%) of these women believed ITN use to be the norm among other households in their community. Nonetheless, the majority of the women believed in their susceptibility to malaria and perceived malaria to be a serious disease. Furthermore, most of the caregivers had a high level of perceived self-efficacy to prevent malaria and to detect a serious case of malaria, although the prevalence of comprehensive knowledge about malaria was low. More than half of the female caregivers (57.5%) had a high level of exposure to the “Take Cover” communication campaign.

Table 3.1 Background characteristics of people in households with at least one ITN, Liberia 2014.

Variable	N	%
Age Group		
0–4 years	611	26.9
5–17 years	584	25.8
Adult	1074	47.3
Sex		
Male	1123	49.5
Female	1146	50.5
Female caregiver’s level of education		
None	1272	56.1
Primary	754	33.2
Secondary and above	243	10.7
Female caregiver’s perceived norm about ITN use in their community		
Perceived ITN use not to be the norm	1593	70.2
Perceived ITN use to be the norm	676	29.8
Female caregiver’s perceived susceptibility to malaria		
Low	519	22.9
High	1750	77.1
Female caregiver’s perceived severity of malaria		
Did not perceive severity	732	32.3
Perceived severity	1537	67.7
Female caregiver’s knowledge about malaria prevention		
Low	1780	78.4
High	489	21.6
Female caregiver’s perceived self-efficacy to detect a complicated case of malaria		
Low	722	31.8
High	1547	68.2
Female caregiver’s perceived self-efficacy to prevent malaria for self and children		
Low	440	19.4
High	1829	80.6
Female caregiver’s exposure to “Take Cover” malaria prevention communication		
Low	964	42.5
High	1305	57.5
Household wealth quintile		

Variable	**N**	**%**
Lowest	245	10.8
Second	274	12.1
Middle	482	21.2
Fourth	586	25.7
Highest	685	30.2
Number of under-5 children in household		
One	1250	55.1
Two	671	29.6
Three or more	348	15.3
Number of ITNs in household		
One	1209	53.3
Two	681	30.0
Three or more	379	15.7
County of residence		
Bong	735	32.4
Cape Mount	604	26.6
Grand Kru	601	26.5
Rivercess	329	15.4
Number of people in households with at least one ITN	**2269**	

More than half (54.7%) of the members were from households with only one under-five child (55.1%), and most were from households with only one (53.3%) or two (30.0%) ITNs. Proportionally fewer of the members were from the lowest or second wealth quintiles than from any of the three upper quintiles. Similarly, proportionally fewer of the household members were from Rivercess County compared to any of the other three counties.

Patterns of ITN ownership, conditions, and use

A little over one third (36%) of surveyed households had at least one net. Almost all (99.1%) of these nets were ITNs; the rest were untreated nets. Overall, only 4% of the study households had enough ITNs for all household members as defined by the WHO as one ITN per two household members. Upon inspection, about three-fifths (58.3%) of the ITNs in use in the surveyed households were found to have no holes while 16.7% had very small holes (smaller than a flashlight battery); the rest (25%) had at least one hole larger than a flashlight battery. Most of the ITNs (78.7%) had been in the household for more than six months. In households with at least one ITN, two thirds (66.6%) of the members slept under an ITN on the night before the survey. This indicator varied widely by country: 85.6% in Bong, 76.3% in Cape Mount, 62.0% in Rivercess, and 36.3% in Grand Kru. A little over one tenth (12%) of the ITNs within the households were not used on the night prior to the survey. Nonetheless, in many households with ITNs, up to four persons slept under the same ITN; the median number of users per ITN was three household members.

Correlates of intra-household ITN use

We used multilevel modeling to assess the correlates of intra-household ITN use. The results of the three-level models are presented in Table 3.2. The empty model revealed significant clustering of ITN use at both the household and cluster levels. The intra-class correlation (ICC) indicates that about 24% of the variance in intra-household ITN use is attributable to factors operating at the cluster level while about 60% of the variance is due to factors operating at the household level. This result justifies the use of multi-level modeling.

Table 3.2 Results (odds ratio) of the multilevel modeling of the relationship between ITN use and selected individual, household, and community variables, Liberia 2014.

Correlates	Empty Model[1]	Full Model[2]
Fixed Effects		
Household member characteristics		
Age Group		
0–4 years (RC)	---	1.00
5–17 years	---	0.09***
Adult	---	0.43**
Sex		
Male (RC)	---	1.00

Correlates	Empty Model[1]	Full Model[2]
Female	---	0.77
Interactions Sex/Age group		
Male X Age group 0–4 (RC)	---	1.00
Female X Age group 5–17	---	1.83‡
Female X Adult	---	2.78**
Female caregiver's socio-*demographic and ideational characteristics*		
Female caregiver's level of education		
None (RC)	---	1.00
Primary	---	0.98
Secondary and above	---	0.74
Female caregiver's perceived norm about ITN use in the community		
Perceived ITN use not to be the norm	---	1.00
Perceived ITN use to be the norm	---	1.00
Female caregiver's perceived susceptibility to malaria		
Low	---	1.00
High	---	0.84
Female caregiver's perceived severity of malaria		
Did not perceive severity	---	1.00
Perceived severity	---	1.62*
Female caregiver's knowledge about malaria prevention		
Low	---	1.00
High	---	1.32
Female caregiver's perceived self-efficacy to detect a complicated case of malaria		
Low	---	1.00
High	---	2.04**
Female caregiver's perceived self-efficacy to prevent malaria for self and children		
Low	---	1.00
High	---	0.96
Female caregiver's exposure to "Take Cover" malaria prevention communication		
Low	---	1.00
High	---	1.90**
Household characteristics		
Household size	---	0.68***
Household wealth quintile		
Lowest (RC)	---	1.00

Correlates	Empty Model[1]	Full Model[2]
Second	---	1.30
Third	---	1.92‡
Fourth	---	1.77
Highest	---	2.47*
Number of under-5 children in household		
One (RC)	---	1.00
Two	---	1.07
Three or more	---	0.65
Number of ITNs in household		
One (RC)	---	1.00
Two	---	6.86***
Three or more	---	13.33***
Community characteristics		
County of residence		
Bong (RC)		1.00
Cape Mount		0.65
Grand Kru		0.18***
Rivercess		0.48*
Random Effects		
Cluster level variance (SE)	1.87***(.57)	0.01 (.12)
Cluster-level ICC[3]	0.24	0.00
Household level variance (SE)	2.63***(.43)	1.98***(.38)
Household-level ICC[3]	0.60	0.38
Log likelihood	-1144.69	-948.91
AIC	2297.39	1955.83
Number of observations	2269	

Notes: ‡ p<0.1. * p<0.05. ** p<0.01. *** p<0.001. [1] Model with no covariates. [2] Model with covariates. [3] Intra-class correlation. RC=Reference category, SE=Standard error

When the covariates were introduced (Full Model), the residual ICC was substantially diminished at the cluster level, indicating that much of the cluster-level variance was due to differences across communities in the covariates included in the estimated model. In contrast, there remains a significant amount of clustering at the household level (indicated by an ICC of 0.38 after fitting the full model), implying that irrespective of socio-demographic characteristics, there are inter-household differences in ITN use among households within the same cluster that were not measured in this study. The results of this model further reveal that the strongest correlates of intra-household ITN use are number of ITNs in the household, age, household size, and county of residence. Other significant correlates of ITN use include caregiver's exposure to malaria prevention messages, her perceived self-efficacy to detect complicated malaria, her perceived severity of malaria, and household wealth.

There is a significant interaction between sex and age group, indicating that the relationship of sex with ITN use varies by age. The findings indicate that sex does not make a difference for ITN use among children under five. Sex does not significantly moderate the association of being an older child or teenager with ITN use. In contrast, among adults, being female significantly alleviates the negative effects of age on ITN use. Among male members, older children and teenagers were 91% less likely and adults were 53% less likely than under-five children to use an ITN. Furthermore, the predicted marginal probability from the estimated full model reveal that adult women (75.8%) were significantly more likely than adult men (65.7%) to sleep under an ITN ($p<0.001$). For under-five children, the predicted marginal probability was 76.2% for boys and 76.3% for girls.

The number of ITNs in a household was one of the strongest predictors of ITN use; having three or more ITNs in a household is associated with a 13-fold increase in the odds of sleeping under an ITN. Individuals residing in households with a female caregiver who reported a high level of perceived severity of malaria were 62% more likely than their peers from other households to sleep under an ITN. Similarly, a female caregiver's high level of perceived self-efficacy to detect complicated malaria was associated with a two-fold increase of household members' use of ITNs. The relationship with exposure to the "Take

Cover" campaign was such that individuals from households in which the female caregiver had a high level of exposure were 90% more likely to sleep under an ITN compared to individuals from households in which the female caregiver had a low level of exposure.

The relationship with household size is negative, such that a unit increase in household size is associated with a 32% reduction in the odds of using an ITN. As for household wealth, the only significant difference is between the lowest and highest quintiles, with individuals from the highest quintile being more than twice as likely to sleep under an ITN as their peers from the lowest quintile. Individuals from Grand Kru and Rivercess were significantly less likely to sleep under an ITN than their counterparts from Bong. Finally, the number of under-five children in the household was not significantly associated with intra-household ITN use.

3.4 Discussion

In this manuscript, we examine the correlates of ITN use among household members in four counties in Liberia using multilevel modeling of survey data. The data showed that only about a third of households had at least one ITN, and fewer households still had universal coverage. Nonetheless, in households with at least one ITN, about two-thirds of the members slept under an ITN on the night preceding the survey.

Results of the multilevel model revealed that the strongest correlates of intra-household ITN use are number of ITNs in the household, age, household size, county of residence, female caregiver's ideational characteristics, her exposure to malaria prevention messages, and household wealth. These findings echo what extant literature already tells us, while also providing new evidence. For example, consistent with evidence from previous studies, we found that the odds of ITN use were considerably lower among older children and adults compared to under-five children (Nuwaha, 2001; Panter-Brick *et al.*, 2006; Bernard *et al.*, 2009; Kulkarni *et al.*, 2010; Rickard *et al.*, 2011; Tchinda *et al.*, 2012). Moreover, we found that being a female alleviates the negative correlation of older age with ITN use. Both of these findings indicate that people understand and tend to act upon the message that young children and pregnant women are the most vulnerable to malaria. Consistent with what other studies have found (Ricotta *et al.*, 2015), the findings also suggest that the woman (rather than the couple) is the one most likely to share a sleeping space with her young children.

This study found that certain female caregiver's ideational characteristics are associated with ITN use among members of her household. The association between a female caregiver's ideational characteristics and experiences of her household members echoes evidence from other health domains including family planning (Kincaid, 2000a; Babalola and Vondrasek, 2005), HIV (Nguyen *et al.*, 2012), water and sanitation (Figueroa and Kincaid, 2010), and female genital mutilation (Babalola *et al.*, 2006). The positive association of female caregiver's perceived severity of malaria with household members' ITN use is consistent with evidence from prior studies (Aleme, Girma and Fentahun, 2014; Hung *et al.*, 2014; Watanabe *et al.*, 2014). Female caregiver's perceived self-efficacy to recognize a complicated case of malaria was positively associated with ITN use. While evidence concerning the role of this specific variable is rare in literature, the finding is consistent with what some studies have found regarding the link between malaria knowledge and ITN use (Nganda *et al.*, 2004; Macintyre *et al.*, 2006; Biadgilign, Reda and Kedir, 2012; Esimai and Aluko, 2014). In contrast to some prior studies (Astatke and Mulatu, 2007; Aleme, Girma and Fentahun, 2014; Hung *et al.*, 2014; Lwin *et al.*, 2014; Watanabe *et al.*, 2014), this study did not find any significant relationship between perceived susceptibility to malaria and use of ITNs. While the reason for this finding is not clear, it is possible that use of ITNs tends to suppress perceived susceptibility to malaria, as ITN users perceive themselves to be protected against malaria. Indeed, a few studies have shown a negative relationship between perceived susceptibility to malaria and use of an ITN (Biadgilign, Reda and Kedir, 2012; Hung *et al.*, 2014).

This study revealed a positive association between exposure to malaria-prevention communication messages and use of ITNs, echoing findings from other studies (Astatke and Mulatu, 2007; Kulkarni *et al.*, 2010; Biadgilign, Reda and Kedir, 2012; Owusu Adjah and Panayiotou, 2014). Furthermore, consistent with previous studies, we found a positive link between household wealth and ITN use (Nuwaha, 2001; Jombo *et al.*, 2010). The strong association of the number of ITNs in the household and ITN use makes intuitive sense and has been found in other studies (Macintyre *et al.*, 2006). The significantly lower ITN use in Grand Kru and Rivercess compared to Bong is due to the fact that considerably fewer households in these two counties had enough ITNs and indicates that these two counties should be prioritized in ITN distribution efforts.

Finally, after controlling for measured variables at the individual, household, and community levels, there are significant unmeasured variables operating at the household level that influence ITN use. While this study did not allow us to identify the specific factors, it is possible that they include socio-demographic and ideational characteristics of the male head of household, conjugal power dynamics, sleeping arrangements (defined by the number, type and location of sleeping spaces, number of persons per sleeping space, and ability to hang an ITN over sleeping spaces), and recent experience of fever among members of the household. Indeed, it is reasonable to assume that male heads of household, as the key decision-makers, exert great influence on health behavior decisions within the household. The position of male heads of household on ITNs, determined by their socio-demographic and ideational characteristics, can be expected to influence household use of ITNs. In the same vein, non-egalitarian conjugal power that puts the woman at a disadvantage in household decision-making may limit her influence on household use of ITNs even if she possesses relevant positive ideational characteristics. Furthermore, a recent episode of malaria may increase a person's desire for malaria prevention and therefore increase ITN use. Indeed some studies have found a positive relationship between recent experience of malaria and willingness to pay for ITNs (Mujinja, Makwaya and Sauerborn, 2004). Sleeping arrangements vary across households and have been found to affect ITN use (Iwashita *et al.*, 2010; Minakawa *et al.*, 2015).

The findings of this study have important implications for programming, policy, and further research. In general, the findings underscore the need for health communication program management to conduct thorough audience profiling in order to construct targeted and effective messages. The considerably lower likelihood of men, older children, and teenagers to use an ITN is concerning. Two interrelated reasons may be adduced for this finding: insufficient ITNs within the households leading to prioritization of allocation for the household members perceived to be most vulnerable; and attitudinal (for example, the belief that malaria is a less serious problem for men and older children and therefore use of ITNs is less important for them). Our study has shown a strong relationship between the number of ITNs in the household and the odds of sleeping under an ITN. The implications of this finding are obvious- helping households attain universal coverage will reduce discrepancies in intra-household ITN use. Since 2010, universal coverage has been a global goal for malaria-endemic countries. To this end, Liberia carried out a universal coverage campaign in April 2015 and is currently scaling up ITN distribution via antenatal care visits and other channels. As many studies have demonstrated, ITN use increases significantly following ITN distribution programs (Grabowsky *et al.*, 2005; Grabowsky, Nobiya and Selanikio, 2007; Skarbinski *et al.*, 2007; Thwing *et al.*, 2011, 2008; Wolkon *et al.*, 2010; Hightower *et al.*, 2010; Bonner *et al.*, 2011; Bennett *et al.*, 2012; Garley *et al.*, 2013; Loha, Tefera and Lindtjørn, 2013; Renggli *et al.*, 2013; Zollner *et al.*, 2015). Future evaluations will hopefully confirm this for Liberia.

In addition, the documented importance of ideational constructs (specifically female caregiver's perceived severity of malaria and perceived self-efficacy to recognize a complicated case of malaria) for ITN use among household members underscores the relevance of an ideational model in developing malaria prevention programs. These programs should seek to increase audience understanding of the severity of malaria and improve knowledge about the symptoms of complicated malaria. Furthermore, the wealth inequity in use of ITNs suggests the need to ensure that poor households are not overlooked in ITN distribution strategies, and that they receive messages to motivate usage of ITNs.

The finding of residual clustering at the household level indicates that interventions that specifically target households are relevant. Such interventions can target heads of households with audience-specific malaria-prevention information, motivational messages, and skills to enable them take health-protective decisions for their families. Peer education interventions that train and equip household heads with relevant materials, mobilize them to reach out to their peers in the community to educate them about ITNs, and encourage them to use ITNs are also relevant.

This study has some limitations that warrant mention. First, the data analyzed are derived from a cross-sectional survey, which precludes all attempts at causal attribution. The relationships documented in this manuscript are associations, although the magnitude of the relationships implies that their implications should be taken seriously. Secondly, since the data are self-reported, they are subject to social desirability bias and memory lapse. Nonetheless, we believe that the rigorous data collection practices during fieldwork have helped to minimize these problems.

3.5 Conclusions

The factors associated with ITN use in Liberia operate at multiple levels, including individual, household, and community. Programs should ensure universal coverage of ITNs and encourage all household members to sleep under them. Interventions designed to promote ITN use are likely to be effective if they address barriers at the individual, household and community levels. Programs should seek to identify and evaluate ideational factors when designing ITN use promotion campaigns. This study indicates that a better understanding of household level factors such as conjugal power dynamics and ideational characteristics of male heads of household is needed to effectively encourage intra-household ITN use in Liberia.

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Chapter 4: Demand and Willingness-to-Pay for Bed Nets in Tanzania: Results from a Choice Experiment

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Abstract

Background: Universal coverage campaigns for long-lasting insecticide-treated nets do not always reach the goal of one net for every two household members, and even when ownership of at least one net per household is high, many households may not own enough nets. The retail market provides these households options for replacing or increasing the number of nets they own with products that best fit their needs since a variety of net shapes, sizes, and colors are available. Hence, it is important to understand the factors affecting private net demand.

Methods: This study explores private demand for nets in Tanzania using a discrete choice experiment. The experiment provides participants the option to buy nets with their own money, and thus should prove more accurate than a hypothetical survey of net preferences.

Results: Nearly 800 participants sampled in two regions showed an overall strong demand for nets, with 40% choosing to buy a net across all seven combinations of net prices and characteristics such as size, shape, and insecticide treatment. Only 8% of all participants chose not to buy a single net. A key factor influencing demand was whether a participant's household currently owned sufficient nets for all members, with rural participants showing lower net coverage and greater demand than urban participants. Both poor and less poor households showed strong evidence of making purchase decisions based on more than price alone. Mean willingness-to-pay values for a net started at US$1.10 and grew by US$0.50–1.40 for various attributes such as rectangular shape, large size, and insecticide treatment. The impact of price on demand was negative but small, with elasticity values between −0.25 and −0.45.

Conclusions: The results suggest that private demand for nets in Tanzania could potentially supplement future coverage campaigns. Net manufacturers and retailers should advertise and promote consumers' preferred net attributes to improve sales and further expand net

access and coverage. To overcome household liquidity concerns and best replicate the experiment results, policy makers should consider making credit available for interested buyers.

4.1 Introduction

Since 2007, the World Health Organization (WHO) has recommended universal coverage with insecticide-treated bed nets (ITNs) to reduce malaria morbidity and mortality. Universal coverage campaigns aim to provide one ITN for every two people in regions of high malaria transmission (Global Malaria Programme, 2014). Typically occurring every three years, these campaigns generally achieve high levels of ITN ownership and access (Zegers De Beyl *et al.*, 2016). However, even when ownership of at least one ITN is high, many households may not own enough ITNs for all family members. The retail market, which offers a variety of net shapes, sizes and colors, provides these households with options for replacing or increasing the number of ITNs they own with products that best fit their needs.

It is important to understand the factors affecting private net demand since purchased nets offer families a way to replace old nets or supplement public-sector distributions of long-lasting insecticide-treated nets (LLINs). Moreover, as policy makers are currently planning long-term national distribution strategies for bed nets, information such as price elasticities and willingness-to-pay (WTP) values should prove vital for designing future distribution schemes and understanding how markets can contribute to filling universal coverage gaps. One means of discerning this information, particularly when ample market data are lacking, is the use of experimental methods. Multiple techniques exist for researchers wanting to apply experimental methods to consumer preference questions. Auction exercises represent one commonly used approach, where participants gather in a group and record their maximum WTP for a product (Shogren, 1994; Alfnes and Rickersten, 2003). In turn, the high or second highest bidder purchases the product with their own funds.

While this technique produces a complete demand curve, showing price and quantity combinations for the group, its implementation presents special challenges, especially in a developing country. First, it requires that a large group of people concurrently complete the exercise. Second, participants must state their preferences in a manner different from their normal shopping experience. Rather than choose to buy a product at a given asking price, they must state their maximum bid price (i.e., WTP). Alfnes et al. argue that this concept is often difficult for participants to follow and implement (Alfnes *et al.*, 2006). Fortunately, a choice experiment or discrete choice experiment (DCE) circumvents these problems yet still yields an experiential derivation of consumer preferences. A DCE involves presenting two or more products (or other decision such as workplace scenarios) before a participant and asking which product she prefers at fixed prices (Mangham, Hanson and McPake, 2009). A DCE thus presents an attractive means to gauge consumer preferences and WTP for bed nets in Tanzania.

The bed net market in Tanzania has experienced significant demand and supply shocks since a study of consumer demand in 2007, namely the availability of pre-treated LLINs and a proliferation of free, mass distribution campaigns (C. D. Gingrich *et al.*, 2011). There are no known market data available since then. Tanzania's bed net market features several kinds of available nets (untreated vs insecticide-treated, small vs large, rectangular vs conical) and consumers are generally familiar with these various attributes. This study explores private demand for bed nets in Tanzania using a DCE, with a special focus on WTP for various net types.

4.2 Methods

Discrete choice experiments are best known for eliciting WTP values for products with no available market data, and particularly WTP values for various product attributes

(Mangham, Hanson and McPake, 2009). Other auction-type experiments do not provide comparable results. While DCEs may ask participants to state their hypothetical preferences among various products, it is also possible that DCE participants make non-hypothetical or ‘binding’ purchase decisions with their own money. When participants know their stated preferences imply binding decisions, the results will more likely reflect their true preferences. Existing research confirms a significant gap between hypothetical preferences and preferences obtained from binding experiments (Moser, Raffaelli and Notaro, 2014). In particular, WTP estimates obtained from hypothetical DCEs typically show an upward bias.

The theoretical framework behind a DCE is well established (Train, 2003; Mangham, Hanson and McPake, 2009). In short, when facing a choice between two goods, good A and B or neither, the participant chooses good A if its expected utility exceeds that of either good B or choosing nothing. Assuming that utility is a random linear function that depends on product attributes, it is straightforward to derive the probability that a participant chooses good A at various prices (i.e., a demand curve), demand elasticities and WTP values for the product attributes.

Sample description

To obtain the sample DCE data for bed nets, this study targeted parents of schoolchildren via invitation letters sent home with students. A key advantage of this particular sample is that the school provided a central location to conduct the DCE and thus prevented field staff from carrying dozens of bed nets during door-to-door interviews. Ruvuma and Mwanza regions were chosen for the study sites, primarily because they both provided significant diversity with respect to urban and rural populations and were mid-tier in income rank. In addition, free LLIN distribution had been implemented more recently in most other regions and the assumption was that recipient households would show little interest in buying additional nets, regardless of their actual demand preferences. Mwanza region borders Lake Victoria in northern Tanzania. As of 2012, it ranked 14th in income per capita among 21 mainland regions at 900,000 TSH (approximately US$400) (United Nations Development Programme, 2015). Ruvuma region lies at Tanzania's southwest corner. It has a per capita income over 1,200,000 TSH (US$550), placing it fourth among mainland regions. National trends suggest a higher poverty incidence in rural areas (33% poverty rate for rural vs 22% for all urban outside Dar es Salaam), and there is no reason to suspect Mwanza and Ruvuma show a different pattern.

