Supplementary Appendix

Supplementary Appendix A: Conceptual Framework

Although Andersen and Newman's Framework for health service utilization was designed to provide a framework for achieving equitable distribution of health services in the United States,[1] it also has been used in studies investigating the use of health services in developing countries. For example, Fosu used the model to examine factors that influence the utilization of medical care facilities for treating childhood morbidity in sub-Saharan Africa. The results showed the factors that account for health service use include the age of the mother, mother's education, family resources, rural-urban residence, and the number of reported diseases.[2] Rahman used the framework to examine factors affecting acceptance of complete immunization coverage of children under five years old in rural Bangladesh. This research concluded that predisposing, enabling, and need factors such as the mother's wealth, distance from health facility, mother's age, parity, and child's gender appear to have a strong association with full immunization coverage.[3] Importantly, this framework suggests that health aid relates to malaria health service utilization through its influence on increasing malaria facility readiness in a defined service area (Path A-B, Research Question 4 above). It also provides a model for understanding the relationship between societal determinants and facility readiness to provide malaria services (indicated by Path A and answering Research Question 2). Furthermore, the model can be used to examine the relationship between facility readiness to provide malaria services and service utilization (Path B, Research Question 3) as well as the relationship between health aid and service use (Path C, Research Question 1).

Societal Determinants

According to Andersen, the funding of medical care is the societal determinant that has the greatest effect on health service utilization.[1] Only recently has there been a shift in the global health agenda from focusing on disease-specific approaches to emphasizing health-system strengthening to improve the effectiveness of health systems.[4-6] The impact of health funding on the delivery of health services remains a matter of debate. Although a few studies have begun to investigate this question; most have been qualitative in nature or focused on investment in HIV/AIDS programs. Grepin conducted an investigation of the impacts of increased HIV donor funding on non-HIV health services in sub-Saharan Africa and found mixed results, suggesting that HIV aid may have positively affected some maternal health services, such as prenatal blood testing, but crowded out childhood immunizations.[7] Within this limited literature, there is some evidence that scaled up investments in HIV/AIDS programs are strengthening fragile health systems in developing countries.[8] However, the approach used in this paper considers all health aid instead of vertical aid, such as malaria specific investments. Thus, it is innovative in that it follows the current, more systematic management of health aid, which concentrates on concerted efforts to understand the synergy between all health aid and health system strengthening.[8]

Health Services System

Next, the conceptual framework used to guide this research links societal determinants directly to health service systems as well as to individual determinants, which are discussed in the next section. Recent research indicates that health facility readiness could be one of the major factors contributing to poor malaria treatment. Frequent antimalarial drug shortages contribute to low

coverage of malaria treatment in many areas in sub-Saharan Africa.[9] Similarly, findings from four East African countries indicate that women are more likely to use modern contraceptive methods when living near facilities with a higher service readiness score.[10] Furthermore, measures of health service readiness appear to improve the explanatory power of health services utilization regressions by 27%.[10]

Individual Determinants

Child, mother, and household-level factors associated with treatment seeking for childhood illnesses are included in the conceptual model as individual determinants. Within the model, these determinants are categorized into predisposing, enabling, and need factors, based on the Anderson and Newman framework.[1]

Predisposing factors

Four measures of predisposing characteristics are associated with treatment seeking for childhood illness.[11] First, mother's age is included to control for the suggestion that younger women tend to use more health services than older women.[2] A child of a younger mother is more likely to be the woman's first child; therefore, she might be more likely to seek treatment.[11,12] Second, mother's education is directly related to employment and socioeconomic status.[2] Mothers with no or only primary education are less likely to take their child for treatment when sick.[13] Several factors account for why this may occur; specifically, women with little or no education are less likely to recognize severe symptoms in a sick child, are more likely to seek treatment from a traditional healer, and are less likely to have financial resources to take a child for treatment at a health facility.[11] Third, the age of the child is also included since age is a strong predictor of treatment seeking for fever, with younger children (under age 2) more likely to have been brought for care than older children (ages 2–5).[2,11] The fourth factor, a belief or culture that in which Western treatment is appropriate could be associated with treatment-seeking behavior. Data that capture this construct are unavailable (indicated in nonitalicized text); therefore, cultural beliefs are included as a predisposing factor in the conceptual model but are unable to be included in the empirical model.[14] In addition to the predisposing factors mentioned, number of siblings was also considered. However, number of siblings was not consistently identified in the literature as influencing diagnostic or treatment-seeking behavior among children under five.[11]

Enabling factors

Three measures of enabling characteristics promote the ability to use malaria services. First, mothers living closer to a health facility are more likely to take their child for treatment of illness. According to Bennett, children in households less than 2 km from a health facility were 1.4 to 1.7 times more likely to be taken for treatment than children at least 6 km from a health facility.[11] Distance from a facility acts as a barrier to treatment through increased travel costs, increased time, and decreased motivation to take a sick child on a long trip.[11] Second, geographic location type (urban/rural) can proxy for the supply of facilities that are available to mothers and the ease of accessing them. Children living in rural households are typically farther from a health facility.[2] Third, wealth is included in the model, as women living in poorer households are less likely to seek treatment for sick kids due to lack of money to pay for treatment costs, transportation costs to the facility, and concerns about lost time from work to take the child for treatment.[2,11,15-17]

