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Is There Evidence for Dual Causation Between Malaria and Socioeconomic Status? Findings From Rural Tanzania

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Abstract. Malaria's relationship with socioeconomic status at the macroeconomic level has been established. This is the first study to explore this relationship at the microeconomic (household) level and estimate the direction of association. Malaria prevalence was measured by parasitemia, and household socioeconomic status was measured using an asset based index. Results from an instrumental variable probit model suggest that socioeconomic status is negatively associated with malaria parasitemia. Other variables that are significantly associated with parasitemia include age of the individual, use of a mosquito net on the night before interview, the number of people living in the household, whether the household was residing at their farm home at the time of interview, household wall construction, and the region of residence. Matching estimators indicate that malaria parasitemia is associated with reduced household socioeconomic status.

INTRODUCTION

Untangling the relationship between health and socioeconomic status has proven to be a difficult process. Qualitative evidence strongly supports the conclusion that health and socioeconomic status are related. On one hand, poor health is seen as a quick way to descend into poverty,[1] and on the other, households may have to sell assets (or stores of wealth) to be able to manage health crises within their families.[2] The dearth of natural experiments (i.e., instances where health or socioeconomic status have changed independently of each other) has meant that there is a lack of quantitative evidence to suggest causation in either direction. A study in South Africa[3] is one exception; this study found that increasing household income through an aged pension, which was paid irrespective of health status, resulted in improved self-reported health among the pensioners. The flow on effects of improved health to non-pension recipients within the household depended on the degree of income sharing in the household.

Malaria is one of the most important challenges to global public health. Globally, the annual number of deaths caused by malaria is estimated to be between 700,000 and 2.7 million, with 75% of deaths occurring in sub-Saharan African children.[4] The geographic relationship between poor countries and malaria incidence suggests that they are related.[5] At the international (macroeconomic) level, Gallup and Sachs[5] found that malaria has a strong negative association with country income levels after controlling for geographical factors. Sachs and Malaney[6] and Malaney and others[7] both argue, however, that dual causation exists between malaria and poverty.

This study is the first to explore evidence for dual causation between malaria and socioeconomic status at the household (microeconomic) level. The term dual causation is used to refer to a bidirectional statistical association and does not necessarily imply that all of the epidemiologic criteria for causation have been met. Households in three rural Districts in Tanzania were chosen for the study for two reasons. First, malaria is the most commonly reported health complaint in Tanzania,[8] and US$64.5 million is spent every year on controlling the disease, of which 70% is spent by households.[9] Second, rural communities are at greater risk of malarial disease because they are poorer[1] and face higher transmission rates[10] than their urban counterparts.

MATERIALS AND METHODS

Study area. The study took place in 52 villages in Kilombero, Ulanga, and Rufiji Districts, southeastern Tanzania; the areas are described in detail in an INDEPTH monograph.[11] The most common occupations are subsistence farming, fishing, and small-scale trading. Rice and maize are the predominant food crops. The site has few paved roads, and some villages are cut off for parts of the year as a result of flooding (usually during the rainy season). Most families have a second house at a farm, where they stay during the planting and harvesting seasons. Malaria transmission at the study site is intense and year round, with a mean entomological inoculation rate ranging between 79 and 1,209 infective bites per person per year.[12]

Study design. The data for this study were collected within the framework of two Demographic Surveillance Sites (Ifakara DSS and Rufiji DSS) operating in three rural districts and managed by the Ifakara Health Research and Development Center (IHRDC). The data were collected as part of the Interdisciplinary Monitoring Project for Antimalarial Combination Therapy in Tanzania (IMPACT-Tz). Twenty full-time interviewing staff visited households in the two DSSs between May and September 2004. Interviewers collected data on household asset ownership and use of malaria preventive methods and took blood smears for malaria parasitemia. Blood slides were read by experienced microscopists at a central laboratory site to determine if individuals were parasite positive for malaria. Thick blood films were prepared and stained with 10% Giemsa for 30 minutes, and parasites were counted in fields containing 500 white blood cells. A 10% sample of slides was reviewed for quality assurance. Although parasitemia is a necessary but not sufficient condition in the

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diagnosis of malaria, it was beyond the financial scope of the study to conduct clinical examinations on all patients to diagnose malaria. Individuals participating in the study who were parasite positive received free treatment at their nearest clinic. Informed consent was obtained for all participating adults and from parents or guardians of any children younger than 11 years of age. Local and international ethics committees reviewed approved the study protocols (ANUHREC 2003/269, IHRDC IRB 2004/97, NIMR HRER/1049/2004, and CDC2730-2004).