Both regions have a recent history of progressive bed net programs, first under a national subsidized voucher scheme for pregnant women and infants from 2004 to 2014, a free under-five coverage campaign between 2008 and 2010, and free universal coverage campaigns in 2010, 2011 and 2015 (Bonner *et al.*, 2011; C. Gingrich *et al.*, 2011; Renggli *et al.*, 2013; Department for International Development, 2015). Fieldwork for this study occurred 12 months after the 2015 campaign in Mwanza (National Malaria Control Programme, pers. comm., (Bonner *et al.*, 2011)). Ruvuma implemented its universal coverage campaign in November 2010, and then began annual rounds of large-scale school distribution in July 2013, August 2014 and August 2015 (National Malaria Control Programme, pers. comm., (Renggli *et al.*, 2013)). Except for the most recent school distributions in Ruvuma, each region's history with nets and net distribution schemes is comparable. One urban and one rural district for each region were used as data collection sites, namely Nyamagana and Magu districts in Mwanza and Songea and Mbinga districts in Ruvuma.

Two school sites were utilized in each district. The specific schools were selected after consulting with local health department and education officials, who chose schools easily accessible by road yet also containing a broad mix of household income levels. Another criteria was the willingness of school administrators and head teachers to participate in the exercise. School administrators selected students from each grade, one to seven, and chose more students from larger sized grades. Moreover, they selected roughly an equal proportion of boys and girls and students from low- and high-income groups. To maximize participation, administrators prioritized students living closer to the schools and whose parents had a reputation of responding to meeting requests. The invitation letters stated the intent of the exercise and explained that participants would receive 10,000 TSH plus the opportunity to purchase a bed net at a discounted price between 2000 and 8000 TSH (US$1 = 2200 TSH). The prices originated from an informal survey of Dar es Salaam markets in October 2015 (eight months before the DCE data collection began) showing prices for both treated and untreated nets in the 8000–10,000 TSH range.

While the sample is not nationally representative of all households, it represents (non-randomly selected) households with school-age children in the two regions. Selection bias may have occurred at several stages of data collection, including the choice of district, the choice of school, and student selection to receive invitation letters. Additionally, participants possibly self-selected according to their potential interest in obtaining a net.

Field staff were recruited by CSK Research Solutions, Ltd, Dar es Salaam, Tanzania, and underwent 5 days' training in both DCE and general research methods. Three authors were extensively involved with the training, which included role playing and mock experiments to ensure the staff clearly understood DCE theory and methods. Prior to data collection, including two days of piloting with 20 participants in Kinondoni district near Dar es Salaam, the National Institute for Medical Research (NIMR) in Tanzania and the Johns Hopkins School of Public Health Institutional Review Board granted full approval for the study.

Following Hensher et al., the minimum sample size for viable choice experiments is roughly 50 observations for each selected option (i.e., net A, net B, or neither net) (Hensher, Rose and Greene, 2005). Hence, treating all four sites separately and allowing that participants would likely not choose each option equally, 200 participants for each site became the desired sample size. In total, 961 invitation letters were distributed for an overall potential participant yield of 83%, with individual school yields ranging from 61 to 97%. Field staff reported that 100% of potential participants consented to complete the preliminary survey and DCE. All interviews occurred between 23 May and 14 June, 2016. Two teams of field staff (two persons each) along with one supervisor worked concurrently in Mwanza and Ruvuma. Roughly 200 participants completed the DCE in each district, for 801 total participants.

Demographic and ideation information

Prior to completing the DCE portion of the interview, participants answered a series of questions covering their household demographics, asset ownership (including bed nets), understanding and perceptions of malaria, and familiarity with and use of bed nets. Measurement of these cognitive, emotional and social factors is defined as ‘ideation’ (van de Kaa, 1996; Kincaid, 2000b). In this study, the cognitive dimension includes attitudes, knowledge about malaria and its prevention, perception of severity and susceptibility to malaria, belief that nets are an effective malaria prevention tool (also known as response efficacy), and knowledge about where to purchase additional nets. The emotional dimension focuses on perceived self-efficacy to use a net to protect against malaria, and belief in one’s ability to obtain enough nets for the household. For the social interaction dimension, the constructs include perceived social norms (whether other households in the community are regularly using nets), and interpersonal communication about decision making for net purchasing and use. The assumption behind the ideation model is that the more of these ideational variables a person has, it is more likely they will behave in a certain fashion.

Questions on perceptions of malaria and bed nets were constructed using a four-point Likert scale, ranging from ‘definitely could not’ to ‘definitely could’, or from ‘strongly disagree’ to ‘strongly agree’. Variables were re-coded −2 to +2 (skipping zero), with factor analysis applied to variables grouped into ideational constructs (e.g., perceived susceptibility and perceived severity). The results were split into high/low summary categories by noting whether each household’s average category value was greater or less than zero. A partial list of ideation questions and responses appears in the next section. A full list is available on request.

DCE design

The DCE aimed to measure consumer preferences for bed nets that are readily available in the Tanzanian marketplace. Hence, nets possibly known to households only through non-market channels, such as free distribution campaigns (e.g., PermaNet brand LLINs), were not considered. In addition, not all nets were available in every possible size and shape combination.

Table 4.1 summarizes the various bed net attributes and levels examined in the DCE. Both the treated and untreated nets, Olyset and Safinet respectively, are manufactured by A to Z Textile Mills, Ltd, in Arusha, Tanzania and available in most local markets. Packages were clearly marked with their brand name and the Olyset nets are also marked as insecticide treated. Field staff also explained the treated/untreated attribute to participants.

Table 4.1 Summary of net attributes examined in the DCE

Attribute and level				
Treated (T) or untreated (U)	Shape	Size (feet)	Price (000 TSH)	Available color[a]
T (Olyset brand)	Rectangular	4 × 6	2, 4, 6, 8	Aqua blue
T (Olyset brand)	Rectangular	6 × 6	2, 4, 6, 8	Navy blue and white[b]
U (Safinet brand)	Rectangular	4 × 6; 6 × 6	2, 4, 6, 8	White
U (Safinet brand)	Conical	3.5 × 6[c]; 6 × 6	2, 4, 6, 8	White

[a]Color is not an attribute examined in the DCE, though it possibly influenced participants' decisions. Field staff did not mention color during the DCE but it was visible through the clear packaging.
[b]Most large Olyset nets used in Mwanza region were white but a few navy blue nets were also included. All large Olyset nets in Ruvuma were navy blue
[c]In terms of size attribute, level 3.5 × 6 is considered identical to level 4 × 6. Both 3.5 × 6 and 4 × 6 are listed as 'small' and 6 × 6 are listed as 'large'

A complete matrix of all attributes and levels in Table 4.1 yielded 24 different 'A vs B' net combinations to consider. Obviously, this presented too many options for any one person to meaningfully consider during a single interview so the following process reduced the number of questions to each participant: first, a fractional design reduced the total DCE scenarios to 14 (Aizaki and Nishimura, 2008). Second, the 14 questions were separated into two equally sized 'blocks', where each participant was randomly assigned to complete either Block 1 or Block 2. The resulting set of net comparisons appears in Table 4.2.

Table 4.2 Fractional factorial design used for the DCE

		Net A				**Net B**			
Block	**Scenario number**	**Brand**	**Size**	**Shape**	**Price (TSH)**	**Brand**	**Size**	**Shape**	**Price (TSH)**
1	1	S	Large	Conical	2000	O	Small	Rectangular	4000
1	2	S	Large	Rectangular	8000	S	Small	Rectangular	2000
1	3	S	Small	Conical	4000	S	Large	Conical	4000
1	4	S	Large	Conical	6000	S	Large	Conical	2000
1	5	S	Small	Rectangular	6000	O	Large	Rectangular	6000
1	6	O	Small	Rectangular	4000	S	Large	Rectangular	8000
1	7	S	Large	Rectangular	4000	O	Small	Rectangular	8000

		Net A				Net B			
Block	Scenario number	Brand	Size	Shape	Price (TSH)	Brand	Size	Shape	Price (TSH)
2	1	O	Large	Rectangular	2000	S	Small	Conical	4000
2	2	S	Small	Conical	8000	S	Small	Rectangular	6000
2	3	S	Small	Conical	2000	S	large	Rectangular	4000
2	4	O	Large	Rectangular	6000	S	Large	Conical	6000
2	5	S	Large	Conical	4000	S	Small	Conical	2000
2	6	S	Small	Rectangular	2000	S	Small	Conical	8000
2	7	O	Small	Rectangular	8000	O	Large	Rectangular	2000

S = Safinet, O = Olyset

In addition to the randomly assigned blocks, each participant was randomly assigned one of two different groups to complete scenarios 1 through 7. Group 1 completed the scenarios in order 5, 2, 4, 7, 6, 1, 3 while Group 2 completed the scenarios in order 2, 5, 4, 6, 7, 3, 1, with each sequence generated using a random number generator without replacement. Both the block and order randomized assignments occurred automatically using a data management system on tablet computers.

To prepare participants for the DCE using nets, the field staff first presented two 'warm up' scenarios using two pieces of candy with similar choices (candy A, candy B, or neither A or B), each costing 50 or 100 TSH. Participants received 100 TSH before the exercise and after each participant stated her choices, a random card selection (1 or 2) identified the 'binding' scenario, followed by an actual purchase if applicable and change provided to the participant. The cards used were from a Rook® game, which do not resemble traditional playing cards, and were intentionally chosen to avoid any negative connotations to gambling. Besides employing only two scenarios and a smaller cash payoff, these warm-up DCE exercises conformed exactly to the DCE using nets. For the subsequent net-based DCE, participants received 10,000 TSH before responding to all seven scenarios for the participants' assigned block. At the end of the seven DCE scenarios with all choices recorded, the participant blindly chose a card between 1 and 7. The card identified the binding scenario, where the preferred net (if any) was purchased with the 10,000 TSH stipend and the remaining balance provided to the participant.

The procedure for estimating a demand curve for bed nets using DCE data requires treating each individual purchase decision as separate binary outcomes that depend on factors such as net attributes, price and the household's socio-economic status. In other words, each DCE scenario for each participant yields three separate binary 'observations' for demand estimation: Choose net A, choose net B, and choose neither net A nor net B. The complete procedure, using conditional logit estimation, is well detailed in Aizaki, Aizaki et al., and Aizaki and Nishimura (Aizaki and Nishimura, 2008; Aizaki, 2012; Aizaki, Nakatani and Sato, 2014). Equation 1 represents a generic form of bed net demand based on the DCE.

$$\text{Buy} = f(\text{ASC, treatment, rectangular, large, price, LessPoor})$$

A full description of each variable appears in "Results" section. Variable *LessPoor*, which indicates the top three socio-economic quintiles, enters into (Eq. 1) in two ways: first as an interactive variable with ASC (alternative specific constant) to capture any potential demand shifts due to socio-economic status and second, as an interactive variable with price to explore whether socio-economic status affects price elasticity.

4.3 Results

Household demographics and net ownership

All data were collected electronically and generally error-free. The DCE scenarios contained 'did not answer' responses for three participants and data for these individuals were removed. In addition, two participants were either troubled by the DCE exercise or could not grasp the concept (as determined by the field staff) and their answers were removed from the analysis. Thus, the final sample contained 796 observations. A brief summary of the participants appears in Table 4.3. Among all participants, 66% were female with 76% female in the urban districts and 56% female in the rural districts.

Table 4.3 Description of participants, percent (number), total n = 796

Description	**Response**				
Status within household	Head of household	Spouse of head	Other		Missing or did not answer
	49.0 (390)	39.4 (314)	11.4 (91)		0.1 (1)
Gender	Female	Male			Missing or did not answer
	66.3 (528)	33.4 (266)			0.3 (2)
Age, mean number of years	39.3				
Can the household head read and write?	Yes	No			Missing or did not answer
	91.8 (731)	7.7 (61)			0.5 (10)
Did the household head attended school?	Yes	No			Missing or did not answer
	93.5 (744)	6.2 (49)			0.4 (3)
Highest level of schooling, head of household	Primary	Secondary	Higher	Other	Missing or did not answer
	66.9 (498)	26.7 (199)	5.9 (44)	0.3 (2)	0.1 (1)
Who is responsible for purchasing nets for your household?	Self	Spouse	Other		Missing or did not answer
	72.4 (576)	17.7 (141)	9.3 (74)		0.7 (5)

Households in each district own significant quantities of nets, of which between one-third and one half, on average, were purchased (Table 4.4). Households in all districts show average net ownership at or above the generally accepted standard of one net per every two people, or a net ratio of 0.50 nets per resident (Global Malaria Programme, 2014). Note, however, that rural Mwanza’s average net ratio (0.55) lies substantially below urban Mwanza (0.82) and standard deviations are large for all districts (0.24 to 0.45). Information regarding households’ net use or whether the nets were insecticide treated was not gathered.

Table 4.4 Household net ownership, by location

	Average number of nets owned per household (std dev)	Average number of owned nets that were purchased per household (std dev)	Average number of nets owned per household resident (std dev)
Mwanza urban	4.77 (2.60)	2.54 (1.87)	0.82 (0.45)
Ruvuma urban	3.47 (1.90)	1.48 (1.57)	0.63 (0.30)
Mwanza rural	3.79 (1.82)	1.16 (1.45)	0.55 (0.24)
Ruvuma rural	3.15 (1.80)	1.02 (1.32)	0.63 (0.35)

Overall propensity to buy nets

Table 4.5 reveals participants' overall propensity to buy nets, showing the number of times they choose to buy either net A or net B out of seven scenarios. Stated differently, participants in the '0' category (7.8%) chose to buy no nets for any scenario and were guaranteed to take home 10,000 TSH. Participants in category '7' (39.7%) chose to buy either net A or B for all seven scenarios and were guaranteed to receive a net regardless of the random card drawn. Participants in categories 1 through 6 found at least 1 scenario where they chose to purchase a net and in other scenario(s) preferred to keep the entire 10,000 TSH.

Table 4.5 Distribution of participants' DCE choices

Number of times participant chose to buy either net A or net B (out of 7 maximum)	Frequency	
	Percent	Number
0	7.8	62
1	8.0	64
2	7.0	56
3	8.3	66
4	9.2	73
5	8.9	71
6	11.0	88
7	39.7	316
All	100.0	796

Results aggregated for both blocks combined across all locations

Figure 4.1 compares net buying behavior across all four districts. The propensity to buy categories are condensed into three groups: Highly Unlikely to Buy (zero to two nets selected out of seven scenarios), Moderately Likely to Buy (three to five out of seven), and Highly Likely to Buy (six to seven out of seven). A chi-squared test for independence between location and propensity to buy rejected this hypothesis ($p < 0.001$), with rural participants showing an overall higher propensity to buy than urban participants. A similar test for independence between propensity to buy and region shows participants from Mwanza with a higher propensity to buy than those from Ruvuma (Figure 4.2; $p = 0.035$). The participant's gender did not significantly affect their propensity to buy a net (Figure 4.3, $p=0.69$).

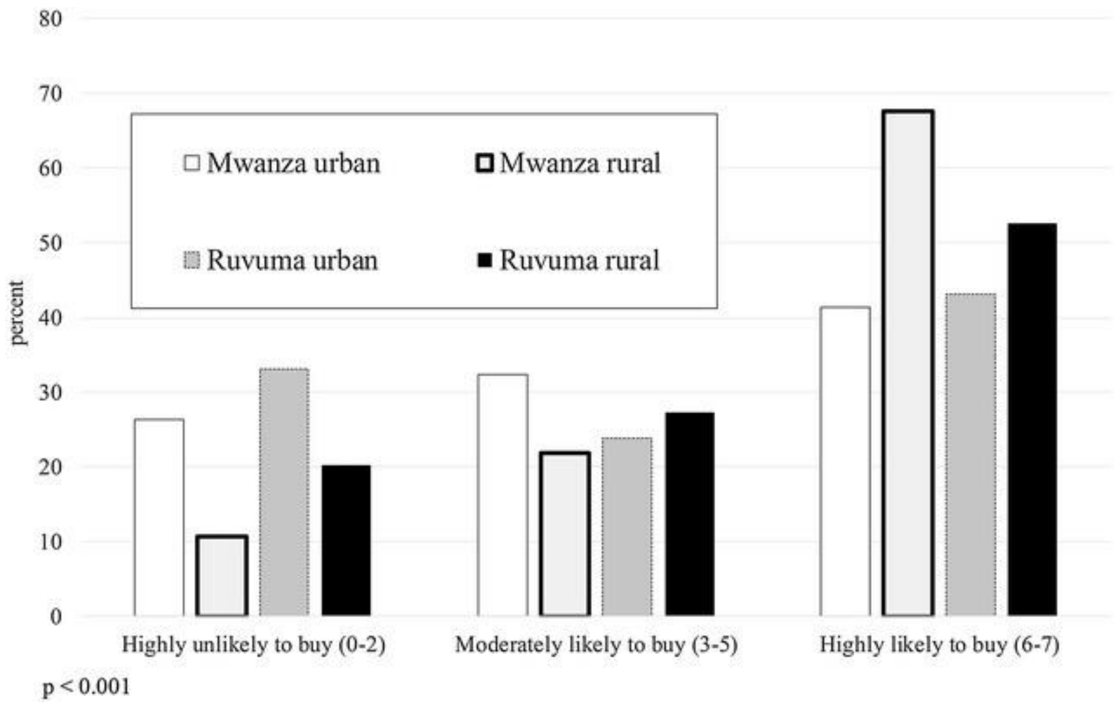

Figure 4.1 Propensity to buy a net (number of times purchased out of seven scenarios), by district

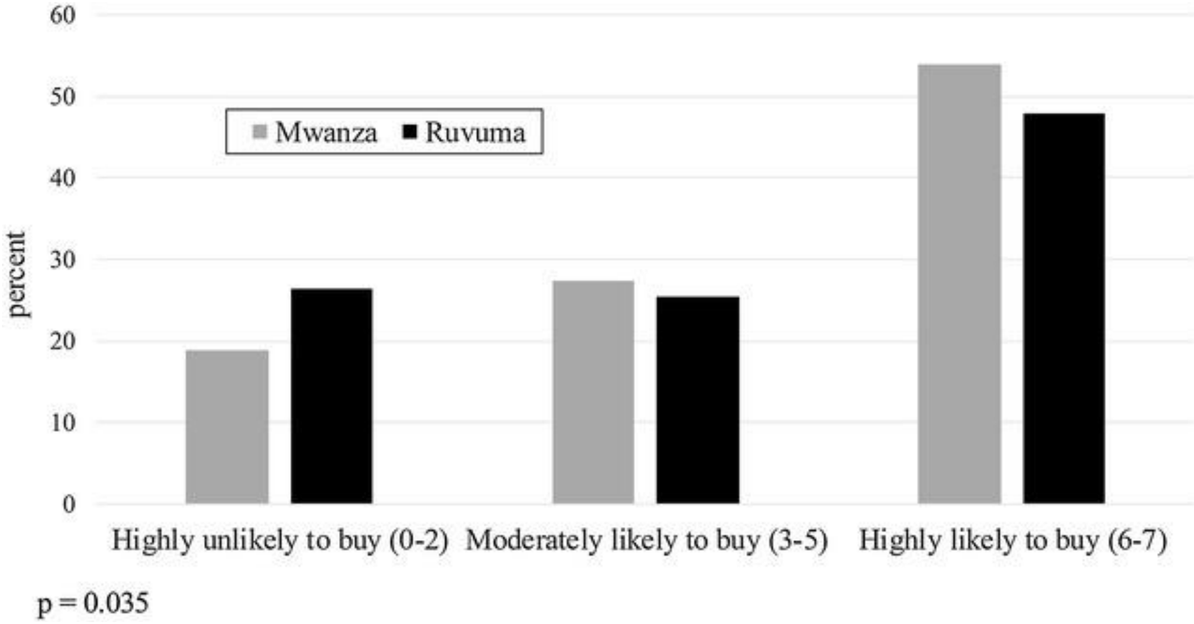

Figure 4.2 Propensity to buy a net (number of times purchased out of seven scenarios), by region

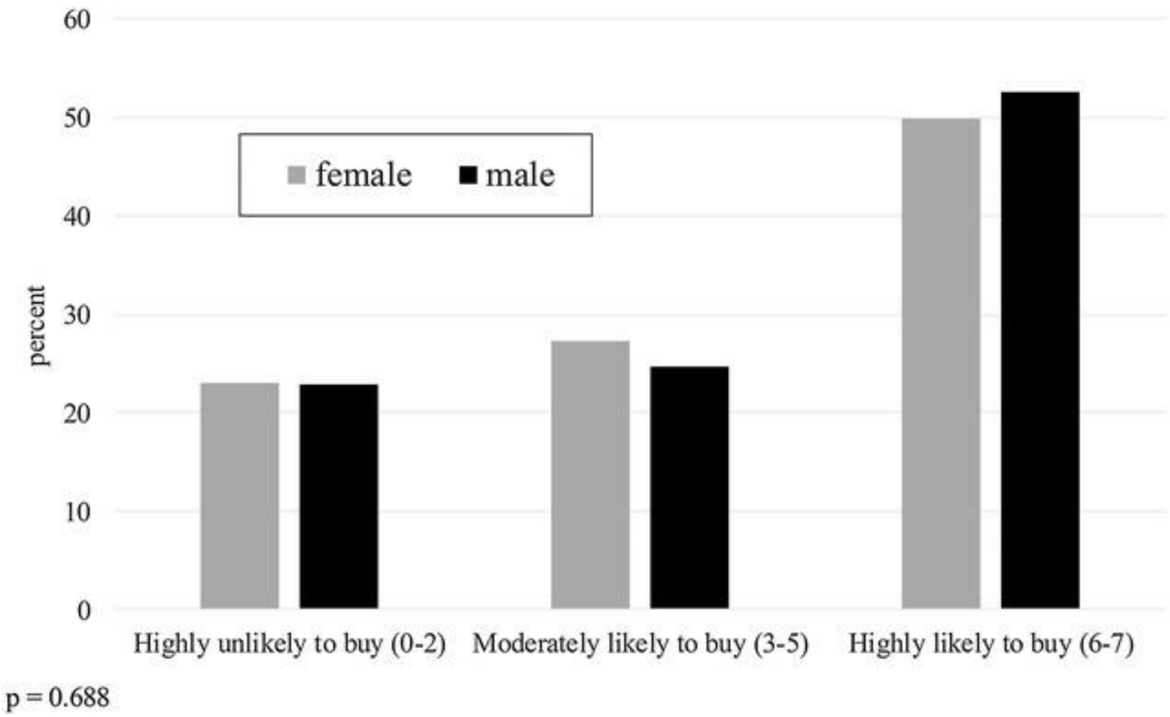

Figure 4.3 Propensity to buy a net (number of times purchased out of seven scenarios), by gender of participant

Principal components analysis was used to create socio-economic status indices based on each household's ownership of various assets, sanitation and water access, cooking fuel type, and the head's education level (Vyas and Kumaranayake, 2006; Fry, Firestone and Chakraborty, 2014). Each household was then assigned a socio-economic quintile rank, with 74.9% of households from the two poorest quintiles located in rural districts. However, by separate Chi square test, socio-economic status and propensity to buy are independent ($p = 0.489$).

