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THE HOUSEHOLD-LEVEL ECONOMICS OF USING PERMETHRIN-TREATED BED NETS TO PREVENT MALARIA IN CHILDREN LESS THAN FIVE YEARS OF AGE

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Abstract. We measured the two-week household-level economic impact of insecticide (permethrin)-treated bed nets (ITNs) used to prevent malaria among children less than five years of age in Asembo, Kenya. The ITNs induced a two-week reduction of 15 Kenyan shillings (KSH) (U.S. \$0.25; $P < 0.0001$) in health care expenditures, but a statistically insignificant 0.5 day ($P = 0.280$) reduction in household time lost due to caring for sick children. The equivalent annual threshold cost was estimated at U.S. \$6.50 (95% confidence interval = 3.12–9.86). If the actual purchase price and maintenance costs of ITNs were greater than this threshold, then households would pay more than they would save (and vice-versa). Both seasonal effects and number of children per household had larger impacts than ITNs on health care expenditures and time lost from household activities. Health care expenditures by a household without ITNs and one child were only 32 KSH per two weeks (U.S. \$0.50; $P = 0.002$), leaving little opportunity for household-level, ITN-induced direct savings. The widespread adoption of the ITNs will therefore probably require a subsidy.

INTRODUCTION

Gallup and Sachs[1] recently reargued that malaria and poverty are intimately connected and estimated that in 1995, countries with intensive malaria had income levels that were 33% lower than similar countries without malaria. In sub-Saharan Africa, the 1998 average annual per capita gross national product was approximately U.S. \$1 per person per day.[2] Such poverty is an important constraint when considering options to prevent and effectively treat cases of malaria. Four trials in sub-Saharan Africa conducted in the 1990s demonstrated that the potentially cheap technology of insecticide (permethrin)-treated bed nets (ITNs) can reduce malaria-related mortality in children by approximately 15–33%.[3–6]

This paper is part of a series of papers[7] reporting results from a fifth trial of ITNs, this time in an area in western Kenya with intense year-round transmission of malaria. Even though the results from this trial showed that the use of the ITNs can reduce infant mortality and morbidity,[8,9] the poverty of Africa makes it essential to consider the economics of using the ITNs. Several studies[10–15] have examined the economics of using ITNs in Africa (see Goodman and Mills[16] for a review), but most considered ITN use from either a societal or government program perspective and often did not consider the resources saved when a case of malaria is prevented (i.e., did not calculate net costs). Aikins and others[13] provide one of the few cost-effectiveness studies, from a societal perspective, to measure and calculate net costs associated with using ITNs. Brinkmann and Brinkmann[17] produced cost-benefit analyses of ITNs using a household perspective. However, their model used previously published data as opposed to conducting a statistical analysis of prospectively collected data. Only two studies[18,19] have considered the household-level contingent valuation (willingness-to-pay)[20] for ITNs, and one study examined the household-level willingness-to-pay for insecticide impregnation.[21] Mills[22] noted the lack of studies with a household perspective when she wrote that it is ". . . common to find [economic] studies neglecting consideration of household costs, yet these may influence strongly each household's willingness to participate in a [ITN] programme."

We therefore analyzed prospectively collected data to determine to what extent the use of ITNs reduced household-level health care expenditures and time lost from important activities (e.g., work in the fields) due to caring for sick children.

MATERIALS AND METHODS

Economic perspective and conceptual model. We examine from the perspective of the household the costs and benefits of using ITNs to reduce morbidity among children less than five years of age. Although the use of ITNs reduced the mortality by approximately 23.5% among infants 1–11 months old,[9] the project was too short-term to effectively measure the household-level economic impact of such reduced mortality. Some investigators[23,24] have used the human capital approach to value an infant death. Such a valuation, however, is essentially a societal-level assumption, not an actual measurement of household-level lost resources. Unfortunately, it would take a long time, perhaps even decades, to accurately measure exactly how families changed their resource allocations, and number of pregnancies, in response to ITN-induced reductions in infant mortality rates.