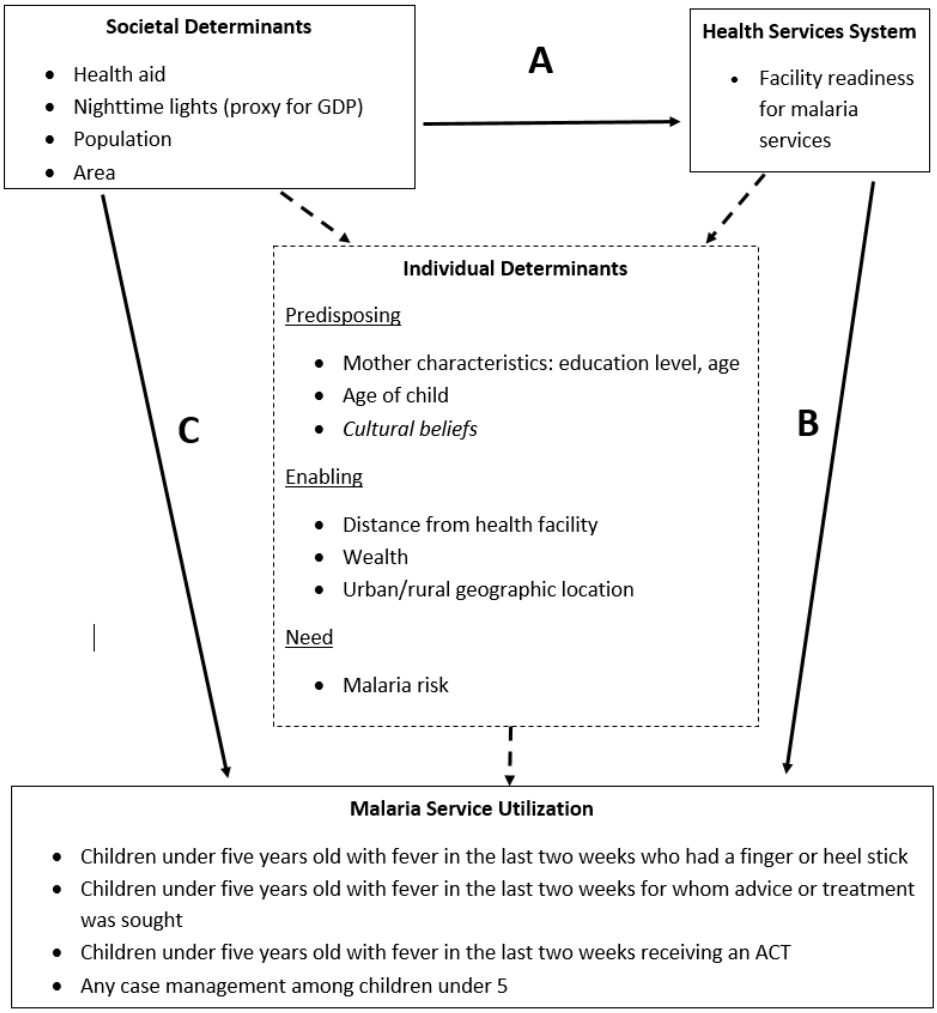
Need factors

In order for malaria services to be used, the model suggests there must be a perceived need for that service. The need factor in this study is the malaria ecology index, which is an index of malaria risk. Women living in areas of higher malaria risk may perceive a greater need for malaria treatment than women living in areas of lower malaria risk.[2]

Malaria Service Utilization

Finally, the conceptual model concludes with utilization of effective malaria services. The Global Malaria Action Plan (GMAP) provides a global framework for malaria control, elimination, and research. These outcome indicators can be used to measure progress toward GMAP targets and are the recommended indicators for malaria case management among children under five years old.[18] These indicators include children under five with a fever in the last two weeks who: (1) had a finger or heel stick, (2) sought advice or treatment, (3) received an Artemisinin-based Combination Therapy (ACT), and (4) received any of the three preceding case management indicators.

Figure 1: Andersen and Newman Model of Health Service Utilization to Examine Malaria Service Utilization by Children under Five in Malawi



Supplementary Appendix B: Data Sources and Empirical Measures

VARIABLE	DEFINITION	SOURCE
Dependent Variables (Conceptual Framework: Malaria Service Utilization)		
Advice/Treatment	Children under five with fever in the last two weeks for whom advice or treatment was sought	National Malaria Control Programme (NMCP) [Malawi] and ICF International. 2012. *Malawi Malaria Indicator Survey (MIS) 2012.* Lilongwe, Malawi, and Calverton, Maryland, USA: NMCP and ICF International.[19]
Heel/Finger Sick	Children under five with fever in last two weeks who had a finger or heel stick	
ACT	Children under five receiving an ACT, with a fever in last two weeks	
Any Treatment	Combination of previous three variables (advice/treatment, ACT, and heel/finger stick). Children under five with fever in the	

VARIABLE	DEFINITION	SOURCE
	last two weeks who had a finger or heel stick, received an ACT, or for whom advice or treatment was sought	
Independent Variables (Conceptual Framework: Societal Determinants)		
Health Aid	Count of the number of health aid projects in each region (first-level administrative boundary)	Christian Peratsakis, Joshua Powell, Michael Findley, Justin Baker, and Catherine Weaver. 2012. Geocoded Activity-Level Data from the Government of Malawi's Aid Management Platform. Washington D.C. AidData and the Robert S. Strauss Center for International Security and Law.[20]
Nighttime Lights	Log of the average nighttime light intensity of the region. Previous literature has shown that nighttime light intensity correlates with GDP at the level of countries, the level of subnational provinces, and at the level of grid cells of 1 x 1 decimal degrees.[21-23]	National Oceanic and Atmospheric Administration (NOAA); Version 4 DMSP-OLS Nighttime Lights Time Series[24]
Population	Sum of the adjusted population count of the region. Recent population mapping methodologies utilize a variety of approaches in order to assign estimated population counts to a grid cell. The primary advantage of the CIESIN GPWv4 is that it is a minimally modeled data set, specifically it uses an areal-weighting approach. This approach allows for the data to be analyzed in conjunction with ancillary data sets, such as land cover, without concern for endogeneity.[25,26]	Center for International Earth Science Information Network (CIESIN); Columbia University.[19,27]
Area	Square kilometers of subnational regions	Directly calculated from the shapefile of subnational boundaries[28]
Independent Variables (Conceptual Framework: Health Services System)		
Overall Malaria Service Readiness Index	Includes unexpired malaria rapid diagnostic test kits or else a functioning microscope with relevant stains and glass slides; staff member recently trained in either RDT or microscopy, and malaria RDT protocol available in facility, malaria treatment guideline, first-line medicine, and personnel recently trained in malaria diagnosis and/or treatment available	Ministry of Health (MoH) [Malawi] and ICF International. 2014. *Malawi Service Provision Assessment (MSPA)* 2013–14. Lilongwe, Malawi, and Rockville, Maryland, USA: MoH and ICF International.[29]