Two critical questions are whether participants understood the DCE exercise and whether it mimics actual marketplace behavior. One way to explore these questions is to test whether participants behaved both rationally and consistently. The term 'rational' in this case implies that participants choose a lower price net (or no purchase) when two identical nets appear in the same scenario. Consistency suggests that participants who show preferences for a specific net attribute behave similarly across multiple scenarios. For example, Table 4.2 suggests that a rational participant would not choose net A for Block 1 Scenario 4 (since net A costs 4000 TSH more than identical net B), nor net A for Block 2 Scenario 7 (since net A costs 6000 TSH more for a small size net versus an otherwise identical large size net B). For Block 1 Scenario 4, 24.9% of participants chose net A and 19.2% chose net A for Block 2 Scenario 7.

Although both results show a surprising degree of 'irrationality', closer inspection reveals that some participants believe a low price net signals low quality to the consumer. Evidence that low price signals low quality appears in the ideation survey, which asks whether participants agree with the statement: "More expensive bed nets are more effective than less expensive or free bed nets". Nearly half of the participants either strongly agreed (38.6%) or somewhat agreed (6.5%) with the statement. Conversely, 42.2% strongly disagreed and 8.2% somewhat disagreed with the statement. More revealing is that for

Block 1 participants, a higher share of those agreeing with the statement chose net A for Scenario 4 compared to those not in agreement (33.6 vs 19.3%; $p = 0.003$). Similarly, a higher share of Block 2 participants who agreed with the statement chose net A for Scenario 7 (24.9 vs 13.9%; $p = 0.011$). Both findings suggest a strong association between the belief that more expensive bed nets are more effective and willingness to purchase a more expensive but identical net. The broad conclusion is that rationality prevailed throughout the sample, except for participants who believed that higher priced nets implied higher quality.

Regarding consistency, the first test examines Block 1, where the same participants willing to pay 6000 TSH more for a large net (net A) in Scenario 2 logically should not accept a small net (net A) for the same price as a large net in Scenario 3. In other words, a disproportionately large number of participants who choose A for Scenario 2 should also choose B for Scenario 3. A Chi square test for independence between Block 1, Scenario 2 and Scenario 3, confirms that a disproportionately large number of participants prefer a large net in both scenarios ($p < 0.001$). Similarly, Block 2 participants willing to pay 6000 TSH more for a conical net in Scenario 6 (B) should more likely pay 2000 TSH extra for a conical net in Scenario 2 (A). A Chi square test for independence confirms that a disproportionately large number of participants prefer a conical net in both scenarios ($p < 0.001$).

As seen in Table 4.6, bed net and malaria ideation indicators were generally high, with a strong positive belief about nets and their benefit for malaria prevention. Over 85% of participants knew where to buy a new net if they wanted to purchase one, and 78% of people felt capable of obtaining enough nets for their family. While a higher proportion of individuals had low perceived severity of malaria (59%), almost 81% felt that their family’s susceptibility to malaria was high. Over three-fourths (76%) of all participants could recall exposure to a malaria-related message within the past 6 months (via health clinic, radio, newspaper, etc.).

Table 4.6 Summary of bed net and malaria ideation questions (total n = 796)

Category (variable name), questions, and summary	**Response, percent (n)**					
Social norm of net use (*Socnorm*)	Hardly any	Less than half	More than half	Most	All	Do not know
"Generally, in how many households in your community do people sleep under a bed net?"	11.1 (88)	11.6 (92)	8.5 (68)	42.7 (340)	17.6 (140)	8.5 (68)
Perceived severity of malaria	Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree	Uncertain/ did not answer	
"I don't worry about malaria because it can be easily treated"	24.0 (191)	12.3 (98)	14.2 (113)	49.2 (392)	0.3 (2)	
"My children are so healthy that they would be able to recover from a case of malaria"	28.4 (226)	8.0 (64)	14.2 (113)	49.0 (390)	0.4 (3)	
"Only weak children can die from malaria"	53.8 (428)	9.4 (75)	7.3 (58)	29.1 (232)	0.4 (3)	

Category (variable name), questions, and summary	**Response, percent (n)**					
"When my child has a fever, I almost always worry that it might be malaria"	7.9 (63)	3.0 (24)	12.8 (102)	76.0 (605)	0.3 (2)	
Ideation summary	Percent high (somewhat/strongly agree) = 40.5					
Perceived susceptibility to malaria (*Suscept*)	Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree	Uncertain/ did not answer	
"During the rainy season, I worry almost every day that someone in my family will get malaria"	9.5 (76)	4.6 (37)	14.3 (114)	71.2 (567)	0.3 (2)	
"People only get malaria when there are lots of mosquitoes"	9.5 (78)	4.3 (34)	7.2 (57)	78.6 (626)	0.1 (1)	
"Nearly every year, someone in this community gets a serious case of malaria"	10.4 (83)	4.0 (32)	12.1 (96)	73.0 (581)	0.5 (4)	

Category (variable name), questions, and summary	**Response, percent (n)**					
"I cannot remember the last time someone I know became sick with malaria"	52.3 (416)	7.0 (56)	9.7 (77)	30.8 (245)	0.3 (2)	
"I know people who have become dangerously sick with malaria"	13.8 (110)	4.0 (32)	11.2 (89)	70.9 (564)	0.1 (1)	
"When my child has a fever, I almost always worry that it might be malaria"	7.9 (63)	3.0 (24)	12.8 (102)	76.0 (605)	0.3 (2)	
Ideation summary	Percent high (somewhat/strongly agree) = 80.9					
Perceived ability to obtain enough nets (*Obtain*)	Definitely could not	Probably could not	Probably could	Definitely could	Uncertain/ did not answer	
"Obtain enough bed nets for all your children"	17.5 (139)	4.4 (35)	13.3 (106)	64.8 (516)	0.0 (0)	
Know where to buy a net	Definitely could not	Probably could not	Probably could	Definitely could	Uncertain/did not answer	
"Find a net seller nearby if I wanted to purchase one"	11.7 (93)	3.1 (25)	10.7 (85)	74.5 (593)	0.0 (0)	

Category (variable name), questions, and summary	**Response, percent (n)**					
Price efficacy of nets	Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree	Uncertain/ did not answer	
"More expensive bed nets are more effective than less expensive or free bed nets"	42.2 (336)	8.2 (65)	6.5 (52)	28.6 (307)	4.5 (36)	
Exposure to malaria messaging	Yes	No	Missing/did not answer			
"In the past 6 months, have you seen or heard any messages about malaria [on TV or radio]?"	76.1 (606)	23.9 (190)	0.0 (0)			

The malaria ideation and bed net variables show a mixed impact on participants' propensity to buy a net. Variable *Obtain* is significantly and positively correlated with propensity to buy, though not to a large degree (p = 0.071; Figure 4.4). However, variables *Suscept* and *Socnorm* are both statistically independent of propensity to buy (p = 0.999 and p = 0.234, respectively). Moreover, all three ideation variables are independent of the household's urban versus rural location (p values between 0.371 and 0.864). Exposure to malaria messaging did not vary by region (p = 0.804) and was independent of propensity to buy (p = 0.359).

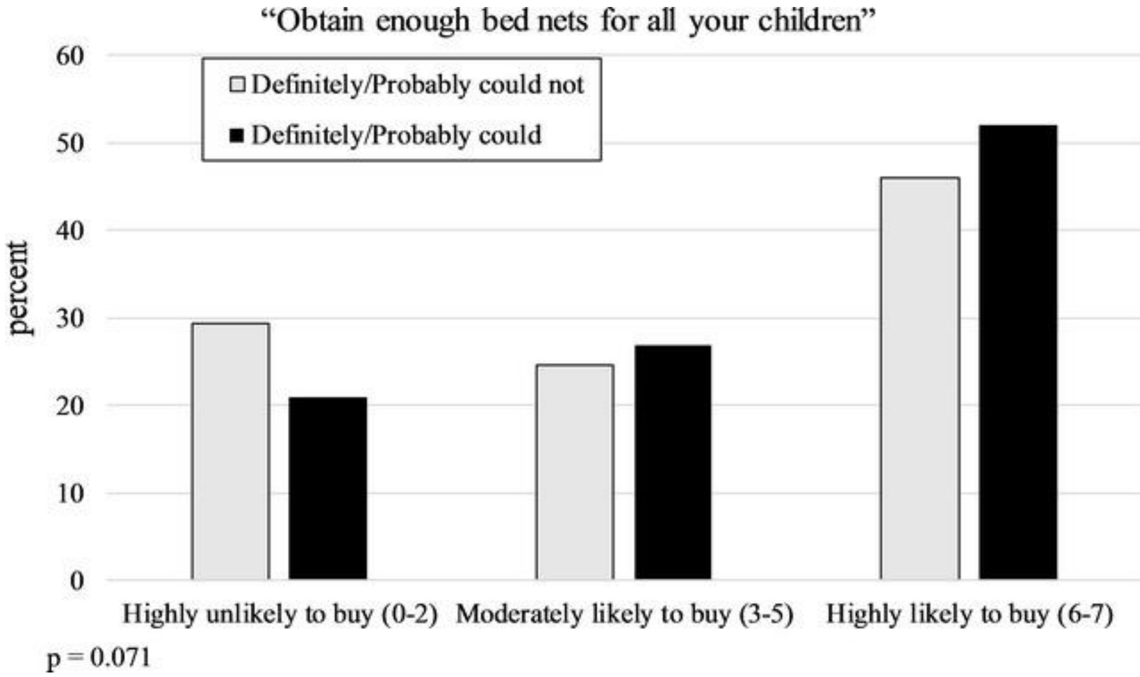

Figure 4.4 Propensity to buy a net (number of times purchased out of seven scenarios), by ideation variable Obtain

Whether households own sufficient nets to cover their inhabitants appears to affect their propensity to buy a net. Figure 4.5 plots participants' propensity to buy a net against household net ratios (the number of nets owned per resident). In general, households' likelihood of buying a net declines as the number of nets per person increases, suggesting that participants made their purchase decision, in part, based on their immediate need for a net ($p = 0.024$). Net ratio varies by location, with 67.9% of rural households owning at least one net per two people compared to 78.5% of urban households ($p < 0.001$). Moreover, among households with sub-standard net ratios, rural locations show a higher, though non-significant, mean number of pregnant women plus children under 5 years old than urban locations (1.63 vs 1.36 per household, respectively; $p = 0.111$). Hence, lower net ratios and greater vulnerability to malaria at least partly explain rural households' greater propensity to buy.

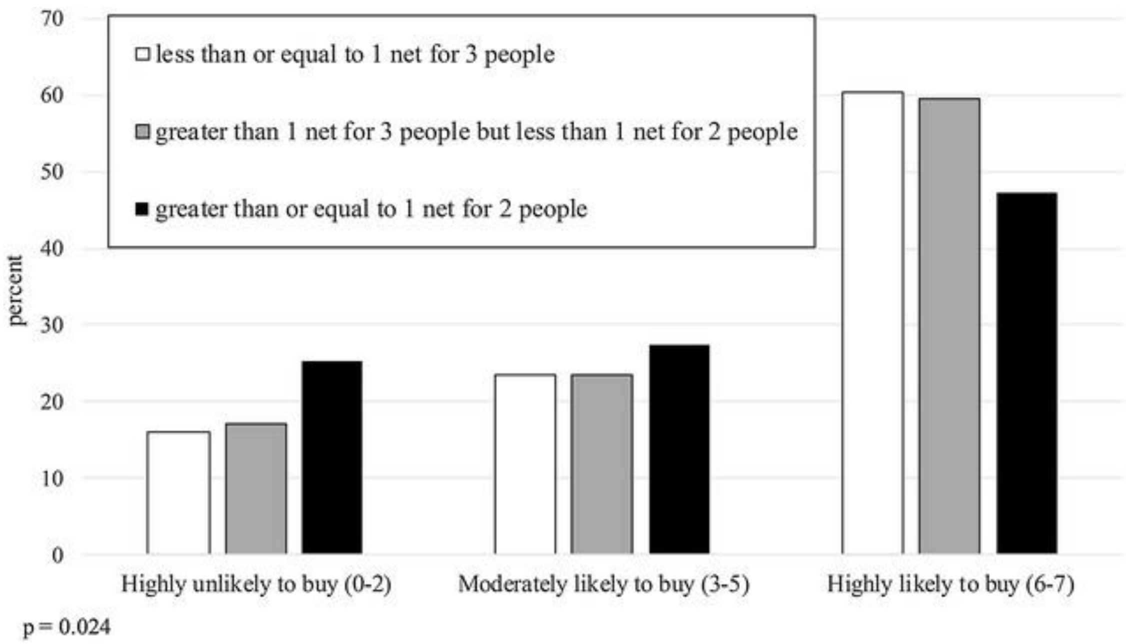

Figure 4.5 Propensity to buy a net (number of times purchased out of seven scenarios), by household net ratio

Demand and WTP for nets

Definitions for all Eq. (1) variables appear in Table 4.7, with corresponding regression estimates in Table 4.8. The restricted estimates reflect omission of the ASC: LessPoor interactive variable which is not statistically significant. In the restricted model, all variables are significant at the 99% confidence level.

Table 4.7 Variables used to estimate bed net demand, Eq. (1)

Variable	Description
Buy	Dependent binary variable = 1 if the individual acted on this choice or = 0 if they did nothing for the specific choice
ASC	Binary variable = 1 denoting either net A or net B, otherwise = 0 for neither net A nor net B
Treatment	Binary variable = 1 if net is brand Olyset (i.e., a treated net)
Rectangular	Binary variable = 1 if net is rectangular shape
Large	Binary variable = 1 if net is large (6 × 6) size
Price	Price of 2000; 4000; 6000; or 8000 TSH
LessPoor	Binary variable = 1 if participant’s household belongs in the upper three socioeconomic quintiles.

Table 4.8 Conditional logit estimate of the DCE demand model (n = 796)

Variable	Unrestricted		Restricted	
	Coefficient	p value	Coefficient	p value
ASC	0.36	<0.001	0.29	<0.001
Treatment	0.26	<0.001	0.26	<0.001
Large	0.28	<0.001	0.28	<0.001
Rectangular	0.17	0.001	0.18	0.001
Price	−0.00009	<0.001	−0.00008	<0.001
ASC: Lesspoor (interactive variable)	−0.11	0.272	–	–
Price: LessPoor (interactive variable)	−0.00006	0.002	−0.00007	<0.001
Rho squared goodness of fit indicator (0–1)	0.03		0.031	

The estimated DCE model generally shows expected results. Significant and positive estimates for coefficients ‘Treatment’, ‘Large’ and ‘Rectangular’ suggest that most participants were willing to pay extra for these specific net attributes (amounts discussed below). Price negatively affects net purchases. While socio-economic status does not significantly affect overall net demand, relatively wealthy households show a larger (negative) impact of price on their purchases.

The estimated coefficients also yield purchase probabilities, price elasticities of demand and WTP values (Louviere, Hensher and Swat, 2000; Train, 2003; Gracia, Loureiro and Nayga Jr, 2009). For example, Table 4.9 shows purchase probabilities and price elasticities for two different net types (a large rectangular Olyset net and a small conical Safinet net, both priced at 4000 TSH), by socio-economic status. Purchase probabilities range from 0.26 to 0.44. Varying the price of a large, square Olyset net from 1000 to 9000 TSH yields a complete demand curve (Figure 4.6). In all cases, demand is highly inelastic, with price elasticities ranging from −0.21 to −0.44.

Table 4.9 Purchase probabilities (and price elasticities) for two different net types, by socio-economic status

	Large, rectangular Olyset at 4000 TSH*	Small, conical Safinet at 4000 TSH*
Less poor (top three quintiles)	0.42 (−0.35)	0.263 (−0.44)
Poor (bottom two quintiles)	0.44 (−0.21)	0.282 (−0.27)

*Comparison net (i.e., net B) is a small rectangular Olyset net priced at 4000 TSH

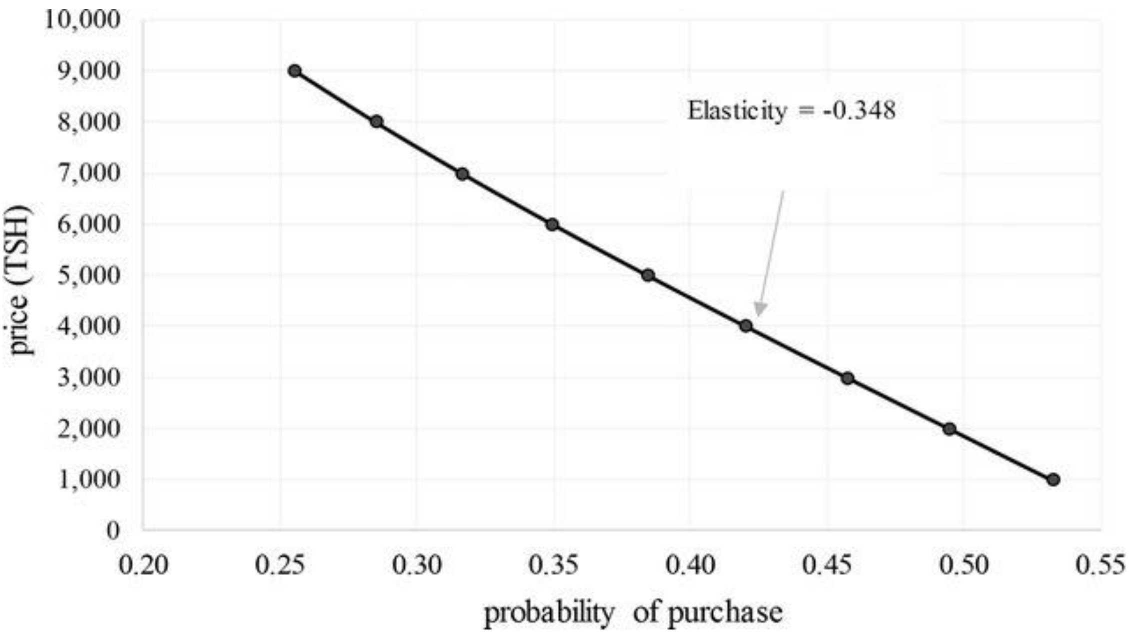

Figure 4.6 Demand curve for a large, rectangular, Olyset net (less poor household)

The final result from the demand model is mean WTP estimates (Table 4.10). The WTP estimates range for a small, conical, untreated net (the ‘base’ net identified by the ASC variable) from 2393 TSH (less poor households) to 3850 TSH (poorer households). For attribute ‘upgrades’, including insecticide treatment, large size and rectangular shape, mean WTP varies from 1161 to 3041 TSH, with shape showing the smallest WTP and size the largest WTP. Households from the bottom quintiles show WTP values for upgrades that are generally 700–1000 TSH higher than for less poor households.

Table 4.10 Mean WTP estimates (in TSH) for net attributes, by socio-economic status

Variable/attribute	Poor (bottom two quintiles)	Less poor (top three quintiles)	Interpretation
ASC	3850	2393	WTP for a small, conical, untreated net
Treatment	2742	1704	Additional WTP for a treated net
Large	3041	1890	Additional WTP for a large net
Rectangular	1868	1161	Additional WTP for a rectangular net

4.4 Discussion

The DCE results and accompanying survey questions indicate a high degree of awareness among Tanzanians regarding the causes and prevention of malaria, and an overall strong demand for bed nets. Moreover, the typical Tanzanian net buyer carefully weighs factors such as shape, size and treatment/material, in addition to price, during her purchase decision. Such factors are important enough that she is willing to pay (roughly 2000 TSH) for the relevant upgrade. It is in net manufacturers' and retailers' best interest to promote such attributes. Further research using focus groups, etc. should be conducted to confirm that they match the desired upgrades found here (rectangular shape, large size, treated/polyethylene). Retailers and policy makers should also examine constraints on buyers stemming from liquidity shortages, provide consumer education, and review tax and tariff policies with the goal of shifting consumers from untreated nets to LLINs. Fortunately, since the findings show households with a moderate willingness to pay for higher-priced treated nets, it should be relatively easy to reinforce the importance of insecticide treatment in both public and private marketing campaigns. Overall, retail sales, in conjunction with large-scale, public-sector distributions and as part of a larger bed net strategy, can help fill gaps in household net ownership.

The strong demand results may partly reflect priming influences. In general, priming refers to changes in consumer behavior that occur due to conscious or subconscious exposure to a related idea, theme or image. Recall that respondents faced a total of 27 bed net and malaria ideation-related questions before completing the DCE. The evidence in the literature for similar priming effects on consumers is quite strong (Mandel and Johnson, 2002; Labroo, Dhar and Schwarz, 2008; Janiszewski and Wyer, 2014). Mandel and Johnson describe the type of positive demand shift that may have occurred here as semantic or conceptual priming (Mandel and Johnson, 2002). Unfortunately, the study did not feature a control group that completed the DCE scenarios before answering the malaria and bed net questions.

While price elasticities of demand are quite low (less than −0.50), they resemble results from a randomized trial on ITN demand in Madagascar (Comfort and Krezanoski, 2017). They also suggest that further price reductions beyond the values used in the study (2000–8000 TSH) would only minimally improve net coverage. Price elasticities at the full retail price should be larger since higher prices would mean that each potential purchase comprises a greater share of a household's income. In reality, however, price elasticities for less poor households were slightly higher (though still inelastic) than for households in the two poorest quintiles.

Recall that the share of 'irrational' participants, those choosing to buy high-priced nets over equivalent low-priced nets, was not trivial (19–25%). These shares fell slightly after excluding participants who agreed with a survey statement that "low-priced nets are inferior to high-priced nets" (14–19%). Zeithaml argues that the relationship between price and perceived quality is complex and thus unlikely to be fully captured by a single survey question (Zeithaml, 1988). Hence, other participants may have made decisions assuming that low price signals low quality even though they did not explicitly agree with the survey statement. Zeithaml also argues that "low price–low quality" perceptions will be strongest when price differences are large, as they are here (200–300% price differences between net A and net B). The marketing research literature further suggests that this perception can be pervasive, affect consumer decisions, and is commonly found for side-by-side product comparisons (Rao and Monroe, 1989). Widespread presence of counterfeit goods in Tanzanian markets may have also caused participants to subconsciously follow this perception even though not explicitly stated.

Despite the overall strong demand for nets in Tanzania, a word of caution pertains to the poorest households still unable or unwilling to buy nets. The DCE results for elasticity, WTP, etc. only refer to the sample mean, suggesting that outlier households (even within the poor vs less poor categories) may show behaviors very different than those reported here. Moreover, the sample population is not nationally representative and there may be poorer sub-groups not captured in the data. Specific non-market delivery channels for these groups should be explored as warranted, which lies beyond the scope of this study.