A sample size of 1,500 households was determined based on the Fisher exact test for 86% power at the 5% significance level to detect a 1.3-fold difference between the highest and lowest socioeconomic status groups (parasite prevalence of 24% in the highest quintile and 32% in the lowest quintile). Clustering effects within households were taken into account in the sample size calculations. The actual sample size for data collection was 3,189 households, because another component of the study required a larger sample size. Of the 3,189 households selected, 2,318 (with 7,657 individuals) provided all of the required information for analysis.

Statistical methods. Data were entered using FoxPro Version 6 (Microsoft, Redmond, WA) and transferred to Stata version 9 (Stata Corp., College Station, TX) for analysis. Household socioeconomic status was determined using the asset index approach outlined in Filmer and Pritchett,[13] whereby household rankings are based on the assets owned by the household. The weights for each item in the index were derived using principal components analysis (PCA), based on the first principal component, which gives an index providing maximum discrimination between households. Households were ranked into socioeconomic status quintiles titled Most poor, More poor, Poor, Less poor, and Least poor. The items selected for the analysis included the following: floor construction, cooking fuel used, water and light source, access to toilet, and ownership of a bed, watch/clock, mattress, iron, radio, clothing cupboard, bicycle, livestock, sofa, motorbike, or car. Following the rationale of Houweling and others,[14] items that may have a direct influence on malaria, for example, wall and roof construction and ownership of a mosquito net, were not included in the determination of household socioeconomic status for the analysis presented here.

The statistical significance of differences in household and individual features between the two study regions was determined using the Satterthwaite *t* test.[15] The statistical significance of differences in household and individual features between socioeconomic status groups was determined using the Pearson χ^2 test, whereas ANOVA was used to determine differences in continuous variables. One instrumental variable probit regression was run to determine associations between malaria parasitemia and individual and household variables including socioeconomic status, the amount the household spent on malaria prevention in the previous month (this amount was divided by the sample mean and multiplied by 100 for easier interpretation of the regression coefficients), knowledge that malaria is transmitted by mosquitoes, use of a mosquito net on the night before interview and if the net had been treated with insecticide in the previous 6 months (the recommended time between treatments), house construction features (wall and roof materials and presence/absence of eaves), religion of the household head, age of the individual, location at the time of interview (village or farm house), the household's region of residence (Ifakara DSS or Rufiji DSS), and the number of people living in the house (used as a proxy for crowding in houses). All tests were performed at the 5% level of significance. The instrumental variable (IV) probit estimation method was chosen to overcome endogeneity (i.e., two-way causation) between socioeconomic status and malaria,[16] because there is much evidence to suggest that there is two-way causation between socioeconomic status and health variables, including qualitative evidence such as the World Bank's Voices of the Poor Report.[2] The two-way causation between malaria prevalence and socioeconomic status means that single-stage regressions would overstate the influence of each direction of causation, for example of socioeconomic status on malaria prevalence. This estimation method assumes a linear relationship between socioeconomic status (SES) and explanatory variables $x_1 \ldots x_k$:

$$\mathrm{SES} = \alpha_0 + \alpha_1 x_1 + \ldots + \alpha_k x_k + v$$

The explanatory variables $x_1 \ldots x_k$ used in this relationship must satisfy two conditions. First, they should be plausible determinants of, and hence be correlated with, socioeconomic status, which is the endogenous variable they are predicting. Second, they must be uncorrelated with the structural error of the equation relating malaria to socioeconomic status. If malaria prevalence (M) was a continuous variable, one could easily use the predicted values of SES from the above regression as an instrument (proxy) for SES in a second stage regression to obtain an estimate of the effect of SES on M that would not be contaminated by endogeneity (reverse causality) bias. However, because M is binary, a probit model is appropriate for it, and because probit models are nonlinear, the estimation of the effect of SES on M is not as simple as using the predicted value of SES from a first stage regression as a proxy for SES. Instead, the dependence of the binary variable M on SES is modeled using an underlying continuous latent variable M* in this way,