Since the bed nets were impregnated, distributed, and re-impregnated free of charge by research project personnel, we had no local market prices for either the bed nets or their maintenance (re-impregnation). Thus, we could only calculate the household-level threshold cost as defined in the following equation:

Household-level threshold $\text{cost}_{\text{bed net+maintenance}}$ =

ITN-related reductions in direct household medical costs + value of ITN-related reduction in time lost from household activities due to caring for sick children

If the actual market-based bed net purchase price and maintenance costs were greater than the calculated threshold, then the households would pay more than they would save (and vice-versa). Since we collected data covering two-week periods only, we initially calculated a threshold cost for a two-week use of ITNs. We then estimated an annual threshold cost by multiplying the two-week period threshold by a factor of 26. Since the calculated threshold values covered a period of two weeks or one year, we did not discount any costs or benefits.[20]

ITN trial. The details of the design and execution of the trial are provided by Phillips-Howard and others.[7] Briefly, data reported in this paper were collected from the Asembo area (Bondo district) in Kenya on the eastern shore of Lake Victoria. The area has intense year-round risk of malaria transmission, and a person living in Asembo could have 60–300 malaria-infected mosquito bites per year.[12] In 1996, Asembo had approximately 55,000 people living in 79 villages. Through a public lottery, all households in 40 of these villages were identified to receive free ITNs sufficient to cover all sleeping spaces at an initial coverage ratio of 1.34 persons (all ages) per ITN. The polyester bed nets (Siamdutch Mosquito Netting Co., Bangkok, Thailand) were treated with permethrin insecticide (55% Peripel®; AgrEvo, Berlin, Germany) such that each bed net received approximately 500 mg/m^2 of insecticide. The project protocol included free insecticide re-treatment of bed nets at approximately six-month intervals. Households in the control villages were given ITNs at the end of the project in early 1999.

Cross-sectional surveys. We used data collected from cross-sectional surveys conducted 14 and 22 months (February–March and November–December 1998, respectively) after ITNs were distributed (see ter Kuile and others[8] for details). The two surveys used a simple random sampling method with households as the sampling unit. Before the February–March survey, 60% of all households in the villages were randomized to participate in either the first or the second survey. This design ensured that a household would only participate in one survey. In the first survey, children less than 36 months old were selected for clinical examination, while the economic questionnaire referred to all children less than five years old in the household. For the second survey, all children less than five years of age were invited for the clinical examination. To avoid bias, we excluded households from the second survey data set who only had children older than 36 months.

Educational data and health care expenditures. The interviews collected information on the number of persons and ages of all the children in the household. The education levels achieved by both the caretaker and the head of household were also recorded. Because even experienced health care professionals can find if difficult to correctly diagnose malaria, interviewers asked for all health care expenses for all illnesses related to treating children less than five years of age in the two weeks prior to the interview. Expenses were categorized as follows: medicines; doctor or clinic fees; laboratory (e.g., needles, syringes, tests); traditional healer (for fees, herbs, etc.); and other items such as travel costs associated with obtaining health care. Respondents were asked to place a monetary value on any items given in barter for goods or services related to health care for sick children.

Time lost from household activities. Respondents were asked to list up to two persons who, during the two weeks prior to the interview, looked after any sick children. The answers were coded into one of the following options: mother, father, grandparent, aunt, co-wife, sibling, and other. The respondents were then asked to list up to two main activities that the caretaker missed while caring for sick children, with the answers coded into one of the following groups: work in fields (*shamba*); house; market selling; salaried work; school (for caretaker); and other. Respondents were also asked to estimate, in days and half days, the total amount lost from the activities missed due to caring for sick children less than five years of age. Finally, respondents were asked if they paid, and how much they paid, a non-household member to do some of the activities that a household member missed due to caring for a sick child.

Wealth index. A rural household in Africa typically receives income in the form of cash and bartered goods and services, which can vary by season (see Ettling and others[25] for examples of income diversity). Furthermore, as Onwujekwe and others found in Nigeria,[18] respondents might be unwilling to provide satisfactory data about household income. Thus, as a proxy for household income available to pay for health care, we constructed a household-level wealth index. The wealth index contains a valuation of the material used to construct the roof and walls of the house, the value of a selection of household durable goods (radio, bicycle, sofas, lanterns), and livestock (cattle, goat, sheep, chickens, and donkeys). These items represent both medium-to-long term household-level investments (e.g., $\geq$ 3–10 years), and a wide range of acquisition costs. Information on variability of ownership between households was also included in the index. Appendix 1 contains further details related to the construction of the index, plus an index constructed using data collected during a baseline survey conducted just before the bed nets were distributed (February–March 1996).