A second caveat concerns how this study's conclusion of strong net demand might apply immediately following a mass distribution campaign. The above results predict and one study of a prior campaign in Tanzania describes how private sales will decline once households' short term needs for nets becomes saturated (Gingrich *et al.*, 2014). A strong demand for nets cannot be expected to continue without pause immediately following any future mass delivery campaigns. However, this demand will be contingent on a mass campaign's ability to fully supply all households. For example, a recent survey found that immediately following the 2015 universal coverage campaign in Mwanza, 90.3% of all households in the region owned at least one treated net, while only 57.1% of households had one ITN for every two household members (Ministry of Health Zanzibar *et al.*, 2016). In Ruvuma, where a universal coverage campaign was not conducted but school distribution had occurred annually since 2013, 66.1% of households owned at least one ITN, and only 36.6% owned one ITN for every two people. It is extraordinarily difficult for distribution campaigns of treated nets to reach greater than 70% of households with one net for every two people. Overall demand is likely to be lower after a mass campaign but should not reach zero, given the inevitable gaps in household net ownership. Similarly in this study, rural participants' overall higher propensity to buy likely stems from their lower overall net access per capita rather than income-related factors.

Three critical questions remain regarding the overall DCE design. First, it is unclear how the cash stipend (endowment) might have affected participant behavior. One previous DCE study suggests a small positive impact on purchases, provided the endowment does not greatly exceed the market value of the good in the experiment (Loureiro, Umberger and Hine, 2003). For this study, the stipend/endowment was needed so that participants would have cash available to buy a net if they chose that option. With no stipend the demand results would be biased downward due to cash/liquidity-constrained participants with a strong affinity for nets. For example, a recent randomized trial regarding the impact of micro-loans on unsubsidized bed net purchases in India showed an overall purchase rate of 52% with available credit versus 10.8% without credit (Tarozzi *et al.*, 2014). Stated differently, the DCE should accurately measure demand if short term, zero-interest loans are readily available to potential net buyers.

Second, a bed net is best conceptualized as a durable or investment good, where a potential buyer has several months to consider a potential purchase (e.g., in the case of a pregnancy) and the net remains functional for several years. However, the DCE compresses this investment decision into an immediate consumption decision, with no time allowed to fully consider product information, mosquito control alternatives (such as coils or environmental improvements), etc. It is unclear how this change affected participants' behavior in the DCE.

Finally, it is unclear the extent that selection bias, for the districts, schools or student invitations, affected the results. While no indications suggest that selection procedures played a major role, any possible impact on net demand was likely positive. For example, school administrators may have sent letters only to students whose parents they presumed would most likely buy a net. Nonetheless, similar findings regarding price elasticity (Madagascar) and overall propensity to buy (India) from previous randomized trials on net demand suggest that selection bias did not greatly affect the results here (Tarozzi *et al.*, 2014; Comfort and Krezanoski, 2017).

4.5 Conclusions

This study finds generally robust demand for bed nets among a sample of 800 Tanzanian households. The results stem from a non-hypothetical choice experiment where participants choose to buy or not buy a net from among two nets of various prices, sizes, shapes, and insecticide treatment options. The households' socio-economic status does not affect net demand. However, a key factor affecting demand is the household's current net ownership: when there are insufficient nets available to cover household members, which is more often true in rural areas, households show a greater likelihood of buying a net. Price does not exert a large impact on demand, with price elasticities under −0.50, and marginal WTP for various attributes such as large size, square shape or insecticide treatment varies from US$0.75–2. The results imply that the net manufacturers and retailers can successfully market nets to the public by focusing on these attributes, and that governments and policy makers can use this as a viable option to increase access to ITNs in conjunction with other public sector distribution channels.

Ethics approval and consent to participate

The study protocol was approved by the Institutional Review Board of the Johns Hopkins School of Public Health, Baltimore, Maryland, USA (#6744 approved 6 December 2015) and the National Institute for Medical Research, Dar es Salaam, Tanzania (approval granted 24 March 2016). Participants were explained the purpose and importance of the study and they provided verbal informed consent before beginning.

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Chapter 5: Determinants of Bed Net Use Conditional on Access in Population Surveys in Ghana

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Abstract

Background: Insecticide treated nets (ITNs) are one of the most effective and available methods for preventing malaria, and there is interest in understanding the complexities of behavioral drivers of non-use among those with access. This analysis evaluated net use behavior in Ghana by exploring how several household and environmental variables related to use among Ghanaians with access to a net.

Methods: Survey data from the Ghana 2014 Demographic and Health Survey and the 2016 Malaria Indicator Survey were used to calculate an individual's access to a space under a net as well as the use/access proportion (UAP). Geospatial information on cluster location was obtained, as well as average humidex, a measure of how hot it feels, for the month each cluster was surveyed. The relationship between independent variables and net use was assessed via beta-binomial regression models that controlled for spatially correlated random effects using non-Gaussian Kriging.

Results: In both surveys, increasing wealth decreased number of net users in households when compared to the poorest category. In 2014, message exposure about bed net use for malaria prevention increased net use (OR: 2.5, 95% CrI: 1.5–4.2), as did living in a rural area in both 2014 (OR: 2.5, 95% CI: 1.5–4.3) and 2016 (OR: 1.6, 95% CI: 1.1–2.3). The number of nets per person was not associated with net use in either survey. Model fit was improved for both surveys by including a spatial random effect for cluster, demonstrating some spatial autocorrelation in the proportion of people using a net. Humidex, electricity in the household, and IRS were not associated with UAP.

Conclusion: Net use given access is spatially dependent in Ghana. Setting (whether the household was urban or rural) also plays a role, with wealthier and more urban households less likely to use nets when they are available. It will likely be necessary in the future to focus on rural settings and urban settings and wealth status independently, both to better

understand predictors of net use in these areas and to design more targeted interventions to ensure universal coverage of vector control methods for the entire population.

5.1 Introduction

Insecticide treated nets (ITNs) are one of the most effective and available methods for preventing malaria, having averted an estimated 68% of malaria cases between 2000 and 2015 (Bhatt *et al.*, 2015). In 2007, the World Health Organization (WHO) recommended full coverage of ITNs for populations in areas at high risk for malaria transmission (Global Malaria Programme, 2007), which has been followed by a massive scaling up of ITN distribution programs aimed at providing enough nets for all households. The success of these programs has historically been evaluated by two primary indicators: the proportion of households owning at least one ITN, and the proportion of people using ITNs the night before the survey (MEASURE Evaluation *et al.*, 2013). These indicators demonstrate that, on average since 2010, 58% of households in sub-Saharan Africa own at least one ITN, and 36% of the population reported using one the night prior to the interview (Koenker, Ricotta and Olapeji, 2017). However, these indicators do not capture whether a household has enough nets for all members and if individuals have access to a net, which is why new indicators were introduced measuring the proportion households that have achieved universal coverage, as well as the proportion of the population with ITN access (MEASURE Evaluation *et al.*, 2013). Knowing what proportion of households have enough nets to cover all members is useful for net distribution campaign planning, and knowing population access provides a way to understand net use patterns in the population that have access (Koenker and Kilian, 2014; Koenker, Ricotta and Olapeji, 2017).

Out of 27 President's Malaria Initiative (PMI) focus countries surveyed with a Demographic and Health Survey (DHS) or Malaria Indicator Survey (MIS) in the 2010–2016 period, Ghana ranks 25th in net use conditional on access (ratio use to access 0.63, 2016 MIS); only Niger (2012 DHS) and Zimbabwe (DHS 2015) have a larger proportion of the population not using nets despite having access to a space under one (Koenker, Ricotta and Olapeji, 2017). In Ghana, the proportion of the population with access to an ITN within their household varies widely by region and wealth quintile. Greater Accra seems to have a particularly large discrepancy between ITN use and access (use:access ratio 0.34); however, none of the regions of the country have a ratio above 0.8 (Koenker, Ricotta and Olapeji, 2017).

While access to an ITN within the household is the best predictor of ITN use, given the differences in use conditional on access seen across Ghana, it is important to understand what additional variables might explain use behavior when household members have access (in theory). In literature, self-reported reasons for not using nets include discomfort (due to heat), fluidity of sleeping arrangements (i.e. moving from inside to outside or vice versa during the night), and little perceived need when mosquito density is low (Pulford *et al.*, 2011). Here, it was explored how several variables, including connection to electricity, exposure to net use messaging, and 'humidex' (how hot the weather feels to an average person), relate to net use among Ghanaians with access to an ITN.

5.2 Methods

Data from the Ghana 2014 Demographic and Health Survey (DHS) and the 2016 Malaria Indicator Survey (MIS) were obtained from the DHS Program (ICF International Inc., no date) and compared in this analysis. Geospatial information about each cluster of households, defined as a census enumeration area of either a village or an urban city block, was obtained as well. Cluster locations are offset between 0–2km for urban clusters, and 0–5km for rural clusters (with an additional 1% displaced up to 10km) to retain confidentiality (Burgert *et al.*, 2013). To calculate household access to any net (ITNs and non-insecticidal nets) from these datasets, the number of people who slept under a net and the number of people who could have slept under a net yet did not (i.e. a space under a net was available for their use) were summed for each household. The proportion of household members that used a net out of those that had access, the 'use/access proportion' (UAP), was calculated as the number of household members that slept under a net divided by the number that could have or did use a net (access). Spatial autocorrelation of UAP was tested using Moran's I ("ape" package in R (Paradis, Claude and Strimmer, 2004)). To understand discomfort in the use of nets due to heat, the humidex (a unitless index) was calculated from spatio-temporal data of temperature and vapor pressure from the CRU TS v. 4.01 dataset which has monthly temporal resolution on 0.5x0.5 degree grids) (Mitchell and Jones, 2005; Harris *et al.*, 2014) using the formula

$$Humidex = T + 0.5555 * (e - 10)$$

where T is the temperature in degrees Celsius, and e is the vapor pressure in millibars (CSG; Computer Support Group Inc. and CSGNetwork.com, no date). These data were extracted at cluster locations for the month and year in which the cluster was surveyed, using ArcGIS 10.5 (ESRI, 2017). Four clusters out of 427 in 2014 and eight out of 200 in 2016 were excluded due to missing coordinates.

Statistical analysis was done in R 3.4.2 (R Core Team, 2017). Means and proportions were calculated using the "survey" package (Lumley, 2004, 2017). Pearson's chi-squared test statistic was used to evaluate differences in access, with a statistical significance level of 0.05. Using the R-INLA package (Rue, Martino and Chopin, 2009; Lindgren, Rue and Lindstrom, 2011; Martins *et al.*, 2013; Lindgren and Rue, 2015; Rue *et al.*, 2017), the relationship between independent variables and net use out of the number having access the night before the survey in households was assessed. Beta-binomial regression models that controlled for spatially correlated random effects using non-Gaussian Kriging were chosen to account for overdispersion in the data. By design, households without nets or without people spending the night at home were excluded from the analysis. Candidate explanatory variables for each model included region, setting (urban or rural), mean humidex for the cluster, wealth quintile, indoor residual spraying (IRS) of the dwelling with insecticides within the previous year, connection to electricity, ratio of nets to household members, and whether the respondent heard a message on the use of nets. Explanatory variables and first-order interaction terms were chosen via forward stepwise selection using the Deviance Information Criterion (DIC). Rasters of predicted UAP and net access at the cluster level from INLA output with spatial effects only (i.e. no covariates) were created using the 'rgdal' and 'raster' packages and imported into ArcGIS to plot maps (Hijmans, 2016; Bivand, Keitt and Rowlingson, 2017). The differences between 2016 and 2014 were compared by examining the overlap of the 95% credible intervals of the logit transformed maps of both access and UAP.

5.3 Results

Survey characteristics

Interviews for the 2014 DHS took place from September through December 2014. There were 11,835 heads of households interviewed, with these households comprising of 40,337 individual members, and with an average size of 3.5 members per household. Interviews for the 2016 MIS were conducted from October through December 2016. Over a six week period, heads of 5,841 households were interviewed, with 20,708 individual household members, and with an average household size of 3.6. Forty-three percent of individuals were <15 years old in both surveys. For both the 2014 DHS and 2016 MIS, 55% of the households were classified as urban and 45% as rural. The average humidex during the months of interview in 2014 was 39 (interquartile range [IQR]: 36), and was 32 (IQR: 33) in 2016.

Net ownership and use

In 2014, there were 16,892 nets in the surveyed households, 16,463 (97%) of which were ITNs. This proportion was similar in 2016, when there were 10,689 nets, 10,490

(98%) of which were ITNs. In 2014, households had an average of 1.4 (95% confidence interval (CI): 1.3–1.4) nets, which increased to 1.7 (95% CI: 1.6–1.7) nets in 2016. The proportion of households without any net decreased from 30% (95% CI: 29–32) to 26% (95% CI: 24–28); access increased from 63% of the population (95% CI: 62–65) having access to a sleeping space under a net in 2014, to 70% (95% CI: 68–72) in 2016. Mean net access over all households within a cluster varied across the country (Figure 5.1). In 2014, the cluster level access to a net ranged from 18% to 100%, and in 2016, it varied from 37% to 100%. Net access was significantly lower in urban areas than in rural areas in both 2014 (1.7 vs 2.7, $p<0.001$) and 2016 (2.0 vs 3.1, $p<0.001$). Access in 2016 was significantly higher than 2014 in parts of western Brong Ahafo, Accra, central and north Northern region, and a few other sporadic areas (Figure 5.2, green). Net access in 2016 was significantly lower than 2014 in parts of the Western, Eastern, and Upper East regions (Figure 5.2, red). UAP in 2014 was 0.52 (95% CI: 0.50–0.54), and this increased in 2016 to a UAP of 0.55 (95% CI: 0.52–0.59). Clustering of the UAP was observed in both surveys (Figure 5.3), as indicated by a positive and significant Moran's I. Overdispersion of net use can be seen in Figure 5.4, where the majority of net users among those with access are clustered at 0% or 100%. The proportion of nets that were unoccupied, were occupied be only one person, by two people, etc. was similar for both surveys (Figure 5.5).

Net use conditional on access

As analysis was restricted to those with access to a net, households where no-one had access were excluded from the analysis, and this left 8,385 out of 11,835 households (71%) in 2014 and 4,279 households out of 5,841 (73%) in 2016 (this increase was statistically significant, $p<0.001$). Comparing the UAP without accounting for covariates in 2016 to that in 2014, at least some significant increase was seen in most regions in the country (Figure 5.6, green). A significantly decreased UAP was seen primarily in the south of the country, although there was a small section in the northernmost part of Northern region as well (Figure 5.6, red).

The final, selected, models for both the 2014 DHS and the 2016 MIS included setting (urban or rural), wealth quintile, IRS of the dwelling with insecticides in the year prior to the survey, the ratio of nets to household members, the humidex in the month of survey, connection to electricity, and whether the respondent heard a message on the use of nets. Interaction terms between messaging, setting, IRS, and electricity were included to improve model fit but were not significantly associated with net use conditional on access.

Table 5.1 Odds ratios and 95% credible intervals for explanatory variables of net use conditional on access in betabinomial regression models with spatial random effects.

	2014		2016	
Effect	Coefficient	95% credible interval	Coefficient	95% credible interval
Wealth (ref: poorest)				
Poorer	0.99	(0.82-1.20)	0.94	(0.74-1.20)
Middle	**0.77**	**(0.62-0.96)**	**0.69**	**(0.52-0.91)**
Richer	**0.55**	**(0.43-0.71)**	**0.60**	**(0.45-0.81)**
Richest	**0.48**	**(0.36-0.64)**	**0.44**	**(0.32-0.61)**
Number of nets per person	1.02	(0.89-1.16)	1.07	(0.90-1.27)
Humidex	1.00	(0.99-1.00)	1.00	(0.99-1.01)
Messaging	**2.53**	**(1.52-4.22)**	1.16	(0.75-1.83)
Setting (ref: urban)	**2.54**	**(1.51-4.31)**	**1.59**	**(1.08-2.33)**
IRS in last 12 months	0.76	(0.36-1.59)	0.82	(0.45-1.50)
Electricity in household	0.84	(0.52-1.36)	0.76	(0.53-1.08)
Messaging x rural	0.68	(0.42-1.10)	1.19	(0.87-1.65)
Messaging x IRS	0.76	(0.42-1.36)	1.12	(0.72-1.75)
Messaging x electricity	0.94	(0.60-1.47)	1.03	(0.68-1.57)
Rural x IRS	1.15	(0.76-1.74)	1.09	(0.67-1.76)
Rural x electricity	0.79	(0.58-1.07)	0.85	(0.57-1.26)
IRS x electricity	1.06	(0.74-1.52)	0.77	(0.47-1.25)

x indicates interaction term

In both surveys, increasing wealth decreased number of net users in households when compared to the poorest category (Table 5.1). In 2014, having heard a message about using a bed net for malaria prevention increased net use (odds ratio (OR): 2.5, 95% credible interval (CrI): 1.5–4.2). Living in a rural area was also significantly associated with an increase in net use in both 2014 (OR: 2.5, 95% CrI: 1.5–4.3) and 2016 (OR: 1.6, 95% CrI: 1.1–2.3). Model fit was improved for both surveys with the inclusion of a spatial random effect for cluster, demonstrating that there is some spatial autocorrelation in the proportion of people that use a net. Coefficients of the humidex in the month of survey, electricity in the household, and having received IRS in the last 12 months were not significantly different from zero.

5.4 Discussion

This analysis evaluated net use conditional on access to a bed net in Ghana by incorporating household-level predictors of net use and geographic aspects such as location and humidex. As Ghana's UAP is low throughout the country, especially in urban areas, relative to other countries, exploring associations with other factors may improve insight in what actions could be taken to increase use of nets by those that have access.

There has been a lot of interest in understanding the complexities of behavioral drivers of non-use among those with access (Russell *et al.*, 2015; Babalola *et al.*, 2016; Dlamini *et al.*, 2017; Koenker and Yukich, 2017). These complexities include issues surrounding personal comfort or convenience of using nets, beliefs about personal risk of disease, and the feelings of one's community and social network toward nets and their value (Storey *et al.*, no date; Watanabe *et al.*, 2014; Russell *et al.*, 2015). The interplay of these factors is important, as it can help us understand how these variables are influenced by community engagement and campaigns aimed at education and behavior change (Storey *et al.*, no date).

While there are many reasons people cite for non-use (Baume and Koh, 2011; Pulford *et al.*, 2011; Manu *et al.*, 2017), thermal discomfort when using a net is common (Pulford *et al.*, 2011; Singh, Brown and Rogerson, 2013; Yukich *et al.*, 2017). Indeed, in Ghana, the practice of sleeping outside during the dry season for the fresher, cooler air is widespread (Monroe *et al.*, 2015). Because of this, the humidex, which combines temperature and vapor pressure into a measure of how hot the weather felt during the month in which the survey took place, was included in this analysis. While the inclusion of this variable improved the fit of our models for both 2014 and 2016, in the final adjusted model, humidex did not have a significant association with net use. Studies have shown that bed nets decrease airflow (Von Seidlein *et al.*, 2012), and it is likely that this is what makes it feel hot and stifling under a net (Koenker *et al.*, 2013; Briët *et al.*, 2016; von Seidlein *et al.*, 2017). A pilot study has been conducted on attempting to improve comfort under nets by including small fans meant to increase air flow (Jaeger *et al.*, 2016), but further research is needed to understand whether this would increase net use.

Access was correlated with setting, with rural households having consistently better access to bed nets than urban households. Due to lower disease burden in the urban areas, which make up 55% of Ghana's population, cities such as Accra were deprioritized by malaria control campaigns (President's Malaria Initiative, 2013); however, a national ITN distribution campaign was conducted in 2014–2015, and in May 2016 there was the addition of a country-wide scale up of school-based continuous distribution in an attempt to decrease gaps in net access across the country (Johns Hopkins Center for Communication Programs, 2016; President's Malaria Initiative, 2016). Indeed, the proportion of households with enough nets for all household members was significantly higher in 2016 in both rural (65% in 2016 vs 58% in 2014, $p<0.001$) and urban (50% vs 46%, $p=0.001$) settings than in 2014.

Net use conditional on access was also spatially correlated; inclusion of a spatial random effect in the regression models for use conditional on access significantly improved the fit. In addition to having better access to nets, rural households were more likely to use them in 2014. This has been observed in Ghana for a number of years (Agyepong and Manderson, 1999; Baume and Koh, 2011). Among households with access, one possible reason for non-use among the urban population is a lower perceived risk of disease from malaria, especially as disease prevalence is much lower in urban areas than rural ones (Frank *et al.*, 2016; Ghana Statistical Service *et al.*, 2016). This is attributed mainly to two things: first, decreases in breeding grounds and resting places for mosquitoes, partly attributable to source management and larvaciding which has severely diminished the mosquito population, and second, urban households in Ghana have used alternative protective measures such as house screening (over 80% of the urban households in Accra have window screens), aerosol sprays, and mosquito coils for several years (JSI Research & Training Institute, 2013). Additionally, it has been shown that both perceptions of susceptibility to and severity of malaria have been associated with increases in net usage, while the belief in one's ability to detect and treat a case of malaria has shown a negative correlation with net use (Storey *et al.*, no date; Babalola *et al.*, 2016). It is possible that urban populations who are at decreased risk of malaria are less worried about (severe) disease, or feel that they are better able to manage the illness if it does occur, thus lessening their belief in the benefit of using a net (President's Malaria Initiative, 2015; Ghana Statistical Service *et al.*, 2016). Whatever the reason for non-use among those with access in urban settings, it is likely different enough from rural communities that targeting alternative interventions or educational messaging based on setting might be warranted. It will also be important to continue to monitor risk of malaria in urban communities, to ensure that the rapid urbanization and subsequent changes in infrastructure do not re-introduce malaria into areas where control is minimal.

Finally, multiple studies have shown a positive relationship between behavior change communication (BCC) and net use in several countries (Boulay, Lynch and Koenker, 2014; Koenker *et al.*, 2014; Owusu Adjah and Panayiotou, 2014; Babalola *et al.*, 2016; Kilian *et al.*, 2016). Ghana has a long history of using mass media and other communication channels to educate the population about malaria, and knowledge about transmission and prevention is generally good (MoHG, 2011). In the first half of 2014, the national communication strategy was revised to reflect updated WHO recommendations and NMCP policy. Special focus was placed on increasing advocacy, communication, and social mobilization for a number of malaria-related topics, including LLIN use and maintenance, and both advertising agencies and other health communication partners were engaged to produce educational materials. In the first quarter of 2016 alone, there were a reported 41 radio and television programs in both English and local languages dedicated to educating the public on malaria control interventions (National Malaria Control Programme Ghana, 2016). These campaigns appear to have been moderately successful, because there was a significant relationship between messaging exposure and net use observed in the 2014 survey, with individuals who were exposed to messaging being 2.5 times more likely to use a net than those without message exposure. What is unclear is why the same relationship was not seen in 2016. In the 2014 DHS, exposure to malaria messaging was remarkably high, with 92% of respondents recalling any exposure to messaging. Messaging included appropriate care seeking behavior as well as use of ITNs by families, specifically pregnant women and children. More men than women had access to mass media (86% vs 69%), and it is conceivable that because in many regions of Ghana, the male head of household is responsible for decision making about health topics, their greater exposure to messaging leads to a larger observed effect in net use. In the 2016 MIS, only 46% of women reported having been exposed to general malaria messaging (as MISs focus on specific target populations, men were not interviewed and their level of exposure to messaging is unknown). Additionally, the head of household's decisions about nets affects the likelihood of use by all individuals in a household (overdispersion) (Figure 5.4). This evidence, coupled with the significant decrease seen in UAP in some regions of Ghana between 2014 and 2016 (Figure 5.6), suggests a need for increased net use BCC.