$$M = 1 \textbf{ if } M^* > 0;\ M = 0 \textbf{ otherwise,}$$
$$M^* = \beta_0 + \beta_1 y_1 + \cdots + \beta_n y_n + \beta_{n+1}\mathrm{SES} + u$$

where $y_1, \cdots, y_n$ are explanatory variables that are a subset of $x_1 \ldots x_k$ with $n < k$. The IV probit estimation method assumes that the error terms in the SES and the M* equations are jointly normally distributed and uses this system of equations to obtain consistent estimates of the effect of SES on M that do not suffer from endogeneity bias. Wooldridge provides more details about this estimation procedure.[16]

This instrumental variable method allows us to use the component of socioeconomic status that is uncorrelated with the error term of the structural equation for consistent estimation of the structural parameters. All models were estimated to correct for clustering of individuals at the household level. The reported results are the marginal effects for each variable, calculated for the individual with average characteristics.

Matching estimators for average treatment effects were used to determine the effect that malaria parasitemia has on socioeconomic status.[17] The matching technique was used in preference to another instrumental variable regression because the matching estimator does not need a parametric assumption about how each characteristic affects the dependent variable, and hence is a more robust way for controlling for other covariates. Because the malaria parasitemia variable is binary, it divides the sample into two groups. The matching estimators impute the missing or potential outcome, in this case the household's PCA score, by using average outcomes for individuals with "similar" values for a set of covariates, or matching variables.[18] In this study, the variables used for matching included length of time the household head had lived in the area, earning an income from a non-farming source, sex, religion, and educational level of the household head, the number of people living in the household, and region of residence (Ifakara DSS or Rufiji DSS). Each individual was allowed four matches.[18] Figure 1 outlines a conceptual framework depicting the relationships between the variables of interest. Notably, socioeconomic status and malaria mutually influence each other. Although several household level characteristics influence both socioeconomic status and malaria, another group of variables only influences one or the other.

RESULTS

Household and individual characteristics. There were 2,318 households that provided both assets information and a blood sample for parasitemia testing during the survey round. Table 1 outlines the differences in household characteristics across the two study sites (Ifakara DSS and Rufiji DSS) and indicates which of the differences are significant.

The average and range of PCA scores by socioeconomic quintile are outlined in Table 2. Household PCA scores ranged between –2.74 and 8.36 and averaged 0. There were disproportionately more houses in the Most poor quintile (594) than in the others because households with the same PCA score were placed into the same socioeconomic status quintile. Separate analysis indicated that this shift of households into the Most poor quintile was caused by the removal of housing construction features from the asset index calculations (results not shown). Although there were no significant differences in household rankings between the study sites, average PCA scores were significantly higher in Rufiji DSS.

Table 3 outlines the differences in individual and household characteristics across socioeconomic status quintiles and whether differences across the quintiles and between the two study regions are significant. For almost all characteristics, there was an obvious trend across the socioeconomic status quintiles, the exceptions being location of the household at