VARIABLE	DEFINITION	SOURCE
Diagnostic Readiness Index	Includes malaria Rapid Diagnostic Testing (RDT) or malaria microscopy diagnostics, either malaria RDT or malaria microscopy training, and having malaria RDT protocols	
Training Readiness Index	Includes having either malaria RDT or malaria microscopy training, malaria RDT protocols, malaria treatment guidelines, and trained personnel	
Independent Variables (Conceptual Framework: Individual Determinants Predisposing Factors		
Mother's Highest Education Level	Highest education level of mother	National Malaria Control Programme (NMCP) [Malawi] and ICF International. 2012. *Malawi Malaria Indicator Survey (MIS) 2012.* Lilongwe, Malawi, and Calverton, Maryland, USA: NMCP and ICF International.[19]
Mother's Age	Current age of mother (years)	
Age of Child	Current age of child (years)	
Independent Variables (Conceptual Framework: Individual Determinants Enabling Factors)		
Distance from Health Facility	Straight line distance in km from the survey cluster to the nearest health facility; calculated in ArcGIS 10.4 using near distance tool	National Malaria Control Programme (NMCP) [Malawi] and ICF International. 2012. *Malawi Malaria Indicator Survey (MIS) 2012.* Lilongwe, Malawi, and Calverton, Maryland, USA: NMCP and ICF International and Ministry of Health (MoH) [Malawi] and ICF International. 2014. *Malawi Service Provision Assessment (MSPA)* 2013-14. Lilongwe, Malawi, and Rockville, Maryland, USA: MoH and ICF International.[19,29]
Wealth Index	Composite measure of a household's cumulative living standard	National Malaria Control Programme (NMCP) [Malawi] and ICF International. 2012. *Malawi Malaria Indicator Survey (MIS) 2012.* Lilongwe, Malawi, and Calverton, Maryland, USA: NMCP and ICF International.[19]
Geographic Location	Type of place of residence (urban/rural location)	

VARIABLE	DEFINITION	SOURCE
Independent Variables (Conceptual Framework: Individual Determinants Need Factors)		
Malaria Ecology Index	Index of malaria risk. The Malaria Ecology Index measures the stability of the transmission of malaria by examining ecological factors such as temperature and rainfall, as well as the dominant mosquito vector and its human-biting rate.	Gordon C. McCord and Jesse K. Anttila-Hughes. "A Malaria Ecology Index Predicted Spatial and Temporal Variation of Malaria Burden and Efficacy of Antimalarial Interventions Based on African Serological Data." *The American Journal of Tropical Medicine and Hygiene* (2017): 16-0602. [30]

Description of Health Aid Sectors (n=108)

Sector	Sector Specific Categories	Count of project locations	AidData Purpose Code
Medical Services	Laboratories; Specialized clinics and hospitals; Specialized medical equipment and supplies; ambulances; dental services; mental health care; control of non-infectious diseases; drug and substance abuse control and counseling	5	12191
Basic Health Care	Basic/primary health care programs; Paramedical and nursing care programs; Supply of drugs, medicines and vaccines (basic)	41	12220
Basic Health Infrastructure	Basic hospitals, clinics and dispensaries; Basic health medical equipment and supplies	19	12230

Infectious and Parasitic Disease Control	All prevention and control activities; Other infectious and parasitic disease, control; Malaria control; Tuberculosis control; Helminthiasis; Polio; Acute respiratory infections	3	12250
Health policy and administrative management	Health sector policy, planning and programs; Institution capacity building; aid to health ministries; medical insurance programs	37	12110
Medical education/training	All medical education/training activities	3	12181

Supplementary Appendix C: Empirical Approach to Mediation Analysis

Step 1: Pathway C, Research Question 1

In Equation 1, a logistic regression was used to investigate the association between health aid ($HeathAid_r$) and an indicator for whether or not a child under five utilized malaria services. It addresses the first research question: is the allocation of health aid positively associated with utilization of malaria services among children under five years old? Informed by the conceptual model above, potential confounders adjusted for nighttime light intensity ($Lights_r$), population ($Population_r$), area square km ($Area_r$), mother's education ($Education$), age of mother ($MotherAge_m$), age of child ($ChildAge_i$), distance from health facility ($Distance_c$), wealth index ($Wealth_i$), rural geographic classification ($Location_c$), and malaria ecology index (MEI_c).

Equation 1

$$pr(Y=1|X)=\frac{\exp(X\beta)}{1+\exp(X\beta)}$$

where Xβ=

$$\alpha + \beta_1 HealthAid_r + \beta_2 Lights_r + \beta_3 Area_r + \beta_4 Population_r + \beta_5 Education_m + \beta_6 MothersAge_m$$
$$+\beta_7 ChildAge_i + \beta_8 Dis\tan ce_c + \beta_9 Wealth_i + \beta_{10} Rural_c + \beta_{11} MEI_c + \varepsilon_{rcmi}$$

and Y = received (1) finger or heel stick, (2) advice or treatment, (3) malaria artemisinin-based Combination Therapy (ACT), or (4) any malaria service use and *r*=region, *c*=MIS interview location (cluster), *m*=mother, and *i*=child.

Step 2: Pathway A, Research Question 2

In Equation 2, multinomial logistic regression was used to address the second research question of whether health aid is associated with health facility readiness to provide malaria services. Terciles of low, medium, and high service readiness was defined using the distribution of the Kernel Density Estimation. Since the outcome is ordinal, ordered logistic regression models were fit but violated the proportional odds assumption using both a likelihood ratio test ($p<0.001$) and a Brant test ($p<0.001$).[31] When proportional odds are violated, multinomial logit is preferred to give consistent estimates and therefore, multinomial logistic was used in this analysis.[32]

Equation 2

$$pr(Y = j) = \frac{\exp(X\beta^j)}{\sum_r^j \exp(X\beta^j)}$$

where Xβ=

$$\alpha + \beta_1 HealthAid_r + \beta_2 Light_r + \beta_3 Area_r + \beta_4 Population_r + \varepsilon_r$$

and j=low, medium, and high malaria service readiness.