Exposure to messaging is generally higher in urban areas than rural ones. Additionally, urban residents are more likely to encounter messages via mass media such as radio and TV, while rural individuals are more frequently exposed to messaging at health centers and from community health workers. However, according to a health communication survey conducted in 2015, health workers were the most trusted source of information (Communicate for Health and FHI360, 2016). This might be one contributing factor to why net use in rural communities is higher; even though urban residents might be hearing a larger quantity of messages, they might consider them less trustworthy, which would lessen their impact on use. This phenomenon was demonstrated by Owusu Adjah and Panayiotou (2014), who found that hearing messaging from a health worker had the highest adjusted odds of net use out of any of the measured messaging channels (Owusu Adjah and Panayiotou, 2014). This highlights another important difference between urban and rural areas for malaria control, and emphasizes the need for unique targeting of interventions as well as messaging and education to each setting.

Both surveys were carried out over the same months of the year. While this provides the benefit of consistency, it leaves an incomplete picture of net use behavior for the remainder of the year. This is important because both surveys were conducted during the dry season, and net use has been shown to vary by season (Tropical Health and Malaria Consortium, 2014). It is possible that at a different time of the year, or in temporal studies, humidex would become a significant predictor of net use among those with access.

5.5 Conclusions

While net use among those with access is low in Ghana, it is spatially dependent. Setting (whether the household was urban or rural) also plays a role, with wealthier and more urban households less likely to use nets when they are available. It will likely be necessary in the future to focus on rural settings and urban settings and wealth status independently, both to better understand predictors of net use in these areas and to design more targeted interventions to ensure universal coverage of vector control methods for the entire population.

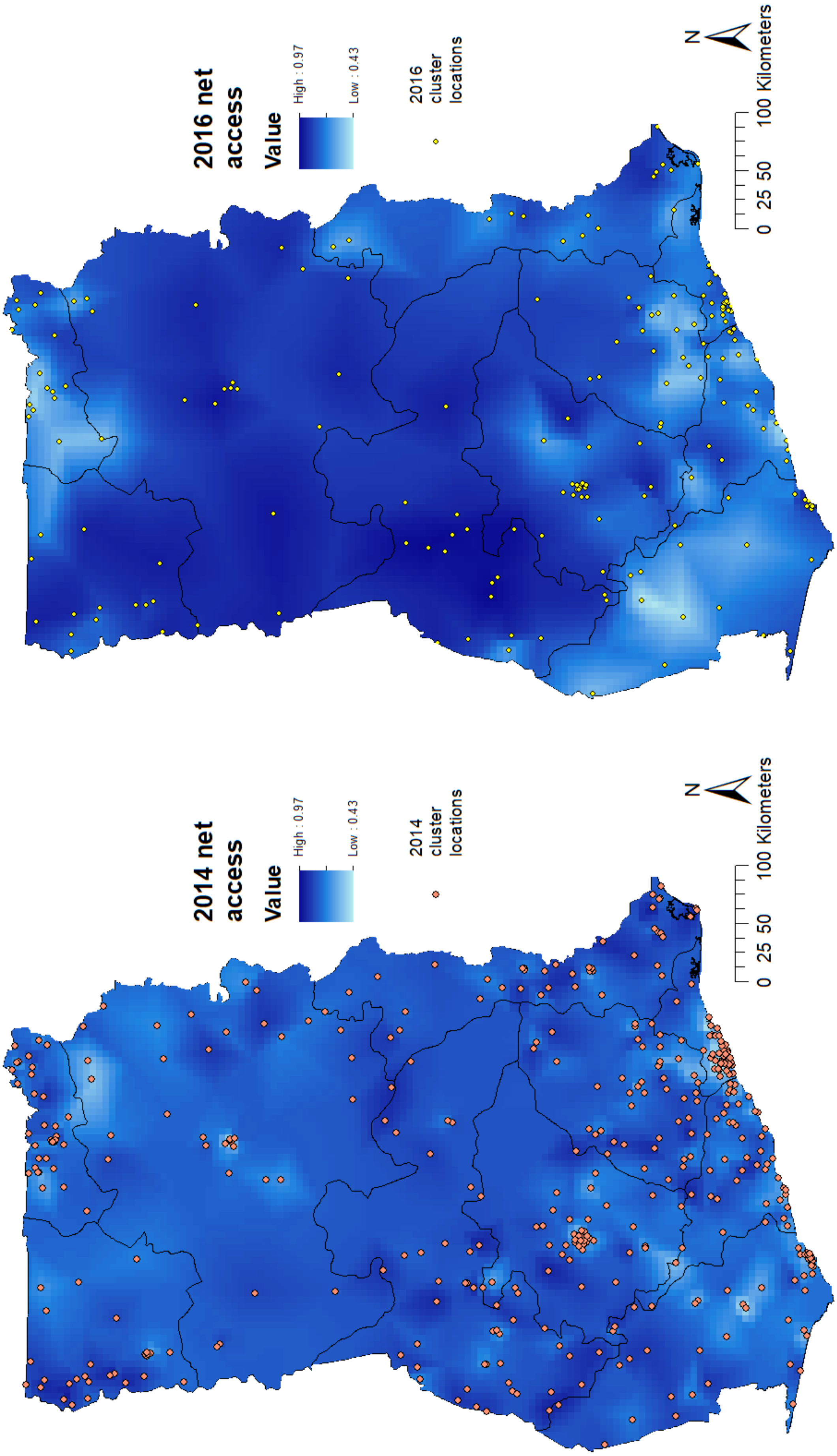

Figure 5.1 Net access in Ghana in the a) 2014 DHS, and b) 2016 MIS.

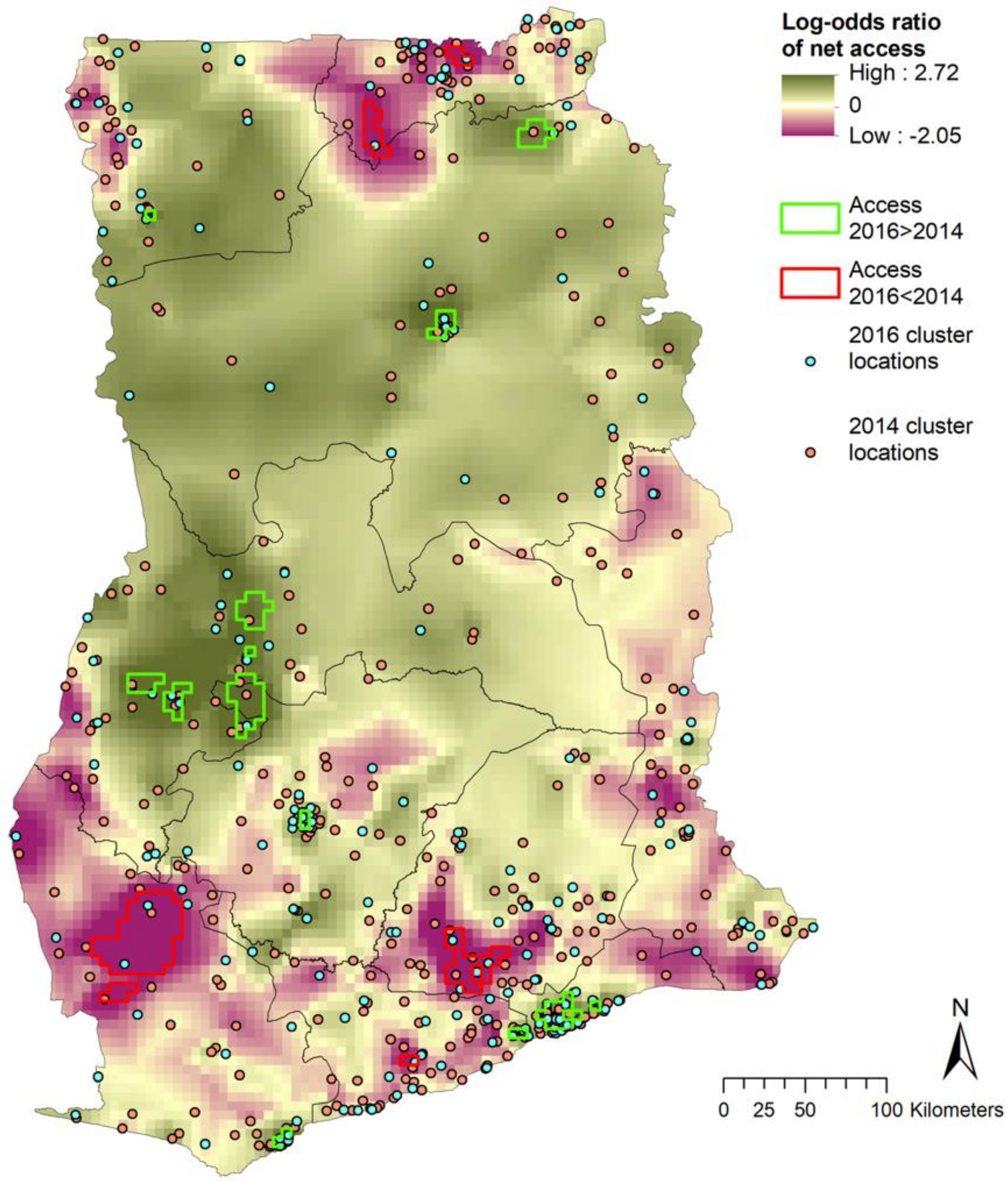

Figure 5.2 Log odds ratio of net access in 2016 relative to 2014. Areas where the lower 95% credible boundary of 2016 was above the upper boundary of 2014 access are demarcated in green, and areas where the lower 95% credible boundary of 2014 access was above the upper boundary of 2016 access are demarcated in red.

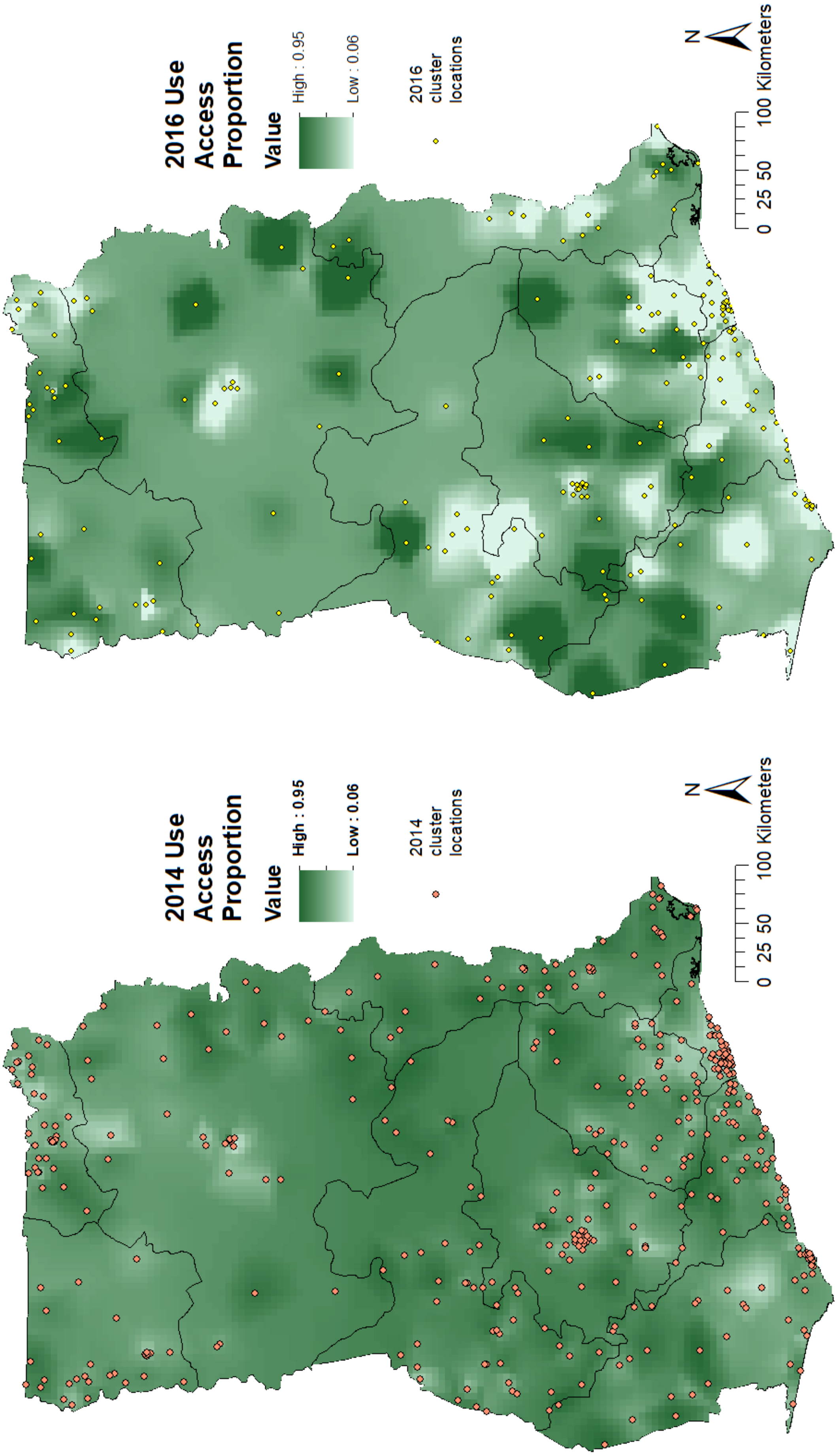

Figure 5.3 Use access proportion in Ghana in the a) 2014 DHS, and b) 2016 MIS.

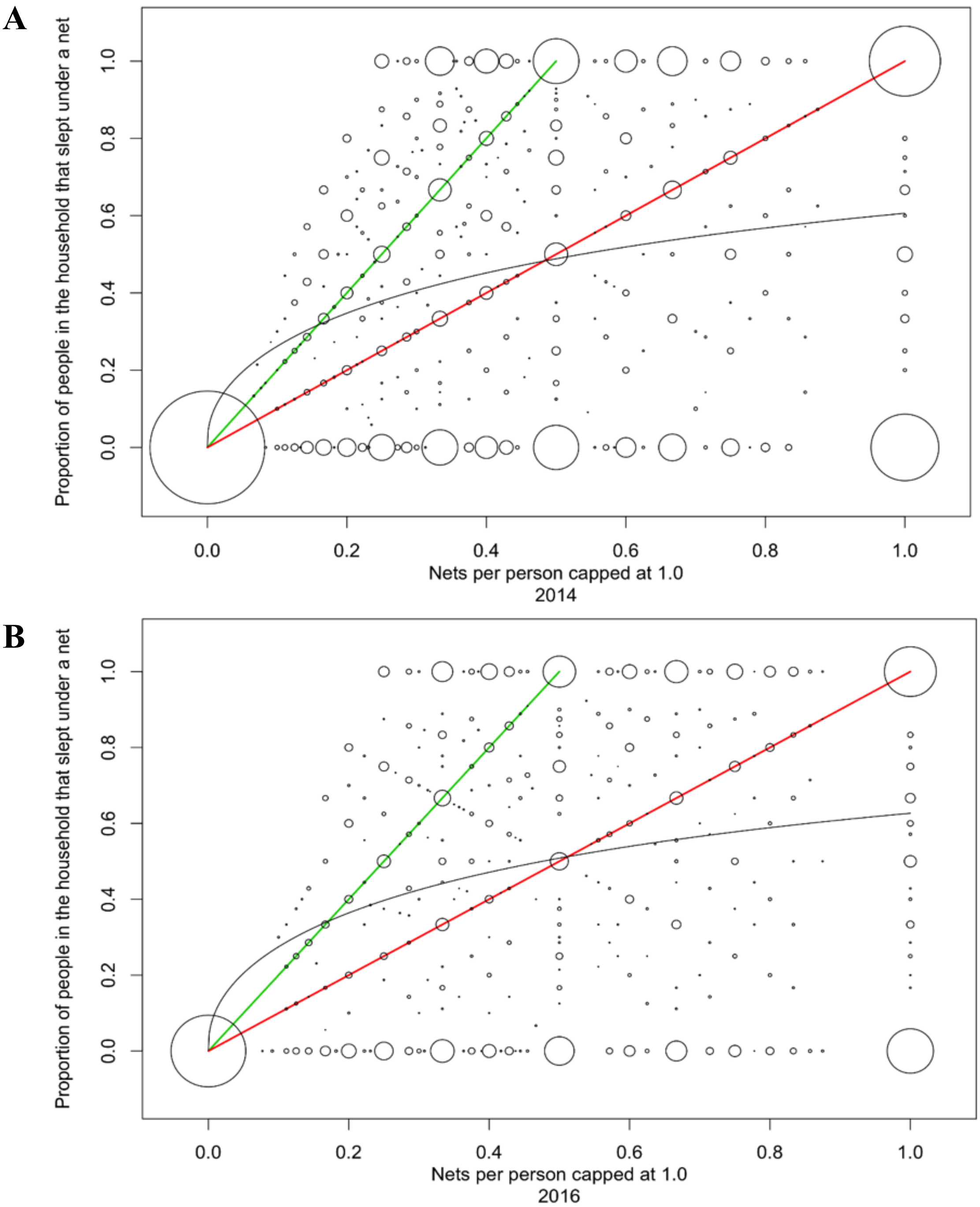

Figure 5.4 Use access proportion in Ghana depending on ITN ownership. A) 2014; b) 2016. The size of the circle corresponds to the number of data points with that value. The green line shows theoretical optimum net use at one net per two people (universal coverage). The red line shows what could be expected if no one shared a net. The gray line is the fitted value using a beta-binomial regression model with logit-link function.

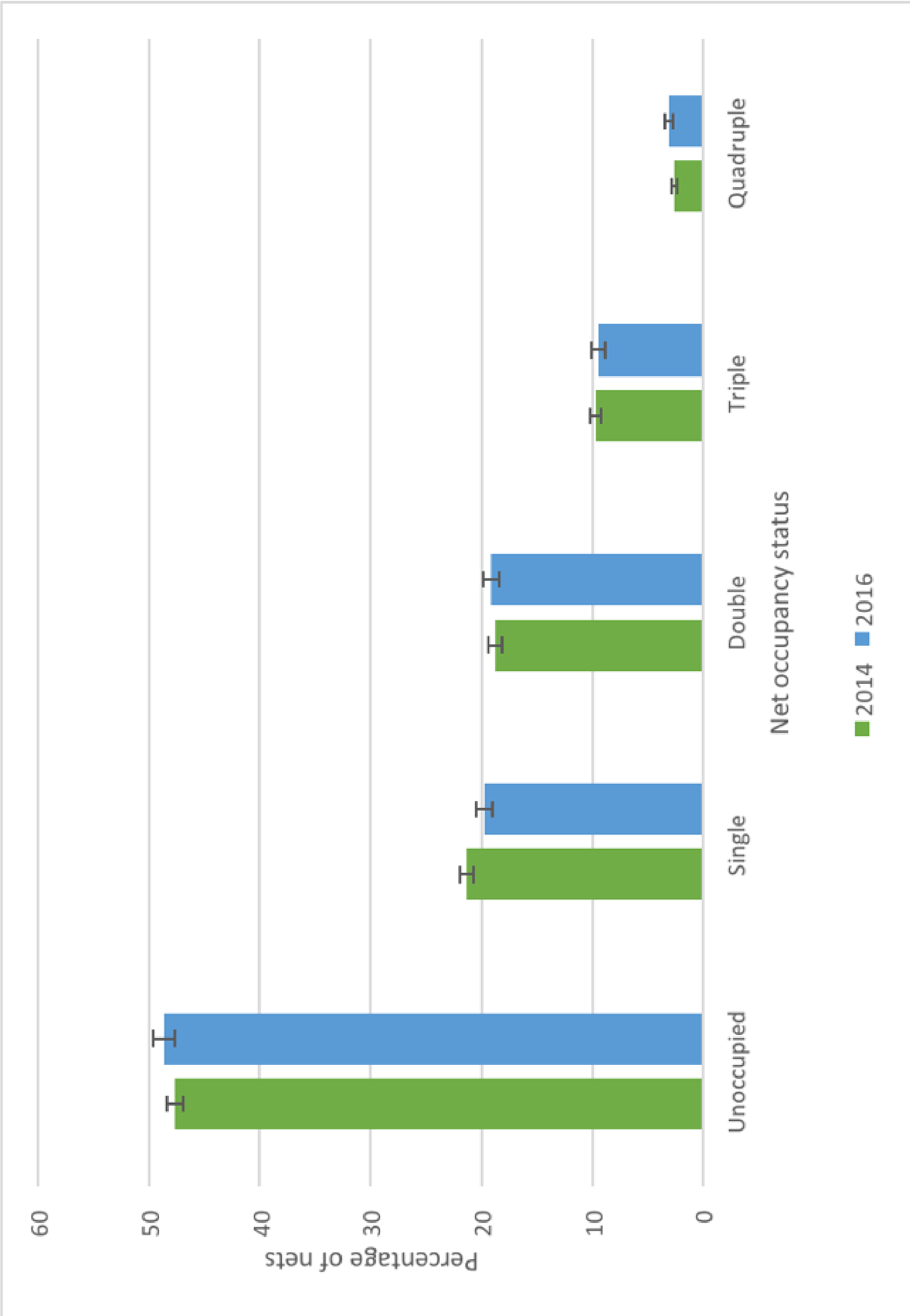

Figure 5.5 Proportion of nets by number of people occupying them the night before the survey.