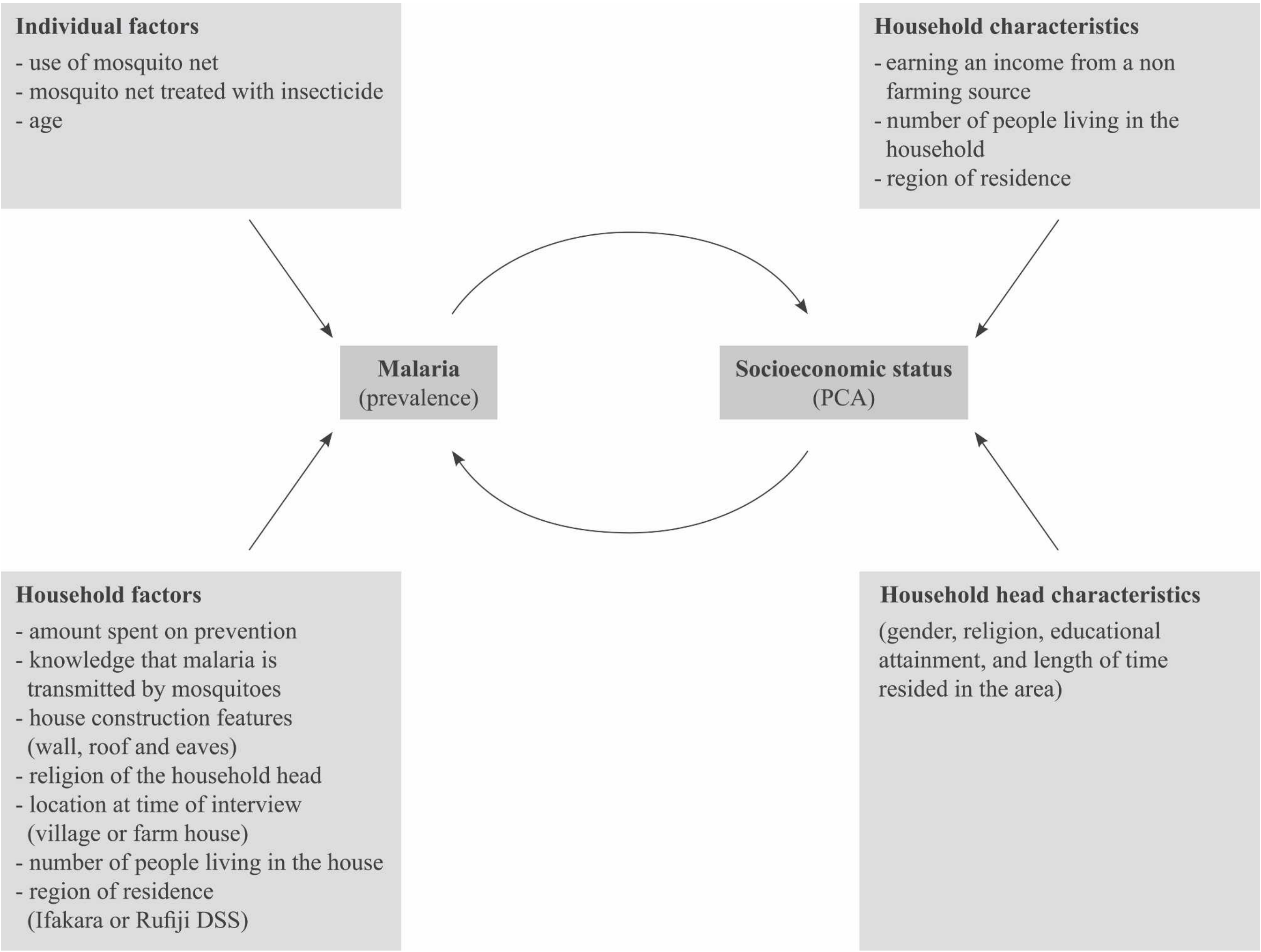

FIGURE 1. A conceptual framework depicting the relationships between the variables of interest.