Step 3: Pathway B, Research Question 3

Equation 3 uses a logistic framework to investigate the association between levels of malaria service readiness and whether or not a child under five received malaria diagnosis or treatment while including measures of health aid. It addresses the third research question, is utilization of malaria services influenced through increasing malaria facility readiness when controlling for health aid?

Equation 3

$$pr(Y=1|X)=\frac{\exp(X\beta)}{1+\exp(X\beta)}$$

where Xβ=

$$\alpha+\beta_1 HealthAid_r+\beta_2 Service\,\mathrm{Re}adiness_f+\beta_3 Light_r+\beta_4 Area_r+\beta_5 Population_r+\beta_6 Education_m+$$
$$\beta_7 MothersAge_m+\beta_8 ChildAge_i+\beta_9 Dis\tan ce_c+\beta_{10} Wealth_i+\beta_{11} Rural_c+\beta_{12} MEI_c+\varepsilon_{rfcmi}$$

and Y = received (1) finger or heel stick, (2) advice or treatment, (3) malaria artemisinin-based Combination Therapy (ACT), or (4) any malaria service use and *r*=region, *f*=facility, *c*=MIS interview location (cluster), *m*=mother, and *i*=child.

Step 4: Pathway C', Research Question 4

Equation 4 is a logistic model fit to investigate the association of health aid on malaria service utilization controlling for malaria service readiness. It answers the final research question, is health aid positively associated with utilization of malaria treatment controlling for service utilization? If evidence of potential mediation exists, I will formally test it using a Sobel test, which tests whether facility readiness carries the influence of health aid to utilization outcomes.[33]

Equation 4

$$pr(Y=1|X)=\frac{\exp(X\beta)}{1+\exp(X\beta)}$$

where
Xβ=

$$\alpha+\beta_1 HealthAid_r+\beta_2 Service\,\mathrm{Re}adiness_f+\beta_3 Light_r+\beta_4 Area_r+\beta_5 Population_r+\beta_6 Education_m+$$
$$\beta_7 MothersAge_m+\beta_8 ChildAge_i+\beta_9 Dis\tan ce_c+\beta_{10} Wealth_i+\beta_{11} Rural_c+\beta_{12} MEI_c+\varepsilon_{rfcmi}$$

and Y = received (1) finger or heel stick, (2) advice or treatment, (3) malaria artemisinin-based Combination Therapy (ACT), or (4) any malaria service use and *r*=region, *f*=facility *c*=MIS interview location (cluster), *m*=mother, and *i*=child.

Supplementary Appendix D: Construction of Measures of Malaria Service Utilization (Dependent Variables)

In parentheses are the specific variables numbers as they are found in the Malaria Indicator Survey (MIS). Children under five years old with a fever in the last two weeks who had a finger or heel stick measures the extent to which children with a fever obtain a parasitological diagnosis. Children were coded as having a finger or heel stick if they had a fever in the last two weeks (h22) and had blood taken from their finger/heel (h47). The next outcome, children under five years old with fever in the last two weeks for whom advice or treatment was sought, captures care-seeking behavior for the treatment of malaria among children under five years old. Children were coded as seeking advice if they had a fever in the last two weeks (h22) and they received medical treatment for a fever (h32z). The third outcome, children under five years old with fever in the last two weeks receiving an ACT, assesses antimalarial treatment received by children under five in accordance with national malaria treatment policy. Children were coded as receiving ACT if they had a fever in the last two weeks (h22) and had taken ACT for fever (h37a-h37h). Finally, any malaria service use among children under five is an indicator for whether any of the previous three outcomes occurred. Children were coded as having any malaria service use if they had a fever in the last two weeks and had a heel or finger stick, received advice or treatment, or received ACT.[18]

Outcome	Variable in MIS
Children under five years old with fever in the last two weeks for whom advice or treatment was sought	h22: fever in the last two weeks h32z: fever/medical treatment (binary outcome as aggregate from h32 treatment by facility type)
Children under five years old with fever in the last two weeks who had a finger or heel stick	h22: fever in the last two weeks h47: blood taken from child's finger/heel
Children under five years old with fever in the last two weeks receiving an ACT	h22: fever in the last two weeks h37a-H37h: type of ACT/taken for fever
Any malaria service use among children under five	Heel/finger stick or advice/treatment sought or receiving an ACT

Supplementary Appendix E: Construction of the Malaria Service Readiness Index

Building upon the Paris Declaration of Aid Effectiveness and the International Health Partnership, global partners including the World Health Organization, the United States Agency for International Development, MEASURE Evaluation, MEASURE DHS, and ICF International developed a general framework for the monitoring and evaluating of health system strengthening in developing countries, including systems to strengthen malaria service delivery.[34] Service availability and readiness assessment (SARA) is one tool within this framework designed as a systematic survey to assess health facility service delivery. This survey includes a set of indicators designed to determine the ability of a facility to provide services based on both quality and quantity.[34] These indicators can be combined into a specific service readiness index, such as an index of malaria services. Service readiness is specifically defined by the WHO as the "ability of health facilities to offer services, and the capacity to provide that service measured through consideration of tracer items that include trained staff, guidelines, equipment, diagnostic capacity, and medicines and commodities."[34]

Construction of Malaria Readiness Index[19]

Category Number	Categories of Malaria Service Readiness Index	Variables from Service Provision Assessment
1	Facilities having malaria diagnostic capacity (unexpired malaria rapid diagnostic test (RDT) kits or else a functioning microscope with relevant stains and glass slides)	1. Interviewer observed RDT being conducted: Q1420(6)=1 OR 2. Providers in facility diagnose malaria: Q1702=1 OR 3. Providers in facility prescribe treatment for malaria: Q1710=1 OR Facility had malaria microscopy capacity (all components 1, 2, and 3) 1. Light microscope used and functioning: Q840(1) B=1 AND Q840(1)C=1 AND 2. Glass slides and covers used: Q840(8)B=1 AND 3. Giemsa Stain, Field Stain, or Acridine Orange stain available: Q847(1)B=1 OR Q847(2)B=1 OR Q847(3)B=1 OR Facility had RDT capacity (components 1, 2, or 3) 1. Observed RDT kit (malaria section): Q1706=1 OR 2. Observed RDT kit (parasitology section): Q843=1 OR 3. Observed malaria rapid diagnostic testing: Q1420(6)=1
2	Staff member recently trained in either RDT or microscopy	If child curative services provided p302=1 AND