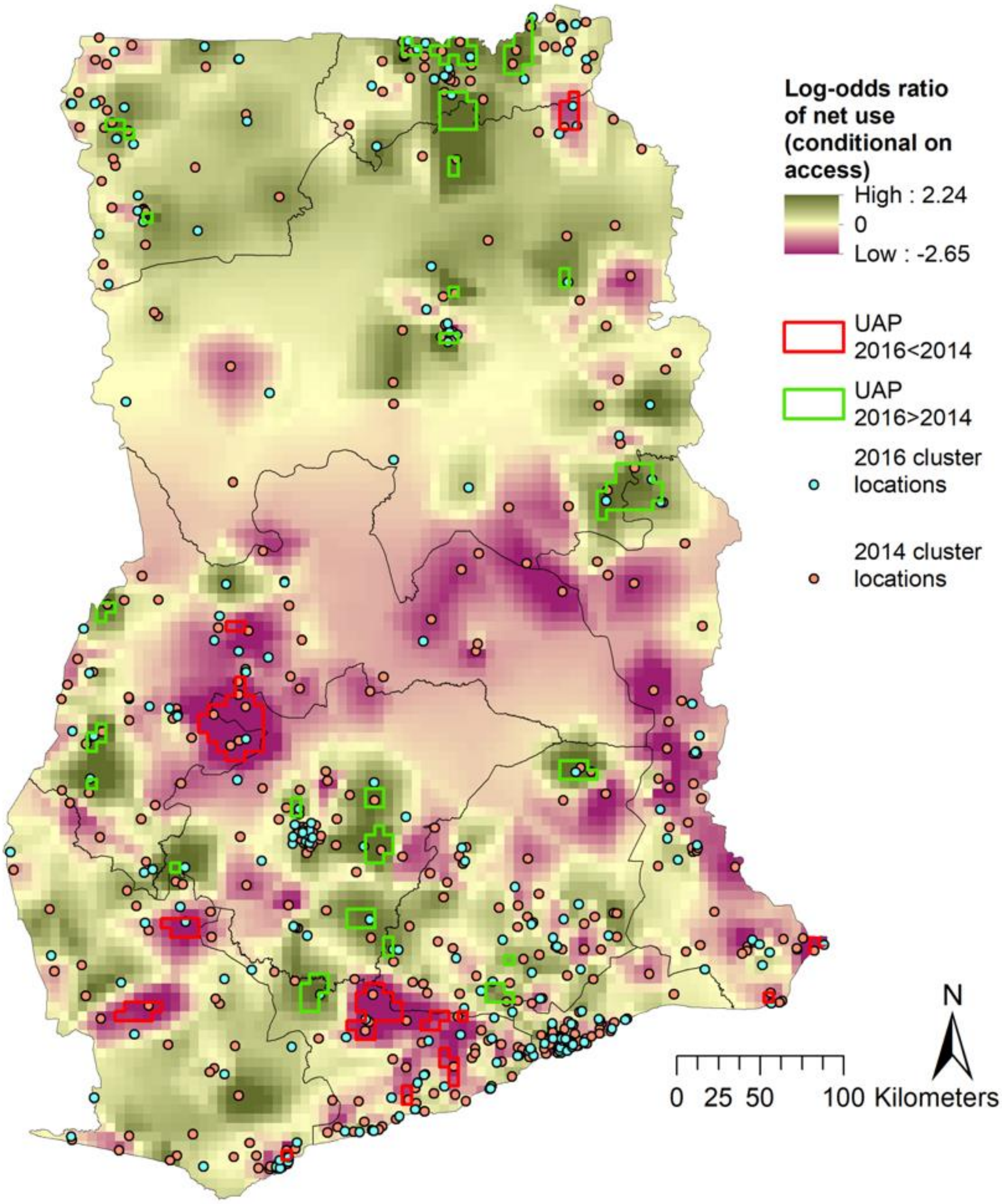

Figure 5.6 Log odds ratio of UAP in 2016 relative to 2014. Areas where the lower 95% credible boundary of 2016 was above the upper boundary of 2014 access are demarcated in green, and areas where the lower 95% credible boundary of 2014 access was above the upper boundary of 2016 access are demarcated in red.

Chapter 6: Determinants of bed net use among those with access in four African countries: an analysis of national surveys and remotely sensed climate data

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Abstract

Background: Population-level access to a net has increased globally from 34% in 2010 to 61% in 2016. To increase net use, it is important to understand why people choose not to use one, especially among those with access. This analysis aimed to evaluate how net use among individuals with access is influenced by household and geospatial factors, including temperature and rainfall.

Methods: The most recent Demographic Health Survey or Malaria Indicator Survey data was obtained for Angola, Mali, Nigeria, and Tanzania, and individual net access and the use/access proportion (UAP) were calculated. Remotely sensed climate data including surface temperature during the month the cluster was surveyed and rainfall one month prior (as a proxy for mosquito density) was extracted. The relationship between independent variables and net use was assessed via beta-binomial regression models that controlled for spatially correlated random effects using non-Gaussian Kriging.

Results: In Nigeria, higher wealth quintiles resulted in lower net use, while increased net use was associated with being in the "richer" quintile in Mali, and the "richest" quintile in Tanzania. As the ratio of nets per person increased, so did the UAP in Mali (Odds ratio [OR]: 2.34, 95% credible interval [CrI]: 1.74–3.15), Nigeria (OR: 1.72, CrI: 1.44–2.08), and Tanzania (OR: 3.11, CrI: 2.47–3.93). Conversely, as the ratio of rooms used for sleeping in the house per person increased, UAP decreased significantly in Mali (OR: 0.80, CrI: 0.68–0.95) and Tanzania (OR: 0.35, CrI: 0.27–0.44). Having electricity was also significantly associated with a decrease in UAP in Mali. Temperature was not significantly associated with UAP in any survey, however in Angola and Tanzania, as rainfall increased so did UAP.

Conclusion: It is important to understand the reasons for non-use of nets among those with access to one. Better knowledge of net use preferences and practices in different contexts,

including whether households need more nets to accommodate unique sleeping situations or require alternative vector control tools, will be important considerations for national malaria control programs.

6.1 Introduction

Malaria is endemic in sub-Saharan Africa and is transmitted by the bite of infective mosquitoes of the genus *Anopheles*. Most sub-Saharan countries work to reduce transmission by using interventions such as indoor residual spraying (IRS) and insecticide-treated nets (ITNs). The World Health Organization (WHO) recommends that country programs provide universal coverage of ITNs to all people at risk of malaria, newly defined as 100% access to, and use of, malaria control interventions (specifically ITNs and/or IRS) (Vector Control Technical Expert Group Report, 2013; Global Malaria Programme, 2014; WHO Global Malaria Programme, 2017). Funding for vector control has increased substantially since the 2000's, and cases of malaria have fallen 62% over the same period (World Health Organization, 2016).

Universal coverage of ITNs (which includes both access and use) has been the goal, but it has proven difficult to measure. Until 2011, the main indicators for the success of ITN programs were the proportion of households owning at least one ITN ("ownership" indicator) and the number of people using ITNs the night before the survey (Roll Back Malaria, 2009). However, knowing how many households have one net does not help countries understand whether people have enough nets for everyone to use or where gaps in coverage might be, and evaluating net use among all households, including those without nets or in households that do not have enough nets for all household members to use, provides an inaccurate understanding of net use. This makes it difficult for programs to understand whether non-use of ITNs is simply due to lack of access, or whether there are other factors. To address this, the Roll Back Malaria Monitoring and Evaluation Reference Group recommended adding an indicator evaluating the proportion of the population with access to a net, as well as an indicator measuring the proportion of households with one net per two people (Kilian and Roll Back Malaria Partnership, 2011). These indicators allow a more accurate evaluation of net use, as non-use of nets due to lack of access can be quantified and factors assessing use behaviors among those with access can be more clearly studied (Vanden Eng *et al.*, 2010; Koenker and Kilian, 2014). As more countries move closer to achieving universal access to ITNs, it becomes increasingly important to understand net use behaviors among those who have access, so that appropriate use-promoting interventions can be designed or alternative malaria prevention strategies can be considered.

Household surveys like Demographic and Health Surveys (DHSs), Malaria Indicator Surveys (MISs), and Multiple Indicator Cluster Surveys (MICS) are commonly used to determine bed net ownership and use at a population level. These surveys provide a wealth of information about families, their health, and wellbeing, and can facilitate a detailed understanding of topics like disease prevention and treatment, child health, comorbidities, among others (dhsprogram.com). In many sub-Saharan African countries, nationally representative DHSs are usually conducted every five years, and can include between 5,000 and 30,000 households. MISs are more targeted, both in terms of population and in terms of timing, with data collection aiming to occur during or immediately following the rainy season when malaria transmission is highest, and focusing on women of reproductive age and children under five (high risk groups) in areas with high malaria endemicity. This targeting can lead to spatial and seasonal bias in some indicators, especially those having to do with malaria parasite prevalence in the population as well as use of interventions (MEASURE Evaluation *et al.*, 2013). The goal of this current analysis was to evaluate how net use among individuals with access is influenced by household factors and geospatial variables such as temperature and rainfall, combining data from national DHSs and MISs with remotely-sensed climate data.

6.2 Methods

Household data and indicator calculations

Four surveys from geographically diverse countries conducted during 2015–2016 were chosen for this analysis: Angola (DHS), Mali (MIS), Nigeria (MIS) and Tanzania (DHS). Data was downloaded from the DHS program website (ICF International Inc., no date). Geospatial information about each cluster of households, defined as a census enumeration area of either a village or an urban city block, was obtained as well. Cluster locations were offset between 0–2km for urban clusters, and 0–5km for rural clusters (with an additional 1% displaced up to 10km) to retain confidentiality (Burgert *et al.*, 2013). Mali and Nigeria had a high malaria prevalence in children under five (32.4% and 45.1%, respectively), while Angola and Tanzania had lower prevalence (13.5%, 14.4%). The indicators for net ownership and use were the percentage of people who had access in the household to any net assuming two people could use each, percentage who slept under any net last night, and the 'use/access proportion' (UAP). Access was calculated as the number of household members who slept under a net plus the number of people who could have slept under a net yet did not (i.e. a space under a net was available for their use, counting two spaces per household-owned net). The UAP was the number of people who slept under a net divided by access. The proportion access was access divided by the total number of household members who spent the night at home.

Satellite data

Average monthly rainfall estimates (in units of mm/month) at ~4 km resolution from the Tropical Applications of Meteorology using Satellite (TAMSAT) database (University of Reading, Reading, United Kingdom) were used (Maidment *et al.*, 2014; Tarnavsky *et al.*, 2014). TAMSAT uses thermal infrared imagery calibrated on rain gauge data to estimate rainfall by calculating cold cloud duration, with the assumption that cold clouds produce most rainfall across Africa (Maidment *et al.*, 2014). This approach has been validated and demonstrated to perform well in comparison to other satellite-derived rainfall estimates (Maidment *et al.*, 2014). Monthly average surface temperature (Kelvin) at 0.25 degree resolution was obtained from the Global Land Data Assimilation System Version 2.1 (GLDAS-2) Noah model via the Goddard Earth Sciences Data and Information Services Center (Rodell *et al.*, 2004; Rodell and Beaudoing, 2016). The GLDAS 2.1 simulation was forced with a combination of GLDAS 2.0 output and various meteorological data including atmospheric analysis fields from the National Oceanic and Atmospheric Administration (NOAA)/Global Data Assimilation System (GDAS), disaggregated precipitation from the Global Precipitation Climatology Project (GPCP), and radiation fields from the Air Force Weather Agency's Agricultural Meteorological modeling system (AGRMET) to produce the diverse output fields.

All data products were obtained for the months in which the surveys took place, and the value at each survey cluster location was extracted using ArcGIS 10.3 (ESRI, 2017) and imported into R 3.4.2 (R Core Team, 2017) for statistical analysis. Rainfall one month prior to the month each cluster was surveyed was extracted to use as a proxy for mosquito density (Teklehaimanot *et al.*, 2004; Briët *et al.*, 2008), values for surface temperature were converted from Kelvin to Celsius, and both variables were rounded to one decimal.

Statistical analysis

All statistical analysis was conducted in R version 3.4.2. Averages and proportions were calculated using the "survey" package (Lumley, 2004, 2017). Using the R-INLA package (Rue, Martino and Chopin, 2009; Lindgren, Rue and Lindstrom, 2011; Martins *et al.*, 2013; Lindgren and Rue, 2015; Rue *et al.*, 2017), the relationship between explanatory variables and net use was evaluated using beta-binomial regression that corrected for spatially correlated random effects using non-Gaussian Kriging (as described in Chapter 5). Regression analysis assessing net use was by design excluding households that had no nets or had no members that spent the night at home. Candidate explanatory variables included region, setting (urban/rural), mean rainfall of the cluster for the month prior to survey (scaled to cm/month), mean monthly surface temperature for the cluster, wealth quintile, indoor residual spraying (IRS) of the dwelling with insecticides, connection to electricity, ratio of nets to household members, the ratio of rooms used for sleeping in the household to household members, whether the respondent heard a message on the use of nets, and an interaction term between wealth and setting. The final models were selected using were chosen via forward stepwise selection using the Deviance Information Criterion (DIC).

6.3 Results

In Angola, 16,109 households in 625 clusters were interviewed between October 2015 and April 2016. Fifteen clusters were excluded due to missing coordinates. Net ownership was low, with 37% (95% confidence interval [CI]: 35–39) of houses owning at least one net, and only 20% (CI: 18–21) of the population had access to a net (Figure 6.1). Despite this, use among those with access was 76% (CI: 74–78) (Table 6.1, Figure 6.2). Average rainfall from August 2015 through March 2016 was 10.15 cm/month (Interquartile range [IQR]: 6.4 cm/month) and mean temperature was 24.9ºC (IQR: 4.7ºC).

Household net ownership and population access in Mali were much higher at 96% (CI: 94–96) and 79% (CI: 77–80) (Figure 6.3), respectively among the 4,240 households in 177 clusters (no clusters were excluded due to missing coordinates), and use among those with access was 86% (CI: 85–87) (Table 6.1, Figure 6.4). Interviews were conducted between

September and November 2015. Average rainfall during August and September was 1.12 cm/month (IQR: 0.8 cm/month), and mean temperature was 28.6ºC (IQR: 2ºC).

In Nigeria, 7,745 households in 326 clusters were interviewed between October and December 2015. Four clusters were excluded due to missing coordinates. Ownership and access were 71% (CI: 69–73) and 60% (CI: 58–62) (Figure 6.5), respectively. Use conditional on access was the lowest out of all countries, with only 58% (CI: 56–61) of people who had a net using one (Table 6.1, Figure 6.6). Average rainfall was 1.26 cm/month (IQR: 2.0 cm/month) and average temperature was 27.3ºC (IQR: 2.1ºC).

Finally, in Tanzania, 12,563 households in 608 distinct clusters were interviewed between August 2015 and February 2016. Households on Zanzibar were excluded in this analysis due to complete missingness of temperature data. This brought the total to 10,808 households interviewed in 527 clusters. An additional four clusters were excluded due to missing coordinates. Net ownership was widespread, with 72% (CI: 71–74) of households having at least one. Access was 68% (CI: 66–70) (Figure 6.7), and 81% (CI: 80–83) of individuals who had access to a net reported using one (Table 6.1, Figure 6.8) Average rainfall was 9.33 cm/month (IQR: 8.1 cm/month), and mean temperature was 24.0ºC (IQR: 4.9ºC).

Table 6.1 Survey characteristics

Country	Type	Start	End	Months	Malaria prevalence*	% HH owning ≥1 net	% pop using a net**	% pop with access to a net	Use/Access Proportion
Angola	DHS	2015	2016	Oct–Apr	13.5	37	21	27	0.76
Mali	MIS	2015	2015	Sep–Nov	32.4	96	67	79	0.86
Nigeria	MIS	2015	2015	Oct–Dec	45.1	71	38	60	0.58
Tanzania	DHS	2015	2016	Aug–Feb	14.4	72	56	68	0.81

*Malaria prevalence in children under 5 by RDT from DHS program Stat Compiler https://www.statcompiler.com/en/

**Number of people using a net who slept in the house the previous night.

Tanzania includes mainland only. Proportions calculated using the survey package in R to account for sampling design.

Based on the DIC, the final models included wealth index, household setting (rural or urban), whether the household had electricity, the number of nets per person in the household, the ratio of rooms used for sleeping to people in the household, rainfall, and temperature, and an interaction term between wealth and setting (in Angola and Tanzania). Wealth was significantly associated with net use conditional on access in Mali, Nigeria, and Tanzania.

In Nigeria, higher wealth quintiles resulted in lower net use (Table 6.2), while increased net use was associated with being in the "richer" quintile in Mali, and the "richest" quintile in Tanzania (Table 6.2). As the ratio of nets to household members increased, so did net use among those with access in Mali (Odds ratio [OR]: 2.34, 95% credible interval [CrI]: 1.74–3.15), Nigeria (OR: 1.72, CrI: 1.44–2.08), and Tanzania (OR: 3.11, CrI: 2.47–3.93). Conversely, as the ratio of rooms used for sleeping in the house per person increased, net use conditional on access decreased significantly in Mali (OR: 0.80, CrI: 0.68–0.95) and Tanzania (OR: 0.35, CrI: 0.27–0.44). Having electricity was also significantly associated with a decrease in net use in Mali (Table 6.2). Temperature was not significantly associated with net use in any of the countries, however in Angola and Tanzania, as rainfall increased so did net use conditional on access (Table 6.2).

Table 6.2 Odds ratios and 95% credible intervals for explanatory variables of net use conditional on access in betabinomial regression models with spatial random effects.

	Angola	Mali	Nigeria	Tanzania
Wealth index (ref: poorest)				
Poorer	1.19 (0.51 - 2.61)	1.12 (0.96 - 1.30)	1.20 (0.98 - 1.46)	0.86 (0.39 - 1.93)
Middle	1.27 (0.54 - 2.78)	1.06 (0.90 - 1.24)	0.92 (0.73 - 1.15)	1.88 (0.92 - 3.88)
Richer	0.93 (0.39 - 2.10)	**1.31 (1.09 - 1.58)**	**0.71 (0.55 - 0.94)**	1.62 (0.91 - 2.85)
Richest	0.73 (0.30 - 1.66)	1.26 (0.95 - 1.68)	**0.50 (0.36 - 0.68)**	**2.11 (1.12 - 3.89)**
Rural setting (ref: urban)	0.85 (0.36 - 1.88)	1.14 (0.83 - 1.55)	0.97 (0.79 - 1.20)	0.65 (0.37 - 1.13)
Electricity	0.92 (0.74 - 1.15)	**0.87 (0.77 - 0.98)**	0.84 (0.70 - 1.01)	0.82 (0.62 - 1.08)
Number of nets per person	0.94 (0.73 - 1.21)	**2.34 (1.74 - 3.15)**	**1.72 (1.44 - 2.08)**	**3.11 (2.47 - 3.93)**
Number of rooms used for sleeping per person	0.81 (0.65 - 1.01)	**0.80 (0.68 - 0.95)**	0.86 (0.73 - 1.01)	**0.35 (0.27 - 0.44)**
Rainfall (cm/month)	**1.05 (1.03 - 1.07)**	1.00 (0.99 - 1.01)	0.99 (0.97 - 1.01)	**1.02 (1.00 - 1.05)**
Temperature (ºC)	0.99 (0.98 - 1.01)	1.00 (0.94 - 1.05)	1.00 (0.98 - 1.02)	1.00 (0.98 - 1.01)
Poorer x Rural	0.99 (0.43 - 2.38)			1.29 (0.57 - 2.91)
Middle x Rural	0.73 (0.31 - 1.83)			0.62 (0.30 - 1.31)
Richer x Rural	2.88 (0.86 - 10.67)			0.89 (0.49 - 1.65)
Richest x Rural	1.07 (0.12 - 9.73)			0.67 (0.35 - 1.31)

x indicates interaction

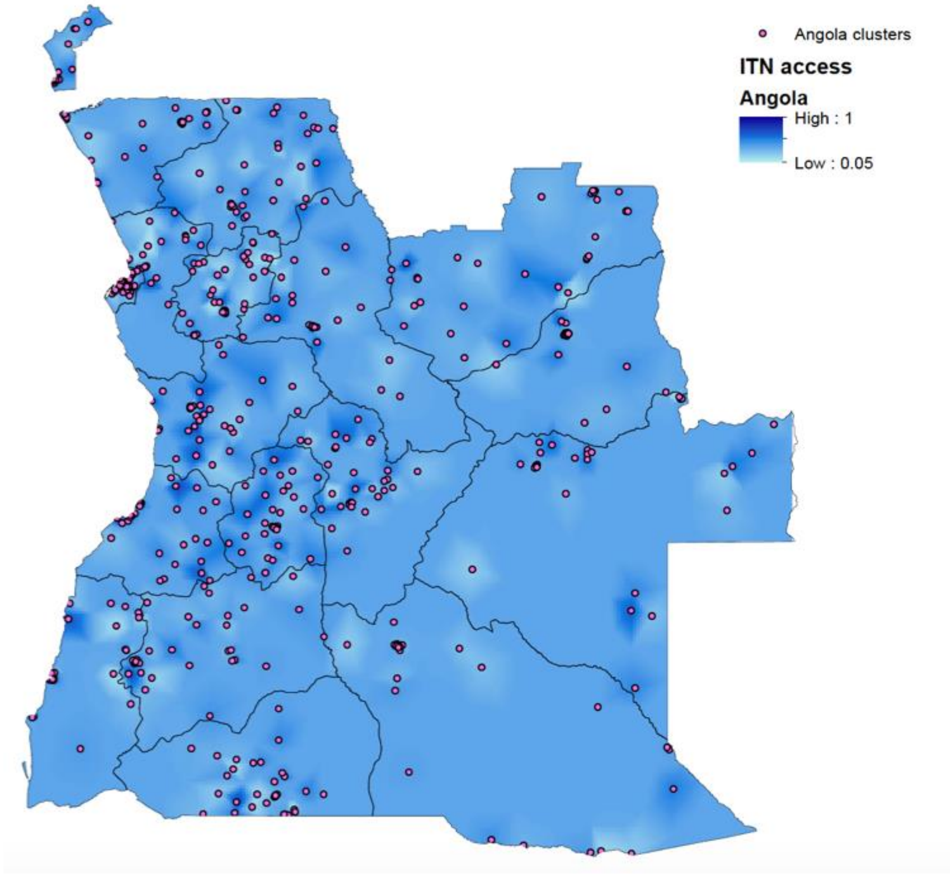

Figure 6.1 Net access in Angola (DHS 2015-2016).

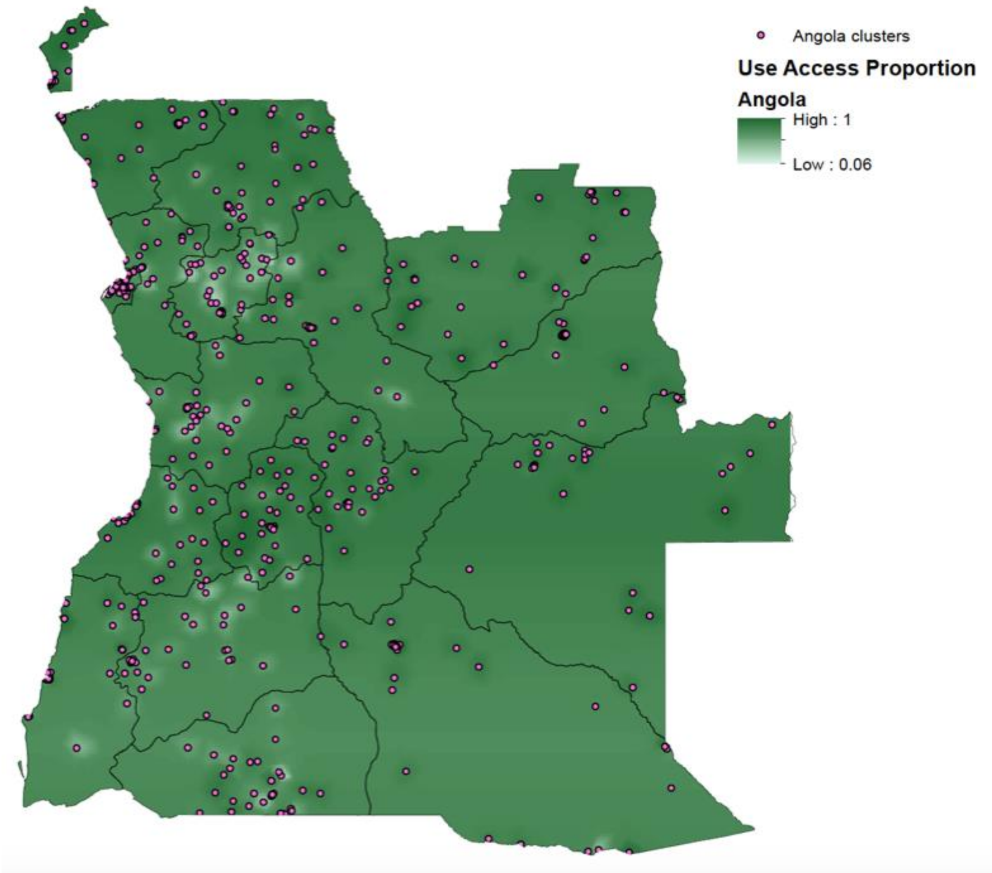

Figure 6.2 Use access proportion in Angola (DHS 2015-2016).