TABLE 1
Characteristics of households in the sample

Characteristic	Ifakara DSS*	Rufiji DSS	Difference is significant ($P < 0.05$)	Total
Number of households	1,252 (100%)	1,064 (100%)		2,318
Average number of individuals	3.5	4	Y	3.8
Education of head of household†				
None	165 (13%)	545 (53%)	Y	710 (31%)
Less than primary	396 (32%)	147 (14%)		543 (24%)
Completed primary	589 (47%)	287 (29%)		876 (38%)
More than primary	98 (8%)	52 (4%)		150 (7%)
Religion of the household head‡				
Christian	868 (69%)	82 (8%)	Y	950 (41%)
Muslim	365 (29%)	983 (92%)		1348 (58%)
Traditional	18 (2%)	0 (—)		18 (1%)
Other	2 (—)	0 (—)		2 (—)
Household receives income from source other than farming	179 (14%)	299 (28%)	Y	478 (21%)
Roof construction is manufactured	325 (26%)	389 (37%)	Y	714 (31%)
Wall construction is manufactured	489 (39%)	15 (1%)	Y	504 (22%)
Eaves present	130 (10%)	102 (10%)	N	232 (10%)
Female headed household	231 (18%)	236 (22%)		467 (20%)
Average amount spent on malaria prevention	153 Tsh	1100 Tsh	Y	588 Tsh
Mosquito nets	114 Tsh	1048 Tsh	Y	543 Tsh
Households with at least one parasitemic member	566 (45%)	433 (41%)	Y	999 (43%)
Households with at least one member reporting malaria or fever in the previous two weeks	346 (28%)	290 (27%)	N	636 (27%)
Number (%) of households in				
Most poor	335 (27%)	259 (24%)	N	594 (26%)
More poor	184 (15%)	150 (14%)		334 (14%)
Poor	238 (19%)	230 (22%)		468 (20%)
Less poor	257 (20%)	210 (19%)		467 (20%)
Least poor	238 (19%)	215 (21%)		453 (20%)
Household PCA score (average)	−0.140	0.164	Y	0

* Includes parts of Kilombero and Ulanga Districts.
† Compares percentages of those completed primary education or higher to those who have not.
‡ Compares percentage of households that are Christians in the DSSs.

the time of interview and parasitemia, which both peaked in Quintile 2 (More poor). For parasitemia, this peak in Quintile 2 was driven by the Rufiji DSS population sample, whereas for location of the household, both Ifakara DSS and Rufiji DSS populations showed this trend.

Impact of socioeconomic status on malaria. For the first stage regression, the instruments used for socioeconomic status were the length of time the household head had lived in the area, earning an income from a non-farming source, and sex and education level of the household head. Education level of the household head was not associated with parasitemia and therefore was used as an instrument. Correlations between socioeconomic status and the instruments ranged between 0.08 and 0.24. Regressing the household's PCA score by the instruments produced R^2 values of 0.11, but at a high significance level ($P < 0.001$) for all variables. The F statistic for the model was 70.78, indicating that, although the instruments were weak, they were not weak enough to distort inference on the structural parameters in the second stage model.[19] Post-regression estimates confirm that these variables were not significantly associated with the error term from the probit regression ($P > 0.05$). These findings indicated that these four variables satisfy the conditions to be instruments for socioeconomic status.

TABLE 2
Average and range of PCA scores by socioeconomic quintile

Quintile	Number of households	Average PCA score	Range of PCA scores
Most poor	594	−1.68	−2.74, −1.52
More poor	334	−1.05	−1.49, −0.92
Poor	468	−0.45	−0.88, −0.17
Less poor	467	0.48	−0.13, 1.06
Least poor	453	2.94	1.09, 8.36

Table 4 outlines the results of the regression, in which 7 of the 12 items are significantly associated with parasitemia. Socioeconomic status was negatively and significantly associated with malaria parasitemia. Once all other variables were controlled for, a one-unit increase in a household's PCA score (the equivalent of, for example, acquiring an iron or a manufactured floor) was associated with a four percentage point decrease in malaria parasitemia ($P < 0.01$). Age and use of a mosquito net the night before interview were both also negatively and significantly associated with malaria parasitemia. Surprisingly, insecticide treatment of mosquito nets was not significantly associated with parasitemia, once all the other variables were controlled for. A separate analysis was conducted using only those individuals who reported sleeping under a mosquito net to see if the association with insecticide treatment was being subsumed by the use of a mosquito net. In this analysis (results not shown), insecticide treatment of a mosquito net remained insignificant.