Distances to nearest clinic. Hand-held global positioning units were used to obtain spatial co-ordinates of all the households and clinics in the survey. These data were then analyzed using geographic information systems software (ArcView, Version 3.2, 1999; Environmental Systems Research Institute, Inc., Redlands, CA) to provide measurements of the linear distance in meters from a household to the nearest clinic.

Chronic conditions. Chronic health problems, such as anemia and stunted growth, can be caused by factors other than malaria and be an important reason for parents to seek health care for their children. We thus measured hemoglobin levels in the children, and defined any child with a hemoglobin level $<$ 7.0 g/dL to have severe anemia.[8] Underweight and stunted growth was evaluated using weight-for-age and height-for-age scores, respectively. If a child had either a height-for-age or a weight-for-age score that was $>$ 2 standard deviations smaller than the relevant age-adjusted standardized mean, then that child was classified as stunted or underweight, respectively.[8]

Statistical analyses. *Basic models.* After producing descriptive statistics of each variable, we analyzed the data using two regression models. The first model had total household health care expenditures on sick children less than five years of age in a two-week period as the dependent variable. The other model had as the dependent variable the total time lost from activities (e.g., working in the fields, housework) by adults and siblings in a two-week period due to caring for a sick child less than five years of age.

Each model considered the impact of the following variables upon the dependent variable: presence/ absence of

ITNs; number of children less than five years of age in the household; the presence of one or more children in the household with severe anemia, underweight, or stunted growth; the total years of education completed by the caregiver and head of household; average age of children who are less than 30 months of age (this identified households with only very young children); household wealth index; distance from household to nearest clinic; and, survey (first or second).

The intercept term from each regression equation represents the amount spent (or time lost from activities) by a baseline household. The baseline household for both models was a household without ITNs, one child between 30 months and 5 years of age, household-level health care expenditures (or time lost for activities) recorded during the November–December 1998 survey, and the caregiver and head of household having completed more than 20 years of education (>12 years when time lost was the dependent variable). The impact of each variable is then added or subtracted (depending on the sign of the coefficient) to the amount spent (or time lost) by the baseline household.

The data describing both the total household-level expenditures on health care and the time lost from activities were very skewed and non-normal. We could not transform these data, so that they had normally distributed values with homogenous variances, preventing us from applying standard linear regression techniques.[26] We thus used the non-parametric technique of quantile regression (Stata software; Stata Corp., College Station, TX) in which we minimized the sum of absolute residuals using the median values of the variables.[26,27] In linear regression, coefficients for the independent variables are estimated so that sum of the squared residuals is minimized, i.e., min $\sum(y_i - \hat{y}_i)^2$, where $\hat{y}_i$ is the estimated value of the dependent variable (at the i th observation) using the values of the coefficients for the independent variables. In quantile regression, we minimize the sum of absolute residuals as follows: min $\sum |y_i - \xi(x_i, \beta)|$, where $\xi(x_i, \beta)$ is the linear function of the independent variables such that the coefficients (β) minimize the difference. See Kennedy[26] and Koenker and Hallock[27] for details.

Ethical considerations and informed consent. The project protocol was reviewed and approved by the institutional review boards of the Kenya Medical Research Institute (Nairobi, Kenya) and the Centers for Disease Control and Prevention (Atlanta, GA). Written informed consent was obtained from caretakers for each participating individual and household.

RESULTS

A total of 1,591 household were surveyed in February–March 1998 (826 households) and November–December 1998 (765 households). Descriptive statistics of households are given in Table 1. Of note is the relative poverty, with the mean wealth index ranging from KSH 35,863 to KSH 42,788 (approximately U.S. $600–U.S. $700) (Table 1). The lower end of this range is equivalent to one thatch and mud plus wood pole house, one cow, one sofa, and a bicycle (see Appendix 1).