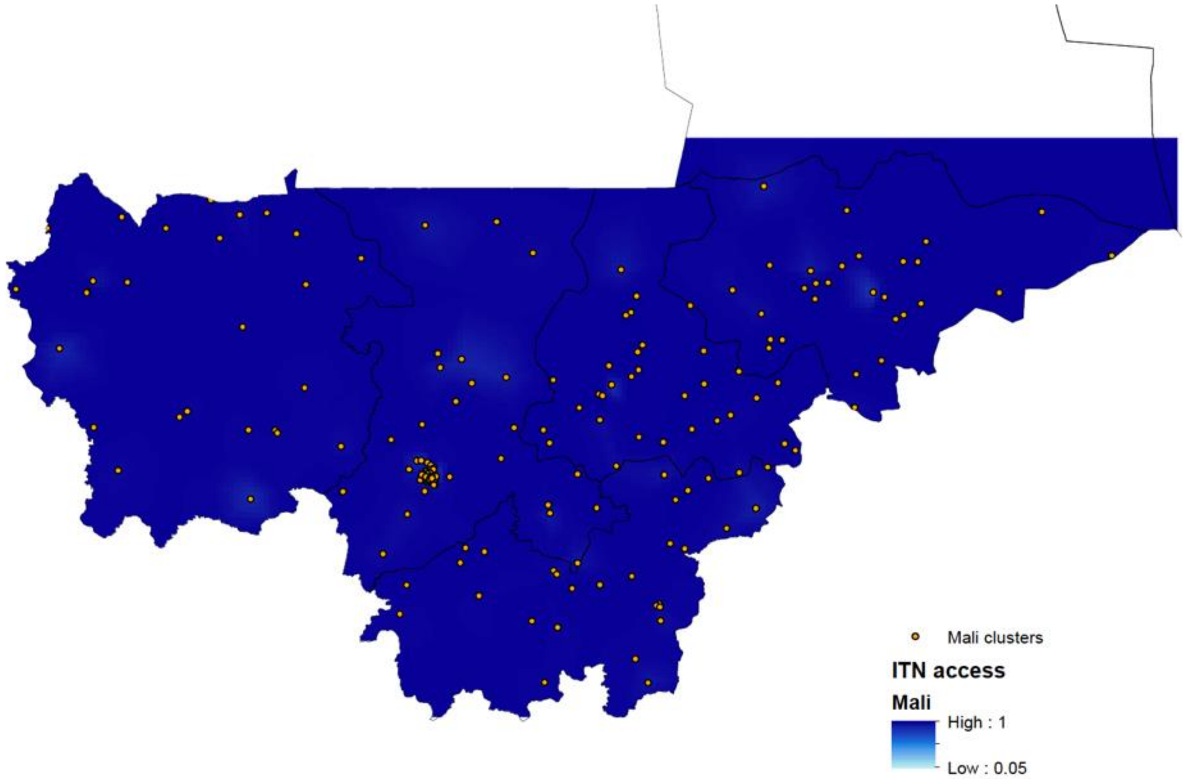

Figure 6.3 Net access in Mali (MIS 2015).

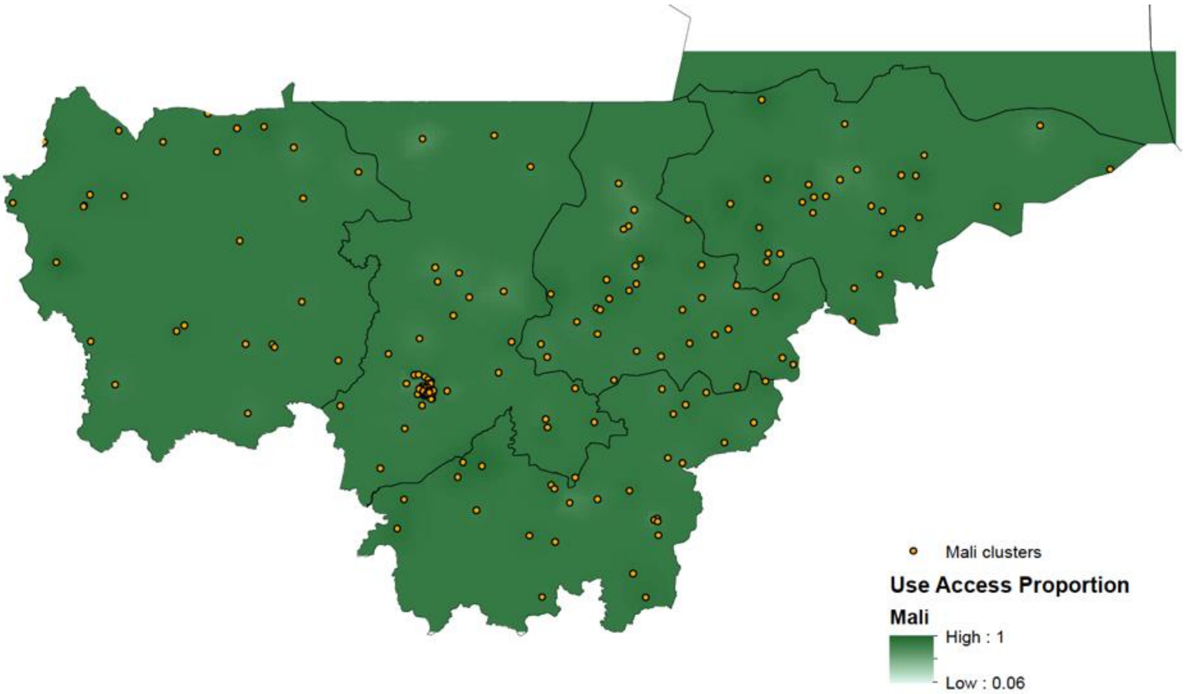

Figure 6.4 Use access proportion in Mali (MIS 2015).

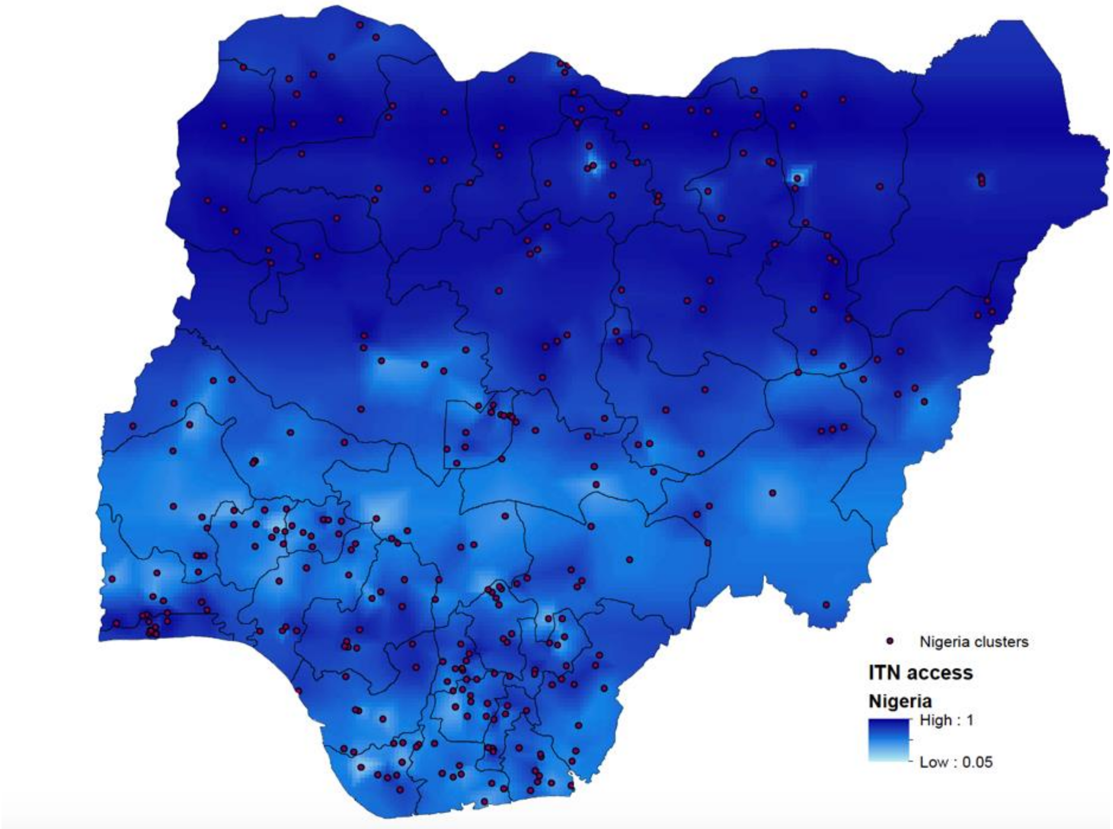

Figure 6.5 Net access in Nigeria (MIS 2015).

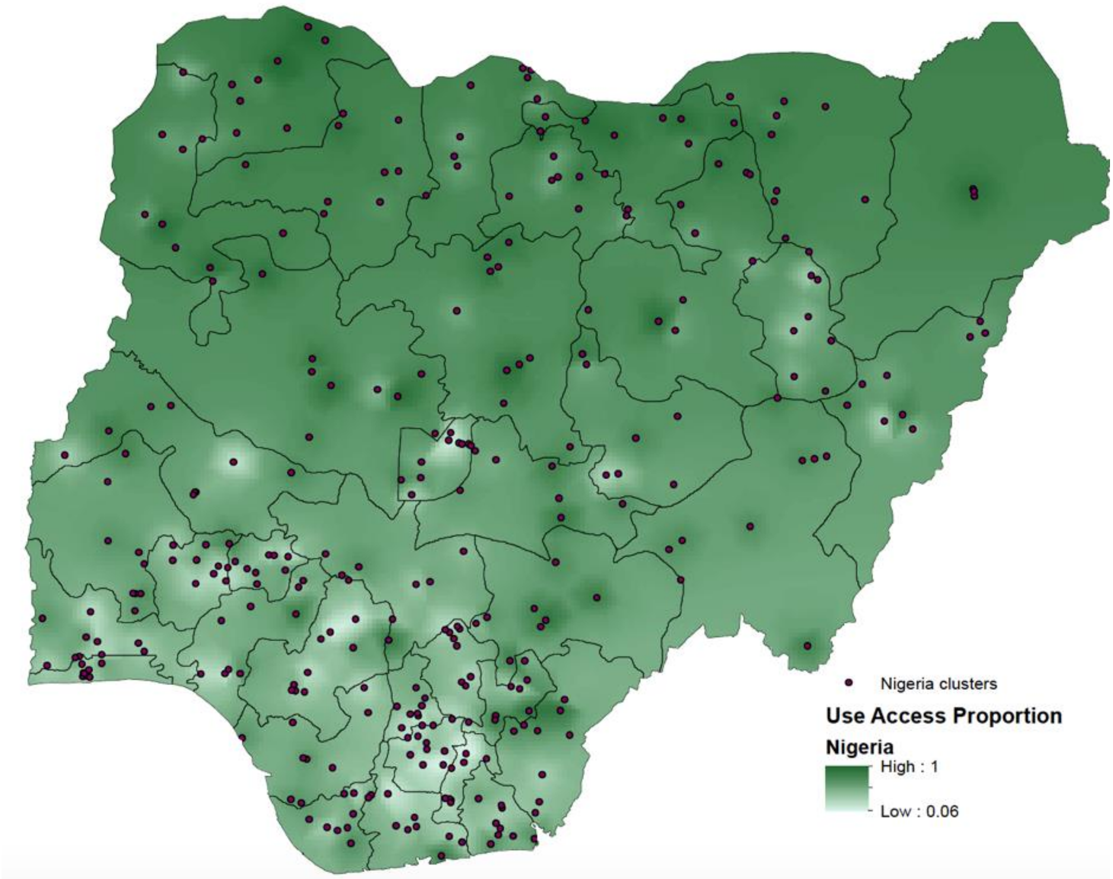

Figure 6.6 Use access proportion in Nigeria (MIS 2015).

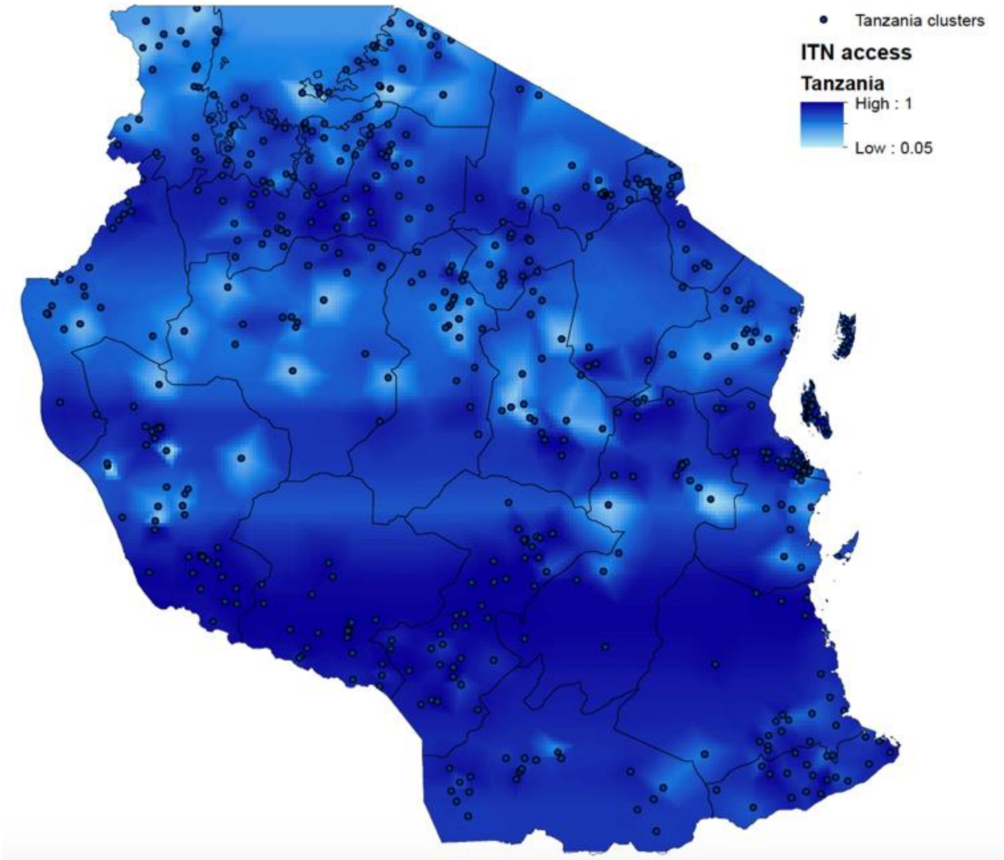

Figure 6.7 Net access in Tanzania (DHS 2015-2016).

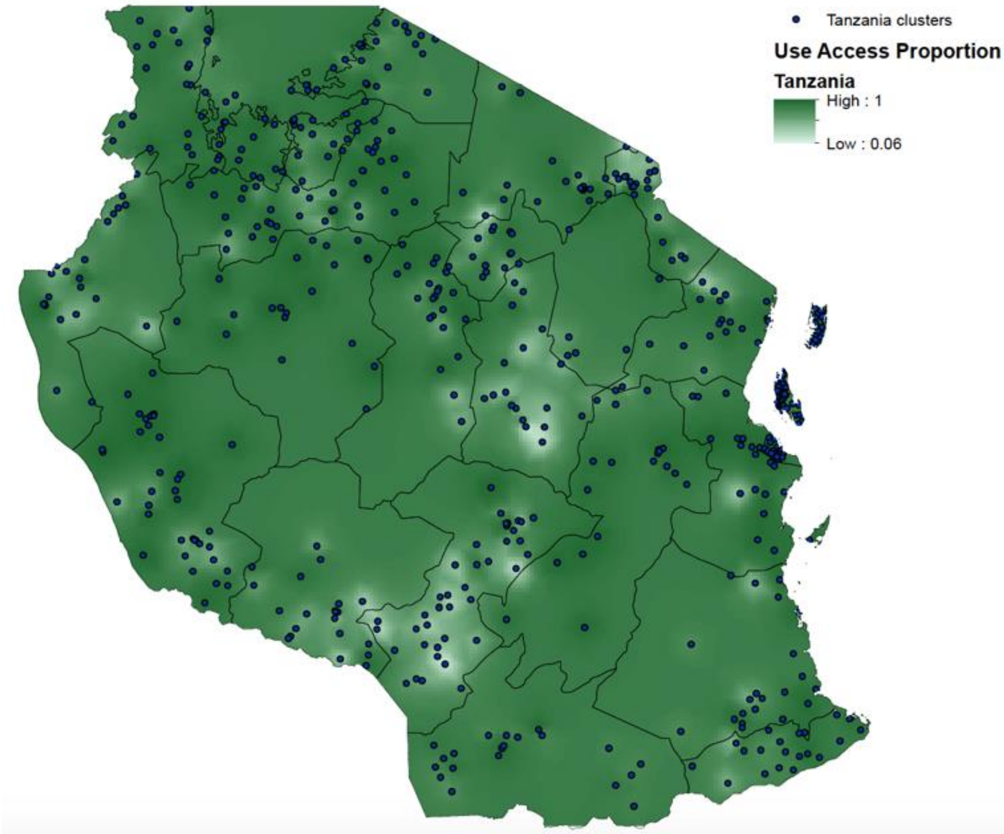

Figure 6.8 Use access proportion in Tanzania (DHS 2015-2016).

6.4 Discussion

ITN use is integral to the effort of achieving elimination, making it important to understand why people who could be using nets are not. There are many reasons cited for non-use of ITNs, including climate-related factors, sleeping arrangements, and perceptions of malaria risk (Toé *et al.*, 2009; Iwashita *et al.*, 2010; Pulford *et al.*, 2011; Moiroux *et al.*, 2012), and this analysis aimed to study the relative importance of some predictors of net use among those with access that are available in standard surveys or from remotely sensed data sources.

Climate affects the development of both the vector mosquito and the malaria parasite (Eckhoff, 2011; Chitnis, Hardy and Smith, 2012; Tompkins and Ermert, 2013), influencing mosquito density and malaria transmission, both of which can have an impact on a person's decision to use a bed net (Pulford *et al.*, 2011; Moiroux *et al.*, 2012). Protection against nuisance biting in particular is a common reason for net use, as the net allows for better sleep and peace of mind for the individual (Toé *et al.*, 2009; Pulford *et al.*, 2011; Koenker *et al.*, 2013; Jaeger *et al.*, 2016). This effect has been seen during the rainy season, as mosquito density increases with the rain (Moiroux *et al.*, 2012; Lebl, Brugger and Rubel, 2013). In the Angola and Tanzania DHS surveys, rainfall was high and variable throughout the survey months (an average of 10.2 cm/month and 9.3 cm/month, respectively), and an increase in 1cm/month of rainfall the month prior to the survey was associated with a 5% and 2% increase in net use conditional on access, respectively. In the Mali and Nigeria MIS surveys, most interviews were conducted after the end of the rainy season (usually between one and three months after), and rainfall was relatively low (an average of 1.1 cm/month and 1.3 cm/month, respectively). By this point in the season with the decrease in rains, mosquito density will have decreased to a point no longer bothersome enough to warrant net use for the purpose of protecting against nuisance insects. There have been previous analyses conducted evaluating net use by season (dry vs rainy or in the three categories early rains, late rains, and dry season) which reported increased net usage in the rainy season (Tropical Health and Malaria Consortium, 2014; Pinchoff *et al.*, 2015), however to our knowledge this is the first study evaluating the relationship between remotely-sensed rainfall data and bed net use.

Personal comfort when sleeping under a net is also affected by temperature, with evidence from qualitative studies (Galvin *et al.*, 2011; Koenker *et al.*, 2013) and behavioral surveys (Baume, Reithinger and Woldehanna, 2009; Aluko and Oluwatosin, 2012; Singh, Brown and Rogerson, 2013) indicating decreased net use with increasing thermal discomfort. In this analysis, temperature was not significantly associated with net use among those with access. It is likely that there was too little variability in temperature during the relatively short period in which the interviews were conducted in any of the countries included in this study (the largest IQR was only 5ºC) to accurately determine whether this influences net use throughout the year. Rather than evaluating temperature on its own, future studies could include the ‘humidex’, an index which combines remotely sensed temperature and vapor pressure into a measure of how hot the weather feels to the average person (Ricotta and Briet, no date; Mitchell and Jones, 2005; Harris *et al.*, 2014).

Wealth was significantly associated with net use conditional on access in Mali, Nigeria, and Tanzania, however the direction of the effect differed. In Tanzania and Mali, richer wealth quintiles were significantly associated with net use. Studies have demonstrated that although equity in household net ownership among wealth quintiles has been achieved in Tanzania and Mali (Taylor, Florey and Ye, 2017), access in both countries and use in Tanzania are weighted toward wealthier quintiles (Galactionova *et al.*, 2017). In this study, increasing wealth decreased net use among those with access in Nigeria, however other studies have found that while ownership tended to concentrate in poorer households (Taylor, Florey and Ye, 2017), use and access were equitable (Galactionova *et al.*, 2017). Further study focusing on differential net use behavior by wealth quintiles, specifically among individuals with access to a net will be necessary to gain a complete understanding of these results.