The number of people living in a household was positively associated with malaria, and each additional person was associated with a two percentage point increase in malaria parasitemia, all other things being equal. Of the housing construction features, only wall construction was associated with carrying parasites. Controlling for wall construction (to determine if the effect of roof construction and eaves was being subsumed by wall construction) did not change the sig-

TABLE 3
Characteristics of individuals in the sample

Characteristic	Socio economic status group					Significant differences between		
	Most poor	More poor	Poor	Less poor	Least poor	Quintiles	study sites	Total
Number of individuals	1,726	1,036	1,645	1,608	1,640			7,657
Average age (years)	27	24	23	22	21	Y*	N	23
Under 5 years (%)	19	22	21	20	19	N	N	20
Location = farm	15	25	23	20	8	Y	Y	18
Mosquito net (%)	37	45	48	51	69	Y	Y	50
Treated (%)	7	13	16	20	34	Y	Y	18
Eaves (%)	6	4	6	6	20	Y	Y	9
Manufactured roof (%)	17	16	20	30	69	Y	Y	31
Manufactured walls (%)	12	15	16	22	41	Y	Y	21
Ave. number of individuals in the house†	4.5	4.7	5	5.1	5.2	Y	Y	4.9
Amount spent on malaria prevention (Tsh)†	199	311	579	651	1293	Y	Y	651
Parasitemia (%)	24	26	22	22	17	Y	Y	22
Under five parasitemia (%)	37	42	34	31	21	Y	N	33

* We used the Satterthwaite *t* test to determine whether the difference between most poor and least poor is significant because there were too many observations for ANOVA calculations.
† These averages were determined at the individual level, not the household level, and so are different to the figures reported in Table 1.

nificance of these variables (results not shown). The household's location at the time of interview (whether at their farm or village homes) was associated with parasitemia, and those residing at their farms were more likely to be parasitemic than those at their village houses, all other things held constant. Controlling for housing features, for example, by running the regression with only individuals with manufactured roofs and walls, resulted in location of interview being insignificant. Running the regression with only individuals without manufactured roofs and walls resulted in location of interview being highly significant. These additional results indicated that, if a house was well constructed, location was not associated with parasitemia. The amount spent on malaria prevention in the month before the interview was surprisingly positively associated with malaria parasitemia, although the effect was not significant ($P = 0.078$). The knowledge that malaria is transmitted by mosquitoes was not associated with malaria parasitemia. There are significant regional differences in parasitemia, and all other things being equal, an individual in Rufiji DSS was less likely to be parasitemic than one in Ifakara DSS.

TABLE 4
Marginal effects from instrumental variable probit regression on malaria parasitemia

Item	Coefficient	*P* value
SES (PCA score)	–0.04	0.012
Age (years)	–0.01	< 0.001
Location of household (farm = 1, village = 0)	0.05	0.001
Used mosquito net on the night before interview	–0.05	0.007
Net was treated in the 6 months before interview	0.02	0.292
Amount spent on malaria prevention in the previous month	0.00001	0.078
Manufactured roof	0.01	0.785
Manufactured walls	–0.04	0.017
Eaves	0.01	0.562
Number of people living in the house	0.02	< 0.001
Knowledge that malaria is transmitted by mosquitoes	0.01	0.461
Region dummy	–0.11	< 0.001
Number of individuals in sample	7,260	
Wald χ^2	757	< 0.001

Impact of malaria on socioeconomic status. Households were matched on the following variables, all of which were significantly associated with a household's PCA score: whether they received an income from non-farming sources, age, education level, religion, and sex of the head of the household, the length of time the household head had lived in the area, the number of people living in the house, and region (Rufiji DSS or Ifaraka DSS). A limit of four matches was allowed for each individual. Sex of the household head, the length of time the household head had lived in the area, and being Christian were negatively associated with a household's PCA score, and the rest were positively associated with a household's PCA score. Correlations between household PCA score and the matching variables ranged between –0.09 and 0.24.

The estimated effect of being parasitemic was a decrease in PCA score of 0.32 units, with a SE of 0.05, and was statistically significant ($P < 0.001$). As a comparison, the SD for PCA scores was 1.87. This suggests that the effects are of a sizable magnitude.

DISCUSSION

The aim of this paper was to show that dual causation may exist between malaria infection and socioeconomic status at the household level and to quantify the associations between the two variables in a rural developing country context. The application of novel statistical approaches (instrumental variable probit regressions and matching estimators) to the data set provided convincing evidence that socioeconomic status and malaria infection influence one another and that the association occurs in both directions, which suggests dual causation. Although the statistical methods used in the analysis were able to show causation in either direction, they were unable to identify which direction of causation was stronger; this is because the units they produce for evaluation do not closely align and therefore do not lend themselves to comparison.