Construction of Malaria Readiness Index[19]

Category Number	Categories of Malaria Service Readiness Index	Variables from Service Provision Assessment
		1. Malaria training in the last 24 months for how to perform RDT p206_3=1 OR 2. Child health services training in the last 24 months for how to perform RDT p304_04=1 OR 3. Diagnostic services training in the last 24 months for how to perform RDT p703_8 OR 4. Malaria training in the last 24 months for malaria microscopy p206=1 OR 5. Child health services training in the last 24 months for malaria microscopy p304_02=1 OR 6. Diagnostic services training in the past 24 months for how to perform malaria microscopy p703_7=1
3	Malaria RDT protocol available in facility	If 1.Training manual, poster, or other job aid for using a malaria RDT observed q1709=1 OR 2. Training manual, poster, or other job aid for using a malaria RDT reported q1709=2
4	Malaria treatment guideline	If 1. National guidelines for the diagnosis and treatment of malaria reported q1712=1 OR 2. Other guidelines for the diagnosis and treatment of malaria observed q1714=1
5	First-line medicine	If 1. Artemether lumefantrine 6 tablet observed and valid q905_01=1 OR

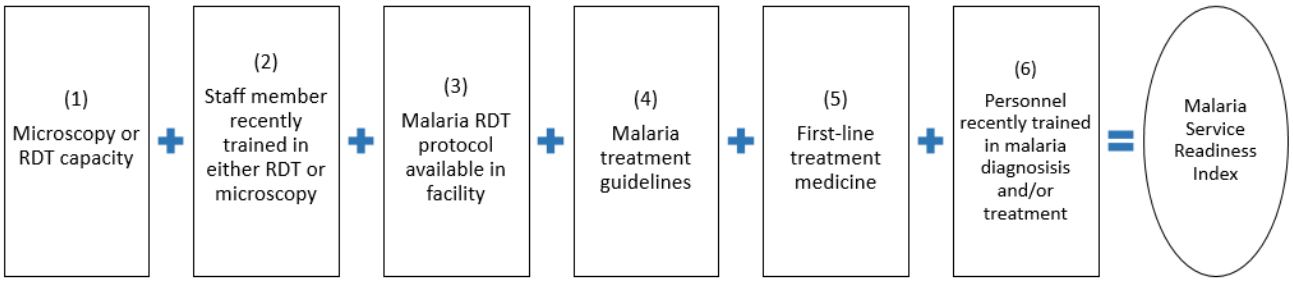
Construction of Malaria Readiness Index[19]

Category Number	Categories of Malaria Service Readiness Index	Variables from Service Provision Assessment
		2. Artemether lumefantrine 12 tablet observed and valid q905_02=1 OR 3. Artemether lumefantrine 18 tablet observed and valid q905_03=1 OR 4. Artemether lumefantrine 24 tablet observed and valid q905_04=1 OR 5. Fansidar/SP tables observed and valid q905_05=1 OR 6. Quinine tablets observed and valid q905_06=1 OR 7. Quinine injection observed and valid q905_07=1 OR 8. Injectable artesunate observed and valid q905_08=1 OR 9. Artesunate suppositories observed and valid q905_09=1 OR 10. Other antimalarial medicine observed and valid q905_10=1 OR 11. Artemether-Amodiaquine 25mg observed and valid q905_11=1 OR 12. Artemether-Amodiaquine 50mg observed and valid q905_12=1 OR 13. Artemether-Amodiaquine 100mg observed and valid q905_13=1
6	Personnel recently trained in malaria diagnosis and/or treatment available	If Malaria training in the past 24 months for 1. Diagnosing malaria in adults p206_1=1 OR 2. Diagnosing malaria in children p206_2=1 OR

Construction of Malaria Readiness Index[19]

Category Number	Categories of Malaria Service Readiness Index	Variables from Service Provision Assessment
		3. How to perform malaria RDT p206_3=1 OR 4. Case management/treatment of malaria in adults p206_4=1 OR 5. Case management/treatment of malaria in pregnancy p206_5=1 OR 6. Intermittent preventive treatment of malaria in pregnancy p206_6=1 OR 7. Case management/treatment of malaria in children p206_7=1

Figure 2: Malaria Service Readiness Index



Supplementary Appendix F: Linking Facility-Level and Household-Level Data in Malawi

In order to conduct the analysis, it is necessary to link the malaria service readiness indices to the individual level data (children under 5). Within the literature, different methods to link household and facility data have been reported, each method has its own set of advantages and limitations.[35] These methods are divided into two categories: 1) indirect methods in which individuals were linked to all or the nearest facilities or providers, and 2) direct linking in which individuals were linked with the exact provider or facility where they received care.[36] A recent literature review that focused on child health care in low- and middle-income countries determined that of the 59 studies included in the review, 51 used indirect linking methods and

only 8 used direct linking methods. Of the studies using direct linking, most were in only rural areas where the number of providers was more limited.[36]

Following the majority of the extant literature, this study links the malaria service readiness index to the household survey data indirectly. Direct linkage is not possible, because the MIS and SPA are independent sources of household and facility-level data. Therefore, it is not possible to link individuals with the exact provider or facility where they sought malaria services. In order to link the malaria service readiness index to the household indirectly, Kernel Density Estimation (KDE) was used. Technical details of this linkage are included below. In short, KDE creates a map that depicts the estimated influence a health facility has over a geographic area to assign a density of each readiness index for each household survey cluster in the MIS survey. Thus, in this paper, malaria service readiness will refer to the average KDE estimates of total service readiness, diagnostic readiness, and training readiness for a 5-km buffer around each MIS household survey cluster.[a]

The primary advantage of this linking method is that it allows for the incorporation of a fundamental aspect of health care utilization patterns, which is distance decay or the idea that the farther away a patient is located from a facility, the lower their access.[35] However, this method also has limitations. The kernel used in a KDE is assigned according to a straight-line distance. This method assumes that patients can travel along a straight-line path to get to a service, while in reality patients take indirect paths following roads. One study found that straight-line distances were strongly correlated with actual driving distance times, demonstrating that in some cases it may be a reliable proxy.[38] Given that the readiness score is a relative measure, three terciles were constructed from the distribution to capture low, medium, and high levels of facility readiness.