In Mali, Nigeria, and Tanzania, the number of nets available per person in the household was one of the strongest predictors of net use among those with access. Related to this, in Mali and Tanzania, net use decreased as the number of rooms used for sleeping per household member increased. These observations possibly indicate an issue with sleeping spaces and net allocation within the household. Many studies have shown that net use decreases with increasing family size, and is contingent on family structure (Iwashita *et al.*, 2010; Tchinda *et al.*, 2012; Diabaté *et al.*, 2014; Lam *et al.*, 2014; Ricotta *et al.*, 2014; Sichande *et al.*, 2014; Kateera *et al.*, 2015; Moon *et al.*, 2016; Ruyange *et al.*, 2016). Universal coverage campaigns for bed net distribution have various designs, but typically aim to provide one net per two people while minimizing inefficiency in distribution (Kilian *et al.*, 2009, 2010). This usually results in a cap on the number of nets a household can receive during a campaign (Plucinski *et al.*, 2015), which can mean that even if households receive “enough” nets (at one per two people), there might still not be enough to cover all sleeping spaces (Thwing *et al.*, 2011; Stevens *et al.*, 2013; Plucinski *et al.*, 2015). Additionally, it can sometimes be difficult to use a net depending on the location of the sleeping space (Baume, Reithinger and Woldehanna, 2009; Toé *et al.*, 2009; Iwashita *et al.*, 2010; Pulford *et al.*, 2011), where it can be difficult or inconvenient to hang a net (i.e. the kitchen or living room). These issues are especially relevant in large households that include extended families living within the same compound, households with multiple wives, and those with many adolescent residents. Furthermore, sleeping spaces are not always fixed, as some people move between the indoors and outdoors throughout the night and do not always move their nets (Pulford *et al.*, 2011; Monroe *et al.*, 2015), and this adds to the challenge of trying to determine the number of nets logistically needed by a household. Net distribution programs have tried to address this by allocating nets to households based on number of sleeping spaces, rather than a fixed number of nets or one net per two people, but in most instances this strategy has not demonstrated marked improvement in coverage or use over other approaches (Plucinski *et al.*, 2015). This underscores the complexities of this issue and indicates a possible need for alternative vector control methods in these situations.

Some limitations exist with the use of these data. Temperature data was estimated from cloud cover, which becomes unstable over large bodies of water. This led to some missing observations in households along ocean and lakeside clusters, however it was less than 10% in all cases. As mentioned, there was little variation in temperature estimates, which makes it difficult to analyze any relationship to net use. It will be important in the future to compare multiple years' data from each country to determine whether the relationships found in this study remain the same. It will also be helpful to have information from different times in the year, for example the continuous DHS conducted in Senegal, to get a better understanding of net use in a country throughout their entire transmission cycle.

6.5 Conclusions

A better understanding of how people across different residential and wealth settings would prefer to utilize their nets is important for understanding non-use of nets among those with access to one. On one hand, it could be that households need more nets to accommodate unique sleeping situations and either require more nets from distributions or a reliable place to acquire the number of nets they need. On the other hand, it is possible that alternative vector control strategies are needed to accommodate these differences. Either way, non-use of nets by people with access is a complex situation that will require careful thought and a unique approach to addressing what would best benefit households still at risk.

Chapter 7: General Discussion

7.1 Background and Justification for Research

It is estimated that at least 90% coverage with WHO-recommended interventions (including ITNs) is required to reach the Global Technical Strategy for Malaria's 2030 goal of a 90% reduction in malaria disease burden (WHO, 2015; Griffin *et al.*, 2016; Patouillard *et al.*, 2017). To that end, it is critical to understand where improvements in access to and use of interventions can be strengthened, from households to the national level. The focus of this thesis was to explore a variety of predictors of bed net use. These factors included psychosocial, household, community, and environmental determinants, both among households owning at least one net, and individuals with access to a net in their household. By understanding what drives net use and non-use, appropriate solutions can be developed to ensure maximum protection against malaria. This may include increasing access and use of nets and/or implementing supplemental vector control strategies.

7.2 Ideation – Beliefs, Values, and Net Use Behavior

In Chapter 2, the ideation model of health communication is described as it relates to malaria. "Ideation" is the collection of factors related to a person's beliefs and values, their social norms and networks, and their emotional responses about a subject, which can be enhanced or influenced by social and behavior change communication (SBCC). Specifically, ideational factors relating to public health topics such as severity of malaria and its prevention can be targeted by media campaigns and health interventions designed to act on an individual and community level, and then be strengthened via social interaction (Storey *et al.*, no date; Kincaid, 2000a; Ricotta *et al.*, 2015). To design strategic interventions informed by these psychosocial constructs, it is necessary to first understand which particular variables are significantly associated with the outcome of interest.

The study presented in Chapter 3 was conducted to determine what ideational variables (if any) of female caregivers or head of the household in households with at least one net were significantly related to bed net use, and whether there were any commonalities in these relationships across countries (with the goal being a generalizable ideational "target" for future SBCC campaigns). In this study, increased net use was observed among households where the female caretaker participated in decision making surrounding health and net use. The caretaker does not always participate in decisions about net use, especially in areas that are strongly patriarchal (Colvin *et al.*, 2013; Konlan *et al.*, 2017), however, there is evidence to support focusing on caregivers' decision-making regarding illness and disease prevention, as they are likely the ones to notice and care for a sick family member (Mitiku and Assefa, 2017).

The relationship between the ideational variables tested in this thesis and net use varied by country, indicating a need for context-specific data to inform communication campaigns and SBCC interventions. In Chapter 2, Madagascar had the largest number of significant ideational variables, and these were all positively associated with bed net use. Mali had only three ideational variables that were significant, which were knowledge of malaria symptoms, knowledge that mosquitos transmit the disease, and self-efficacy to obtain enough nets to cover all household members, all of which were significantly associated with increased net use. Perception of malaria severity and belief that nets were effective at preventing malaria were significant in Nigeria, and both decreased net use (Table 2.2). Liberia (Chapter 3), had two ideational variables positively associated with net use: perception of severity and self-efficacy to detect malaria (Table 3.2). These variables have been shown to relate to general knowledge of malaria, which has been linked to increases in net use (Nganda *et al.*, 2004; Hwang *et al.*, 2010; Pylypchuk and Norton, 2015).

These results underscore the notion that an individual's decision-making process related to bed net usage is complex and multi-dimensional, but is an important and significant aspect to keep in mind when studying this issue. In addition, an individual's choice to use a net is not always independent from those of the rest of their household. In Chapters 5 and 6, the data was overdispersed, meaning that either the probability using a net or not using a net varied rather than being identically distributed as expected in a typical binomial model, or that the net use (or decisions about net use) of one individual influenced the net use of others in the household. Both of these scenarios are likely present when considering household net use, however the data analyzed here strongly suggest the latter (Figure 5.4). The head of household or primary caretaker's decision about where to allocate the household supply of nets thus influences who sleeps under each net, and this can vary depending on a number of things, including the number of children in a household, sleeping spaces, or other household arrangements. These issues will be discussed further in the sections below, but it highlights the need to evaluate both individual- and household-level factors when trying to understand net use.

7.3 Net Ownership and Access – The Desire to Have Enough Nets and Needing to Prioritize Use Among Vulnerable Household Members

One of the predominant themes seen throughout the studies in this thesis is that net use is heavily dependent on number of nets owned by a household, and that in the absence of "enough" nets (either defined as one net per two people or as enough nets to cover all sleeping situations of a family), certain family members will be more likely to use them.

At the population level, it is important to ensure the groups most vulnerable to severe malaria, such as pregnant women and children under five, are adequately protected.

However, this is not enough to achieve malaria elimination, nor is it sufficient to prevent disease in areas of unstable malaria transmission (Global Malaria Programme, 2007). In regions with stable malaria, adolescents have been shown to act as parasite reservoirs and can serve as a source for continued infection among family members (especially as cases of malaria tend to cluster in a household) (Teklehaimanot, Sachs and Curtis, 2007; Noor *et al.*, 2009; Searle *et al.*, 2013). There is also a need to ensure all women of reproductive age sleep under nets, so that in the event of pregnancy, they are protected from malaria both before they aware of their disease status and before they are eligible to receive intermittent preventive therapy (IPTp) (Roll Back Malaria Malaria in Pregnancy Working Group, 2013). Additionally, in areas with unstable malaria transmission, reduced malaria exposure in childhood has led to a shift in the age range for severe malaria cases, with the highest burden among adolescents and cases continuing into adulthood (Pemberton-Ross *et al.*, 2015; Griffin *et al.*, 2016). In response to these scenarios, the guidance by WHO and RBM has changed to ensure adequate access to nets for everyone in the population at risk for malaria, regardless of whether they qualify as “vulnerable” (Global Malaria Programme, 2007).

Because of the long-standing concentration on pregnancy and infants by non-governmental organizations and national malaria control programs, community education has focused on the importance of households themselves prioritizing these individuals. Research has been conducted on understanding who gets to sleep under nets in the absence of enough nets for all household members, and in most instances, pregnant women, infants, and even non-pregnant women of reproductive age tend to be the highest users of nets (Lam *et al.*, 2014; Ricotta *et al.*, 2014). Chapters 2 and 3 found that children under five were more likely to use a net than any other age group, and that gender modified this age effect, with adult females being more likely to use a net than their adolescent or adult male family members. However, ideally, households would have enough nets for their family and home setup so that all individuals could use a net comfortably. To that end, Chapters 2–4 explore both the desire to obtain enough nets and a person's belief in their ability to do so, both of which had an influence on net use behavior.

Chapters 2 and 3 include ideational variables "Self-efficacy to obtain enough nets for the household", which was positively associated with net use in Madagascar and Mali, and "Female caregiver's perceived self-efficacy to prevent malaria for self and children", which was not significantly associated with net use in Liberia, but was generally very high (80% of caregivers felt they were able to prevent malaria). This is reflected in Chapter 4 both in terms of ideation as well as application, that is, when a respondent answered negatively to "Obtain enough bed nets for all your children" (definitely/probably could not), they had a lower propensity to buy nets than those who answered positively (definitely/probably could) and vice versa (Figure 4.4). Households without enough nets for all household members also had a higher propensity to buy (Figure 4.5). This emphasizes the importance of the ability to seek out nets as well as a willingness to pay for them as a major influence of net use, both of which could be leveraged in future net distribution strategies, especially in the setting of vouchers and private markets.

Private markets have been implemented in certain situations with varying levels of success, yet most bed nets are obtained via public distribution channels (i.e. mass distribution campaigns). Additionally, reviews of continuous distribution programs have determined that these channels are underutilized (Theiss-Nyland, Lynch and Lines, 2016), so the question of whether and how families are able to obtain enough nets outside of a campaign remains. This is unfortunately a problem that will require time and money from country and global players alike, as well as a paradigm shift away from such heavy reliance on mass distributions funded by external agencies to a more permanent and sustainable solution.

Perhaps the most difficult issue to address logistically is how to provide households with enough nets to meet the needs of a given family situation. Even when households have one net for every two people, it might not be feasible for every space under a net to be used, resulting in more “theoretical” than actual access. This is likely the reason that in Chapter 6, there was a positive correlation in use given access with an increasing ratio of nets per person. For example, the head of household will frequently share a sleeping space with their spouse and their children <3. Adolescent children tend to segregate by gender and sleep with siblings, while older children and adult relatives will sleep alone. A study of net distribution based on assumed sleeping patterns and sleeping spaces demonstrated that in households with male children <10 and female children <16 who slept alone when they could have shared a sleeping space with a sibling, there was usually an insufficiency of nets (Plucinski *et al.*, 2015). This is supported by studies evaluating net use by age groups, where children >5 are less likely to use nets than other household members (Baume and Marin, 2007; Khan, Arnold and Eckert, 2008; Ricotta *et al.*, 2014). Other examples of situations where use might not be 100% in households having one net per two people is when households have members sleeping in rooms that serve multiple purposes, which was observed in Chapter 6, where net use given access went down as the ratio of rooms used for sleeping to people increased. When households have multi-use rooms, it can be inconvenient or impractical to hang and remove or tie up a net daily to ensure it is out of the way (Toé *et al.*, 2009; Iwashita *et al.*, 2010). In cultures where sleeping spaces can be fluid throughout the night (e.g. in Ghana, where some individuals sleep outside part or all of the night during certain times of the year), people might not move a net from one sleeping space to another (Monroe *et al.*, 2015). Some households prefer to reserve nets for visitors to use (Macintyre *et al.*, 2012), or for use by a pregnant woman after delivery (Pulford *et al.*, 2011). These and other reasons demonstrate a need to provide options for households to obtain more nets. While novel and complex distribution strategies have attempted to account for household size and structure, the added logistical complications might be neither efficient nor cost-effective enough to implement widely. Continuous distribution channels can help to fill this need, but necessitate attendance at facilities where these nets are provided (e.g. ANC, EPI, and schools). Net vouchers and private markets have also been put in place in different countries, notably Tanzania and Ghana, but can be inequitable if places to buy a net are inaccessible or if the price of insecticide-treated nets are cost-prohibitive for some households (de Savigny *et al.*, 2012; Kilian, 2013).

7.4 Net Use Conditional on Access – Why Are People Not Using Nets?

Since we know that access to a net within the household is one of the primary drivers of net use, increasing the number of nets in each household's possession would substantially increase use in many countries. Indeed, evaluations of national population-based surveys have determined that 20 out of 26 PMI focus countries have achieved population use:access ratios above the RBM target of 0.80 (ITN use access report), meaning that of the population that has access to a net, over 80% use them (although some of these surveys have not been updated in over a decade and likely have a different net situation). Among PMI countries, the peak proportion of a population with access was 79% in the Uganda 2014–2015 MIS (which was following Uganda's first universal coverage campaign in May 2013–August 2014) (USAID, 2016b), and the lowest post-2010 proportion was 11% in the 2011 Cameroon DHS (their first UCC was in 2011. As of 2014, the proportion of people with access has increased to 37%) (USAID, 2016a). While progress has been made, there is still much work to be done.

In the meantime, one area for continued research is the proportion of the population with access to a net who choose not to use one, which is, on average, around 20% (Koenker, Ricotta and Olapeji, 2017). There are currently a number of indicators that have been developed to quantify net access and use. As described in RBM's Household Survey Indicator Guide for Malaria Control and reported in the PMI Malaria Operational Plans and Vectorworks' ITN Access and Use Report, "Proportion of population with access to an ITN within their household" is the indicator of choice for measuring population access to nets. This indicator is useful for informing ITN distribution programs (i.e. PMI, NMCP) where and to what extent there is a need for achieving higher ITN coverage (MEASURE Evaluation *et al.*, 2013; Koenker, Ricotta and Olapeji, 2017). In this thesis, this indicator has been refined to provide a more accurate reflection of net access within a household, as on many occasions, more than the recommended two people sleep under a net, and in others, only one person uses a net, leaving an unused but available space. In the RBM indicator calculation, the total number of individuals who *could* use a net (number of ITNs x 2) is divided by the number of individuals who spent the previous night in surveyed households, which does not account for the "alternate" use patterns mentioned. In the access indicator presented here, the number of people who *did* or *could have* slept under a net (i.e. a space under a net was available for their use) is calculated. Use among those with access, called here the use/access proportion (UAP), is the number of individuals who slept under a net, divided by access. While the calculation of this indicator is less straightforward than RBM's (one must count nets and sleepers together rather than just nets), it provides a more accurate picture of net use which can then be incorporated into studies about net use behavior, as demonstrated in Chapters 5 and 6. As stated extensively in these two chapters, there are many reasons why individuals choose to or are unable to use a net, even with one available, including level of nuisance mosquitos or sleeping space structure of the household. To that end, the goal of these manuscripts was to determine whether there was a quantifiable relationship between both household-level and remotely sensed environmental variables and reported net use among individuals with access to a net.

In Chapter 5, the humidex, which is an indicator of how hot it feels to a person and is a combination of temperature and atmospheric water vapor, was evaluated. In Chapter 6, rainfall the month preceding the survey (used as a measure of nuisance mosquito biting), and a modelled temperature product comprised of a variety of meteorological data products (to understand personal comfort due to the environment) were used. In this thesis, the only significant environmental predictor of net use was increased rainfall in two surveys conducted during the rainy season (Angola and Tanzania), adding evidence to the scientific literature that mosquito density vis a vis rainfall is an important consideration when assessing net use among those with access. As malaria transmission can continue throughout the year, it is important for malaria programs to emphasize net use year-round and to explore alternative measures, either by making net use more desirable in the hot, dry season (for example, by providing fans to use under the net) or controlling vectors in a different fashion (such as by using IRS, spatial repellents, larvaciding in appropriate settings, etc).

Net use among those with access was also affected by household wealth status, both positively and negatively depending on the country. In both surveys in Ghana (Chapter 5) and the Nigeria MIS (Chapter 6), net use was lower in wealthier households. This could be due to several reasons. Wealthier households tend to have better access to housing improvements like window screens and closed eaves that act as vector control (Tusting *et al.*, 2017). The reduced presence of mosquitoes could then be a reason to not need to use nets. Along with this, having a decreased perception of vulnerability to malaria has been shown to decrease net use (Auta, 2012). In contrast, net use increased with wealth in Mali and Tanzania. Taylor and colleagues (Taylor, Florey and Ye, 2017) and Galactionova and colleagues (Galactionova *et al.*, 2017) found that net ownership and use are both more pro-rich in Tanzania, and that these indicators are more equitably distributed in Mali (possibly explaining why net use in the "richest" wealth quintile was not significantly different from the poorest quintile). One study found livelihood and cultural issues with net use, in Tanzania, specifically migrant farming (Dunn, Le Mare and Makungu, 2011), which made it harder for families to use their nets. Regardless of the direction of influence wealth has on net use, there needs to be a more detailed understanding of why these differences exist (beyond just access to interventions) to know whether nets are the best solution in these locations (e.g. people with screened housing probably do not need to rely as much on nets), and how strategies to improve net use can be targeted if they are the best solution in an area.

The final theme found in this thesis affecting net use among those with access was sleeping arrangements and net allocation within the household. Chapter 6 demonstrated that even when people had "theoretical" access to a net, one of the strongest predictors of net use was the number of nets per person in the household (although this was not true in all cases, such as Angola, or Ghana in Chapter 5). In addition, in Mali and Tanzania, the more rooms used for sleeping in the household per person, the fewer net users there were. This indicates that even when households meet the basic requirements of "enough" nets at one per two people, it might not be enough to ensure 100% net use. Households with extended families residing in the same compound, the presence of visitors, having adolescent children, sleeping outdoors, attending events away from the home, and having multi-use rooms where it is difficult to hang a net have all been cited as reasons for non-use of nets when one is available (Toé *et al.,* 2009; Iwashita *et al.,* 2010; Pulford *et al.*, 2011; Monroe *et al.*, 2014, 2015; Kateera *et al.*, 2015; Plucinski *et al.*, 2015). If households had the ability to acquire the number of nets they needed for their unique situation, net use would likely increase. Solving this in a sustainable and equitable manner to ensure equitable access to nets across all population strata will require careful thought as to the best way to approach this issue, and will likely entail a combination of mass campaigns, continuous distribution channels, and private markets (Galactionova *et al.*, 2017).

7.5 Strengthening Net Use Among Those with Access

Clearly, net use is a complicated issue, particularly among those with access, and the decision to use a net is multi-dimensional and not always straightforward. What then does this mean for country and global programs who are trying to reach elimination?

In addition to exploring new options for vector control, insecticide-treated nets will continue to be an integral part of disease prevention. This means that the malaria community needs to improve understanding of the reasons why people who have nets do not use them, and the best way to address those issues for each situation. As an example, people say they do not use nets when they do not see mosquitoes, and when nuisance biting is not bothersome enough to warrant the use of nets. However, as malaria is transmitted throughout the year in some places, and extends weeks past the end of the rains in places with seasonal transmission (Hoshen and Morse, 2004; Chitnis, Hardy and Smith, 2012), net use needs to continue after mosquitoes are no longer a noticeable nuisance. This means that people will have to use a net for a longer period of time throughout the year than they normally do, and accept the discomfort of using a net despite the lack of visible threat and annoyance of mosquitoes. Behavior change communication will be essential to explain the reasons why this is necessary, and it will be crucial to identify the specific ideational drivers of net use in each setting, so that the proper personal and social constructs can be targeted for highest impact. However, if people will be expected to use nets “out of season”, personal comfort under a net will need to be addressed. Studies have shown that people sometimes choose to use nets to prevent the nuisance of other insects besides mosquitoes (Koenker *et al.*, 2013), or that they like the privacy the net provides (Panter-Brick *et al.*, 2006), but one of the most common reasons cited for non-use of nets is that they are hot and stifling, making it difficult to sleep (Pulford *et al.*, 2011). A small pilot study has tried to address this by providing compact solar-powered fans to increase airflow and decrease temperature within the net (Jaeger *et al.*, 2016), and they have demonstrated in this population that there is a willingness by the households to pay for at least one such device (Yukich *et al.*, 2017). Further research should be done to consider other innovative approaches to improving comfort when using a net.

7.6 Limitations and Considerations

This thesis had some limitations worth considering. Chapters 2–4 did not assess net use among those with access. As the study was not powered for analysis at this level, there were insufficient households with enough nets for all household members (using the RBM access indicator), thus prohibiting statistical analysis. It is possible that different relationships with the ideational variable in particular would have been observed if assessed among individuals with access (using the calculation introduced in this thesis), as it would not necessitate dropping households without enough nets, and could possibly be assessed in secondary analysis of this data or in future surveys powered for this sample. The DCE in Chapter 4 was conducted in Tanzania, which has a somewhat unique history of net distribution and access, having had a successful voucher program as well as regular mass campaigns for over a decade, and the results are likely not representative of other countries. Chapters 5 and 6 suffered from a lack of temporal variation, having all been national surveys conducted over only small portions of the year. In order to fully understand the association of net use and climate, having both survey and environmental data from longer time periods within the same country (for example the continuous DHS in Senegal) would allow a deeper and more informative exploration of this relationship. Finally, this thesis has demonstrated that even if people want to use or seek out a net, they are often unable to do so due to lack of availability. This highlights the importance of understanding structural or operational factors that might be influencing net use outside of the household, including hurdles in campaign logistics, stockouts at continuous distribution facilities, or lack of infrastructure for providing nets for purchase; however, this topic was not evaluated during this thesis and could be an area of future work.

7.7 Final Conclusions

This thesis considered multiple aspects of net use behavior at the individual, household, and social levels, as well as use specifically among those with access to a net. While net use is generally high among those with access, to go the last mile to elimination, the malaria community needs to work with countries and communities to understand how household prevention needs can be addressed, whether that is through access to nets or to other prevention methods. This will require creativity and innovation to ensure the entire population at risk of malaria is covered by the best preventive tools for their given situation, and research into the needs of different population strata should be conducted and considered in the development of future malaria control programs. Indeed, the RBM Action and Investment to Defeat Malaria plan (World Health Organization, 2015) emphasizes the importance of human-centered approaches at all levels of malaria control programs, which would increase the agency of individuals at risk and allow them to participate in improving prevention coverage by informing implementing organizations of the most useful ways to provide a customized malaria control plan for specific communities. Additionally, community engagement will provide a way to gauge changing perceptions of malaria risk, and there will be a need to adapt messaging and education channels to ensure diminishing risk perceptions do not decrease ongoing malaria control efforts. By providing individuals with ways to take a more active role in acquiring the protection that best fits their needs, adequate malaria prevention can be achieved in the populations at risk for this disease.

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Appendices

1. Chapter 2 – Nigeria SBCC Individual Questionnaire
2. Chapter 2 – Mali SBCC Individual Questionnaire (French)
3. Chapter 2 – Madagascar SBCC Individual Questionnaire (French)
4. Chapter 3 – Liberia SBCC Individual Questionnaire
5. Chapter 4 – Tanzania Discrete Choice Experiment Interview Questionnaire

(The surveys in the appendices were created and designed by the Johns Hopkins Center for Communication Programs. Appendices 1-4 are the property of the Health Communication Capacity Collaborative project. Appendix 5 is the property of the VectorWorks project. For access to the survey instruments, please contact the manuscript's corresponding author for the chapter of interest.)