Amounts spent on health care costs. Most (64–76%) of the households reported health care expenditures on children in the two-week period covered by the surveys (Table 2). The

TABLE 1

Characteristics of the sample population of households (HHs) by survey and use of insecticide (permethrin)-treated bed nets (ITNs)*

Variable	First survey: Without ITNs (n = 411)	First survey: With ITNs (n = 415)	Second survey: Without ITNs (n = 364)	Second survey: With ITNs (n = 401)
% HHs with 1 child < 5 years old	45	50	50	51
% HHs with 2 children < 5 years old	41	40	42	42
% HHs with 3 children < 5 years old	13	11	7	6
% HHs with 4 children < 5 years old	1	0	0	1
Average age of children in HH (months)†	18	18	24	22
% HHs in which average age of children ≤30 months	88	88	68	76
% HHs with ≥1 child with Hb level < 7 g/dL (anemic)‡	17	10	9	7
% HHs with ≥1 child with WAZ 2 SD from mean§	23	19	32	28
% HHs with ≥1 child with HAZ 2 SD from mean¶	25	24	36	32
Average years of schooling (5th, 95th)#	16 (7; 24)	15 (4; 23)	15 (7; 24)	16 (4; 23)
Average distance (5th, 95th): house to clinic (meters)**	1,914 (307; 3,678)	2,434 (886; 4,089)	1,997 (317; 3,835)	2,418 (1,021; 3,960)
Average HHs wealth index (KSH) (5th; 95th)††	35,863 (32,413; 39,313)	39,493 (35,595; 43,391)	42,788 (38,410; 47,167)	41,636 (37,045; 46,227)

* The first survey was conducted during February–March, 1998, and the second survey was conducted during November–December, 1998.
† Average in months of the household-level average age of children who are ≤5 years old.
‡ Percentage of households that had ≥1 child < 5 years of age, with a hemoglobin (Hb) level < 7 g/dL, defined in this study as marked anemia. See Materials and Methods for further details.
§ Percentage of households that had ≥1 child < 5 years of age with a weight-to-age Z-score (WAZ) that was 2 standard deviations less than the normalized mean for the appropriate age group (Z-score).
¶ Percentage of households that had ≥1 child < 5 years of age with a height-to-age Z-score (HAZ) that was 2 standard deviations less than the normalized mean for the appropriate age group (Z-score).
# Average total number of years of schooling reported to have been completed by the primary caregiver and the head-of-household (with 5th and 95th percentiles).
** Average distance (5th and 95th percentiles) from the house to the nearest clinic, measured in meters.
†† Average household-level wealth index, in Kenyan Shillings (KSH) (with 5th and 95th percentiles). On March 26, 1998, U.S. $1 = KSH 60.11 (KSH 1 = U.S. $0.017). On March 26, 1999, U.S. $1 = KSH 64.75 (KSH 1 = U.S. $0.015). See Materials and Methods and Appendix 1 for further details of how this index was constructed.

TABLE 2

Amounts (KSH) reported spent by households on treating sick children < 5 years of age in a two-week period: Amounts by category of expenditure, survey, and use of insecticide (permethrin)-treated bed nets (ITNs)*

Variable*	First survey: Without ITNs (n = 411)	First survey: With ITNs (n = 415)	Second survey: Without ITNs (n = 364)	Second survey: With ITNs (n = 401)
Median cost of medicine (KSH)*	18	13	8	5
% purchasing medicine	61	61	55	54
If buying medicine, average KSH spent	75	53	58	62
Median cost of lab items (KSH)*†	0	0	0	0
% paying for lab items†	3	1	7	2
If paying for lab items, average KSH spent†	52	88	41	31
Median cost of doctor fees (KSH)*	0	0	0	0
% paying doctor fees	26	22	21	15
If paying doctor fees, average KSH spent	167	164	189	167
Median cost of traditional healer fees (KSH)*‡	0	0	0	0
% paying traditional healer fees‡	17	15	10	7
If paying traditional healer fees, average KSH spent‡	85	87	37	50
Median cost of other items (KSH)*§	0	0	0	0
% paying for other item§	27	16	7	3
If paying for other items, average KSH spent§	187	134	141	83
Median total amount spent on treating sick children (KSH)*	55	40	30	12
% paying > 0 KSH for treatment¶	76	75	70	64
If paying average total KSH spent	202	140	127	103

* KSH = Kenyan Shillings. On March 26, 1998 U.S. $1 = KSH 60.11 (KSH 1 = U.S. $0.017). On March 26, 1999, U.S. $1 = KSH 64.75 (KSH 1 = U.S. $0.015). The median estimates of costs refer to expenditures for all illness, calculated using entire sub-sample. The first survey was conducted during February–March, 1998, and the second survey was conducted during November–December, 1998.

† Lab items refers to items such as syringes, latex gloves, etc., as well as any laboratory tests that the doctor may order and charge separately.