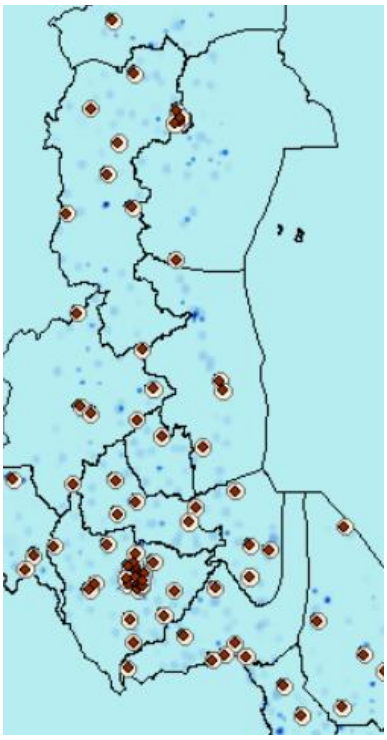
Technical Details of MIS and SPA Linkage

This analysis includes geographic data from both household surveys as well as health facility surveys, which were linked within a geographic information system (GIS). For this analysis, the MIS and SPA surveys were linked using Kernel Density Estimation (KDE), which creates a map that depicts the estimated influence a health facility has over a geographic area. This link requires definition of the kernel size, the density variable that determines the probability density distribution across the kernel, and the grid size.[39] In this analysis, the kernel size was set to reflect patient preference for higher-order facilities: 10 km for hospitals, 5 km for health centers, and 2.5 km for dispensaries.[37,40] The density variable is a facility-level Malaria Readiness Index, and a quartic kernel function was used that is further described in Silverman.[41] The grid cell size was set to 1 km. The size of the grid cell was selected because it is a standard size that would allow for density to be reported in a meaningful unit of malaria readiness per square kilometer. The KDE for each facility type (hospitals, health centers, and dispensaries) was created separately, and then the Map Algebra Raster calculator was used to sum the value within each grid cell. The spatial coordinates (latitude and longitude) of the MIS interviews represents the centroid of a group of households dispersed across a geographic region. Therefore, I generated an average KDE value for each interview centroid by creating 5-km Euclidean buffers around each MIS cluster. Next, I averaged the KDE estimates for the total 5-km surface for each

[a] Following Skiles, 5-km buffers were selected because MIS survey cluster spatial coordinates (latitude and longitude) are taken at a centroid and we know the cluster population is dispersed over a surface area.37

cluster.[37,42] Figure 3 shows a partial image of this linkage. The red dots are the MIS survey centroids, the tan circles are the 5-km buffers, and the blue surface is the resulting KDE output.

Figure 3: Partial Image of household and facility level linkage using Kernel Density Estimation



Sensitivity to Kernel Density Estimation Bandwidth

It is well recognized that bandwidth selection is an integral part of Kernel Density Estimation. An appropriate bandwidth can produce estimated densities of facility readiness close to the true density; however, a poorly chosen bandwidth can severely distort the true underlying features of the density.[43] To address this concern, I created a surface using a Quartic kernel with an adaptive bandwidth, selected based on minimizing the mean square error. Figures 4–6, located below, show the resulting output of bandwidth estimation for hospitals, health centers, and dispensaries. Results indicate an optimal bandwidth of 250 for all facility types. This bandwidth was used to generate a new surface that
was used in estimation of Steps 2–4 of the Baron and Kenny approach.[b] Results indicate that health aid is negatively associated with overall, diagnostic, and training readiness. Steps 3 and 4 differ in magnitude but remain qualitatively similar in terms of direction to those in the main specification. Readers should be aware that multiple approaches to bandwidth estimation exist. Although, KDE is a useful way to consider facility readiness, future research could estimate the bandwidth several ways to ensure the optimal size is selected.

[b] Step 1, which examines the association between health aid and utilization, was not estimated for this sensitivity analysis, because it does not include the malaria service readiness index.