Although this was the first study to show evidence for dual causation between malaria and socioeconomic status at the household level, it was, however, not the first study to show the association in either direction. There have been many studies looking at the impact of socioeconomic status on malaria, the results of which have been inconclusive. Those that found a positive association between malaria prevalence and socioeconomic status include studies by Clarke and others[20] and Koram and others[21] in The Gambia, by Tshikuka and others[22] in the Congo, and by Henry and others[23] in Cote d'Ivoire. Those that found no association between malaria prevalence and socioeconomic status include the Africa-wide study of Filmer,[24] the study of Biritwum and others[25] in Ghana, and the study of Schellenberg and others[26] in Tanzania. Interestingly, Mensah and Kumaranayake[27] found a positive association between malaria prevalence and socioeconomic status in Benin. The differences in results across the studies were difficult to explain, until a closer examination of the papers revealed that the method of classifying malaria was different between the two groups of papers. Studies using self-report of malaria or fever have not found socioeconomic status to be associated with malaria, whereas studies that used parasitemia (including this study) have found that socioeconomic status is negatively associated with malaria. Studies that report both self-report of malaria and laboratory confirmation of parasitemia are rare, but two were found for review. The study of Uzochukwu and Onwujekwe[28] from Nigeria found that, whereas there were no significant socioeconomic differences in malaria reporting, significant socioeconomic differences existed in laboratory-confirmed parasitemia. An earlier study from Ifakara and Rufiji DSS[29] undertook a similar analysis and found that individuals in the poorest third were significantly more likely to be parasitemic but not to report malaria or fever in the 2 weeks before interview. Wagstaff[30] noted that the use of subjective indicators for health inequalities, for example, self-report of illness in the previous 2 weeks, is likely to introduce bias because better-off individuals are more likely to report worse health than the poor. In their review of Livings Standards Measurement Surveys from five developing countries, Baker and van der Gaag[31] found that self-report of illness or injury within the previous 4 weeks did not follow distinctive patterns across socioeconomic status quintiles and that, in four of the five countries, the prevalence of illness or injury was highest in the Least poor and Less poor quintiles. If better-off individuals were to report ill health more frequently than poorer individuals, any associations between socioeconomic status and true malaria prevalence would be impossible to determine, because higher (lower) socioeconomic status individuals would over (under) report prevalence.

In looking at the impact of malaria parasitemia on socioeconomic status, Audibert and others[32] found in Cote d'Ivoire that malaria was a barrier to property accumulation and that in areas where malaria was highest, property accumulation (livestock, durable goods, and agricultural equipment) was lowest. Also in Cote d'Ivoire, Girardin and others[33] found that farmers lost an average of 8–9 days over a 10-month period because of malarial illness. Overall, malaria accounted for 58% of all the time that the farmers stayed at home because of disease or injury. When farmers were stratified between those ill with malaria for 0–2 days and those for > 2 days during the study period, it was found that marketed cabbage yields were 47% lower, and gross margins (profits before costs) were 53% lower in the higher morbidity group. When farmers were sick for only a few days during critical periods of a single cabbage production cycle, it resulted in huge losses of yields, and consequently, revenues.

Taking both sides of influence together, and thus potential dual causation, it is possible that households are trapped in reinforcing cycles. On the one hand, low socioeconomic status households experience high malaria prevalence, which in turn maintains their low socioeconomic status. On the other hand, high socioeconomic status households are able to prevent malaria infection, which allows them to maintain their high socioeconomic status. Conceptualizing such a relationship between these two variables has important implications, particularly for poverty alleviation strategies. First, the presence of dual causation indicates that poverty alleviation strategies should incorporate malaria preventive and treatment activities to appropriately address poverty in malaria-endemic settings. The findings of this study suggest that malaria is a cause of poverty; as such, poverty interventions should adequately incorporate this relationship into their models and designs. Second, the presence of dual causation may offer new points of intervention in the poverty cycle. In a framework that incorporates dual causation, malaria prevention and treatment would actually be considered poverty alleviation strategies rather than as health interventions per se.