‡ Although anecdotal evidence suggests that many traditional healers in southern and eastern Africa now readily accept and even demand cash payments, many transactions with such healers are still paid in the form of goods (such as chickens) or services. Both surveys attempted to account for any goods or services bartered in the two weeks prior to the interview in exchange for a healer's services by asking the respondents to place a KSH value on the items that they exchanged.

§ Other items: respondents were asked to place a KSH value on items such as food and travel costs spent as part of treating a sick child, < 5 years of age, in the two weeks prior to the interview.

¶ The % of respondents reporting a total > KSH 0 spent in treating a sick child < 5 years of age is not equal to the sum of the five categories of expenditures (medicine, doctors fees, lab items, traditional healers, and other items). This is because many respondents reported expenditures in more than one category, while some reported expenditures in only one category.

two most common expenditure categories were medicines (54–61% reporting) and clinic fees (15–26% reporting). Among those households that reported paying for health care, clinic fees represented more than 80% of those expenditures (Table 2). A relatively low number of households reported paying traditional healer fees (7–17%) (Table 2). The frequency distributions of the total household health care expenditures over a two-week period (both surveys combined) for sick children less than five years of age are clearly non-normal (Figure 1). This implies that the mean expenditure is not very representative of the typical household expenditure on health care for children.

Productivity losses due to caring for a sick child. When listing two persons who cared for sick children, approximately 90% first identified mothers, and approximately 45% mentioned "other" when listing a second caregiver. When listing two household activities missed while caring for sick children, approximately 60% of respondents identified field work (*shamba*) as their first choice. Market selling and other were the most commonly listed second activity. Most (67–75%) of the households reported an average of 5–6 days of household activities lost (Table 3). Only 3–5% of interviewed households reported paying a non-household member to do activities missed by a household member who was caring for a sick child (Table 4). We were unable to determine if the paid labor completely replaced all the household-reported time lost from activities. The frequency distributions of the total household time over a two-week period (both surveys combined)

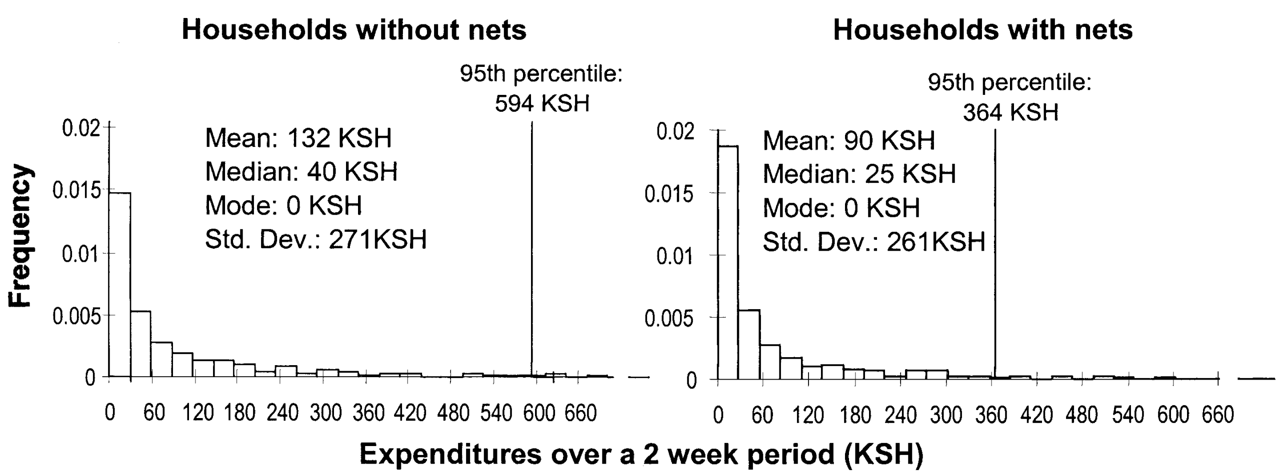

FIGURE 1. Distribution by intervention status of total household expenditures (Kenyan Shillings [KSH]) on health care for children less than five years of age during a two-week period. On March 26, 1998, U.S. $1 = KSH 60.11 (KSH 1 = U.S. $0.017). Std. Dev. = standard deviation.