Figure 4: Bandwidth selection for kernel function for hospitals

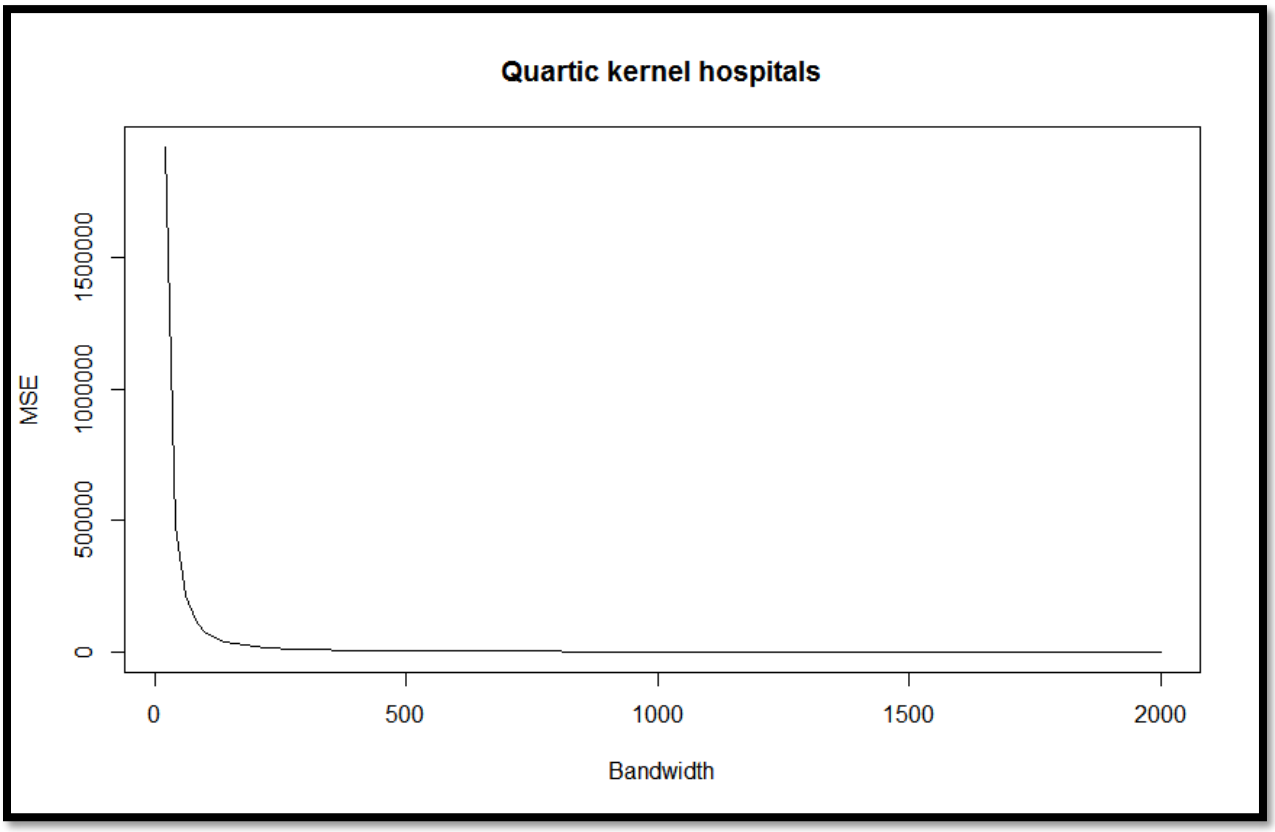


Figure 5: Bandwidth selection for kernel function for health centers

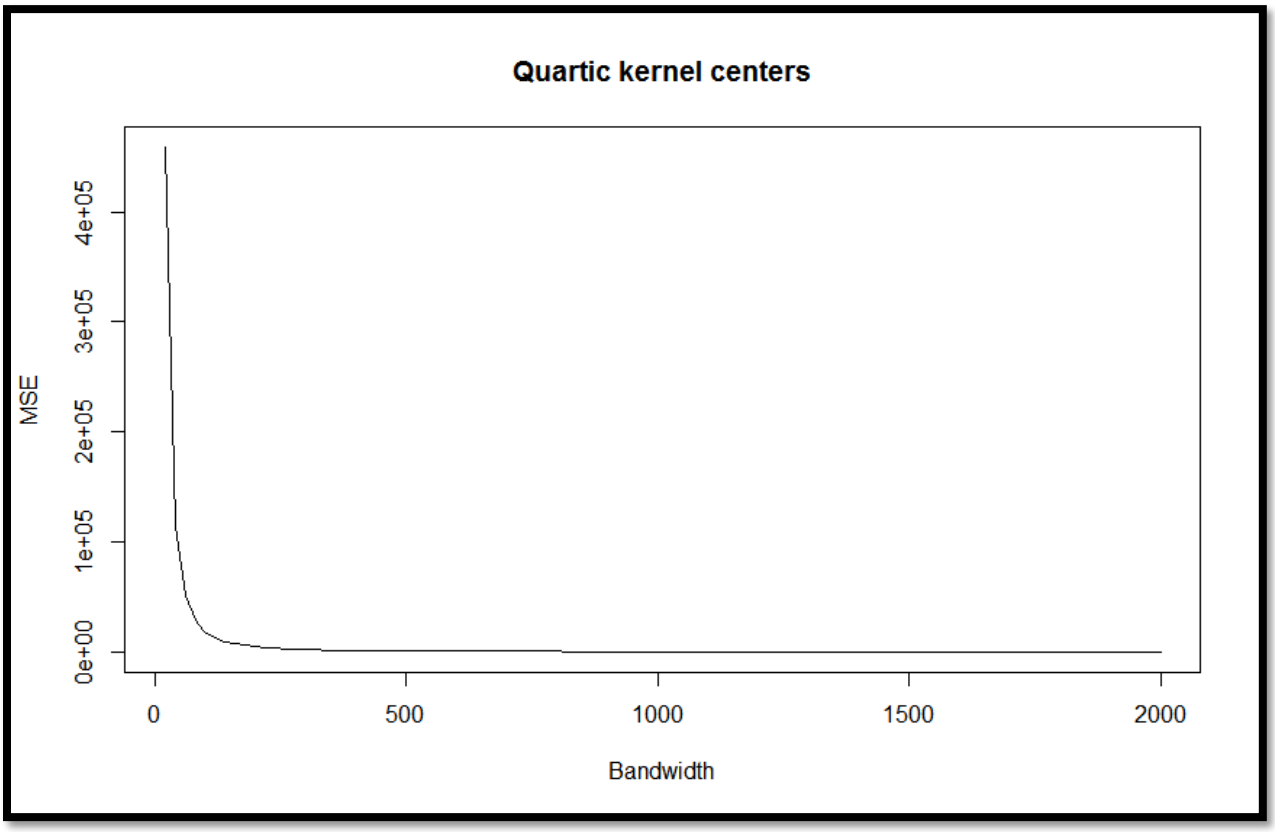
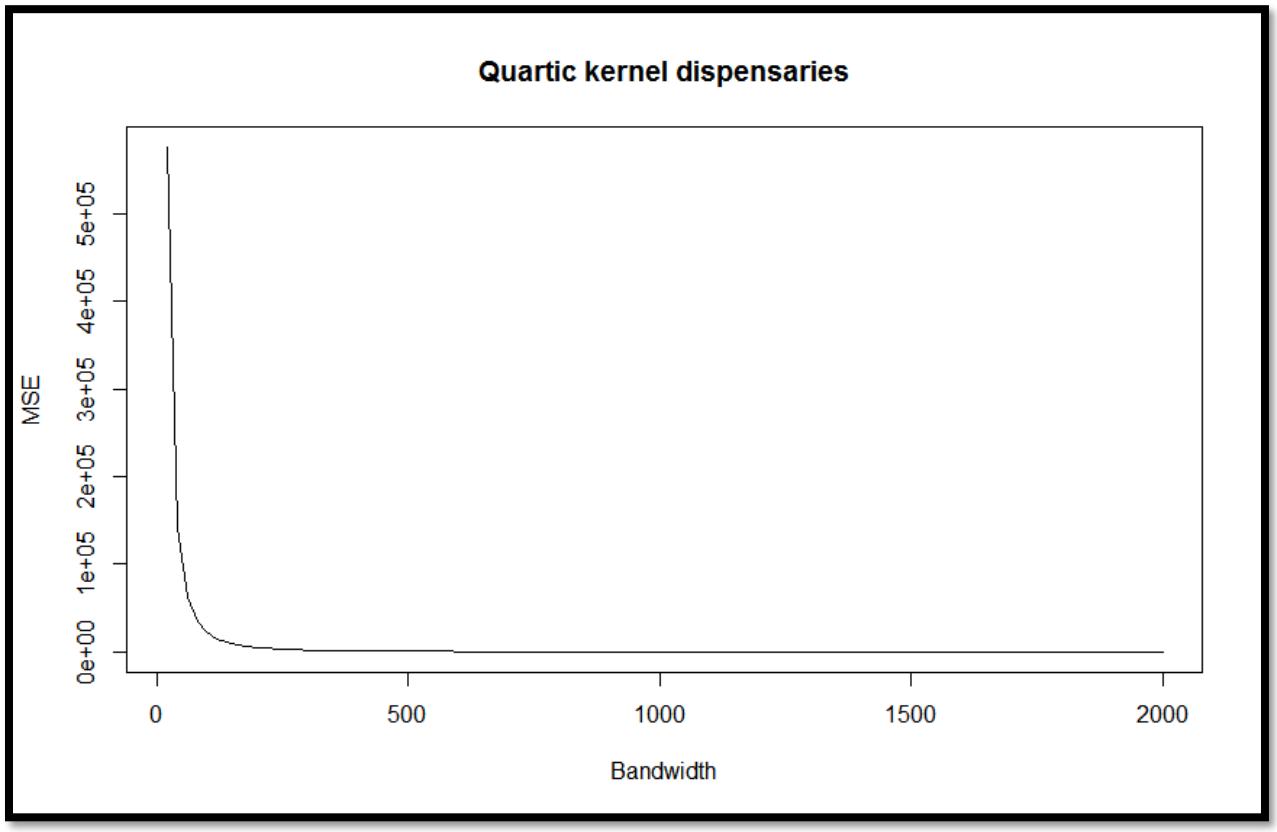