Mosquito nets again proved to be protective against malaria parasitemia at the study sites. A large-scale insecticide-treated bed net social marketing campaign was implemented in Kilombero and Ulanga Districts in 1997 and is still ongoing. Several papers have provided evidence of the efficacy of mosquito nets and insecticide treatment of mosquito nets in reducing parasite prevalence and malaria-related health outcomes.[34,35] In Rufiji DSS, households are spending a considerable amount on mosquito nets, suggesting that the community recognizes the protective effects of mosquito nets. The large difference in spending may also be a catch-up phase, because the history of net availability and current net use in the communities varies significantly. Surprisingly, insecticide treatment of mosquito nets is not significantly associated with malaria prevalence in the sample. In settings of low or exclusively seasonal malaria transmission, earlier work[20] has established that untreated mosquito nets were sufficient to reduce malaria parasitemia. Regular insecticide treatment is generally more important in areas of intense perennial malaria transmission, and treatment within 6 months substantially improves the public health benefit of using a net.[36] In addition, it is likely that reporting of insecticide treatment of mosquito nets was not accurate; that is, that nets reported as treated were not in fact treated or had been retreated > 6 months ago. Erlanger and others[37] assayed insecticide content on mosquito nets collected in Kilombero and Ulanga Districts. They found only 20% of net owners reported having treated their net within 12 months, and most of these nets had a lower insecticide content than would have been expected. The authors concluded that reported insecticide use correlated poorly with measurable insecticide on nets collected from households.[37]

Of the housing construction features, only wall construction was significantly associated with malaria parasitemia, supporting findings from studies in several countries.[38,39] The insignificance of roof construction features was surprising, particularly given findings from studies showing the importance of both roof and wall construction[40–43] and of roof construction on its own.[44,45] A review by Lindsay and others[46] of studies on the association between eaves and malaria prevalence/mosquito numbers indicated that only three of seven studies found the association significant.[38,44,47] An important methodologic difference between this study and the others is the use of multivariate analysis, which allows for tests of associations to be conducted while other variables of interest are controlled for. The findings from this study indicated that once wall construction is controlled for, roof construction and eaves are not significantly associated with malaria parasitemia. Further work needs to be done in this area to determine the role that eaves may play in reducing malaria transmission.

Other studies have also found that various proxies for crowding in houses have been associated with malaria prevalence, including number of people in the house,[27,48] the number of rooms available for sleeping,[44] and the number of people per sleeping room.[21,38] The positive association between malaria parasitemia and the amount that a household spent on malaria prevention in the previous month was unexpected (although this finding was just beyond significance, it requires some consideration). It makes sense, however, that spending on malaria prevention activities would increase at the time of peak malaria transmission, the rainy season, which is when the survey was conducted. It also makes sense that a household's willingness to pay for malaria prevention would be positively associated with a previous (perhaps recent) bout of malaria. Additionally, a large share of preventive spending was on mosquito nets, and the direct effect of mosquito nets on parasitemia is already controlled for in the regression.

Although the findings from this study are clear, several limitations must be borne in mind when evaluating their significance. First, the data were collected in only one season; as such, seasonal differences in any of the variables studied (in particular, malaria prevalence) will not have been accounted for. The cross-sectional design of the study also limits our ability to infer causality, despite the intriguing findings that suggest socioeconomic status and malaria infection mutually influence one another. Although longitudinal data would be ideal for studying the relationship between socioeconomic status and malaria, financial and logistic constraints made a cross-sectional design much more feasible. Second, the two sites in the study are relatively homogeneous; they are both relatively poor rural sites. Before definite conclusions can be drawn from these results, they must be replicated in other settings, for example, relatively wealthy rural areas and urban areas. Third, in looking at some individual and household features that may influence malaria parasitemia prevalence, many individual and environmental features fell beyond the scope of the study. Features such as host immunity and transmission rates were not available for the study sample. Although this information would have been useful in further understanding the etiology of disease, it would not have added to our understanding of the relationship between socioeconomic status and malaria infection. However, the high levels of immunity likely to be found in such a highly endemic setting would have made it difficult to show an association between these two variables. The variables included in the analysis covered many potential mechanisms by which socioeconomic status and malaria could act on each other, yet the analysis still found a direct relationship between them.

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