Figure 6: Bandwidth selection for kernel function for dispensaries



Supplementary Appendix G: Sensitivity Analysis

Sensitivity to Clustered Standard Errors

An assumption of logistic regression is independence of error terms. Failure to control for correlations can lead to misleadingly small standard errors and consequently narrow confidence intervals and low p-values.[32] To address this concern, within household correlations were accounted for by clustering standard errors at the household level. Results from within household correlations that are presented remain qualitatively the same as the main specifications with the exception of results for Steps 3 and 4 where the weak associations identified in Tables 4A–C are no longer present.

Temporality and Sensitivity to Endogeneity

If health aid and facility readiness determine each other simultaneously, then there is an endogenity problem in the relationship that needs to be checked. If this is the case, then standard

estimation procedures, which assume that health aid is exogenous, will produce inconsistent estimates of the parameters.[32] It seems logical that even if causality exits in both directions, it does not occur instantaneously, but with a time lag. Enough time may not have elapsed for changes to occur in facility readiness that influence utilization. Examining aid in the aggregate may explain the null results found in this research. It is not possible to test the sensitivity around readiness and utilization due to the timing of the MIS surveys. However, sensitivity around aid and readiness could be tested by examining aid in two bins of early and late aid. Early aid was defined as health aid with a completion date of 2005–10, and late aid was health aid with a completion date of 2011 and 2012. Bins were defined based on project counts and with the purpose of creating a bin of five years of preutilization aid.[c] F-tests were used to test if coefficients of early and late aid were jointly zero for all regressions with significant coefficients. Results indicate that there is a significant difference in the coefficients for early and late aid; therefore, future research could apply the Granger-causality test to examine the statistical significance of lagged values of health aid.[32,44]

Results including bins of early and late aid in the specifications indicate that it is appropriate for future research to consider binning aid into early and late periods. Referring back to the Baron and Kenny model, findings indicate that health aid is associated with utilization (Step 1) and that health aid is correlated with malaria facility readiness (Step 2). The results provide limited evidence that facility readiness was significant in two cases of overall malaria service readiness (Step 3). Although limited, there is some evidence of significant relationships from Steps 1–3, which could indicate partial mediation is observed in the data. In Step 4, full mediation is supported if the effect of health aid on utilization controlling for facility readiness (C') is zero. Results indicate that health aid is not zero and, therefore, consistent with the main specification; full mediation is not supported when binning health aid into early and late periods. Again, although the evidence of partial mediation is weak, future research could calculate the indirect effect using the Sobel method.[33]

Sensitivity to Moderation

It is possible that facility readiness does not explain the relationship between health aid and utilization (mediation). It is possible that facility readiness influences the strength of the relationship between health aid and utilization (moderation).[45] In order to examine moderation I interacted health aid and facility readiness. Given the relatively small number of project counts in each region, I collapsed aid into three categories, then two categories, and convergence was not achieved indicating that the validity of the model fit was uncertain. Therefore, results are not included in the Supplementary Appendix.

Supplementary Appendix H: Descriptive Statistics of Individual Determinants of Children under Five by Predisposing, Enabling, and Need Factors (n=2,118)

	%
Predisposing Factors	
Mother's Education Level	

[c] Within the AidData data set, there were no health projects recorded during 2007.

	%
None	19
Primary	64
Secondary	16
Higher	1
Mother's Age	
<20	6
20–34	76
35–49	18
Child's Age	
<1	20
1	22
2	20
3	19
4	19
Enabling Factors	
Distance from Health Facility	
2 km	29
5 km	35
10 km	36
Wealth Index	
poorest	20
poorer	19
middle	19
richer	19
richest	23
Geographic Location	
urban	25
rural	75
	Mean (SD)
Need Factors	
Malaria Ecology Index	.310 (.262)

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