TABLE 3

Time in days missed from activities reported by those identified as caring for a sick child < 5 years of age during the two weeks prior to the interview*

Variable	First survey: Without ITNs (n = 411)	First survey: With ITNs (n = 415)	Second survey: Without ITNs (n = 364)	Second survey: With ITNs (n = 401)
Median reported time lost (days)	4	3	7	7
% reporting time lost	75	74	67	65
If time lost, average total time lost (days)†	5	5	6	6

* The first survey was conducted during February–March 1998, and the second survey was conducted in November–December 1998. Amounts are by survey and use of insecticide (permethrin)-treated bed nets (ITNs).
† Average time reported lost just for those who actually reported time lost (i.e., not averaged across the entire sample).

lost from activities while caring for sick children less than five years of age are also non-normal (Figure 2).

Multivariate regression of household health care expenditures. Variables that had a P value > 0.25 were defined as statistically insignificant and removed from the final model examining household-level health care expenditures. The variables removed were those defining the presence of underweight or stunted children or severe anemia, the household wealth index, and distance from house to nearest clinic. In the final model (Table 5), the baseline household (no ITNs, one child, and caregivers with more than 20 years of education) had median health care expenditures of KSH 32 (95% confidence interval [CI] = 12–52, P < 0.002). In contrast, a household with no ITNs, four children, and caregivers who had less than 20 years of education, and whose expenditures were measured during the first survey (February–March) would spend a median of KSH 94 (Table 5). The presence of ITNs was associated with a median reduction in baseline costs of KSH 15 (95% CI = 23–7, P < 0.0001) (Table 5). All remaining variables, except the variable labeled average age of children in household ≤ 30 months, had a larger impact on health care expenditure than ITNs (Table 5). The regression had a pseudo R^2 of 0.03, indicating that there was a great deal of variability unexplained by the estimated coefficients.

Multivariate regression models of time lost from activities. Variables that had a P value > 0.28 were defined as being statistically insignificant and removed from the final model examining time lost from household activities due to caring for sick children. The variables removed were the same as those removed from the health care expenditure model (see previous section). The baseline household (no ITNs, one child, and caregivers with less than 12 years of education) lost five days (95% CI = 3.4–6.6, P < 0.0001) from activities while caring for a sick child (Table 6). The largest median number of days lost was 7.5 days, occurring among households with no ITNs, four children, and caregivers having less than 12 years of education (Table 5). The presence of ITNs reduced this loss by an average of 0.5 days (95% CI = −1.4–0.4), but this was not statistically significant (P < 0.262) (Table 6). The single most important determinant of time lost from activities was time of survey. Time lost during the first survey was 2.5 days less (95% CI = −3.7 to −1.3, P < 0.0001) than time reported lost during the second survey (Table 6). The regression procedure for time lost had a pseudo R^2 of 0.04.

Household level economic threshold. Because there was no statistically significant ITN-induced reduction in time lost from activities, our calculated two-week, household-level threshold price for bed net and maintenance consists of only the ITN-related reductions in health care expenditures of KSH 15 (95% CI = KSN 23–7). Using 1998 exchange rates, this is approximately equivalent to U.S. $0.25 per two-week period (95% CI = U.S. $0.38–$0.12), or the equivalent of U.S. $6.50 for a 12-month year (95% CI = U.S. $3.12–$9.86).

DISCUSSION

In 1996, few stores in the Asembo area sold bed nets. Since then, possibly because of the ITN trial, more stores are selling both the bed nets and insecticides for impregnation. We conducted an informal survey in March 2002 and found that the unsubsidized cost for a 4′ × 6′ net ranged from KSH 310 to KSH 650 (U.S. $3.90–$8.23) and that for a 6′ × 6′ net ranged from KSH 450 to KSH 960 (U.S. $5.70–$12.15). Single-treatment tablets of insecticide cost KSH 66.50–117 (U.S. $0.84–$1.48). These estimates are similar to other reports. Mills[22] reviewed cost-of-net data and reported a range of U.S. $4–$49 with a mode of U.S. $10–$15 (1995 prices).

TABLE 4

Amount paid (KSH) in a 2-week period to non-household members to take over activities while household members cared for sick children < 5 years of age*

Variable	First survey: Without ITNs (n = 21)	First survey: With ITNs (n = 9)	Second survey: Without ITNs (n = 11)	Second survey: With ITNs (n = 14)
Average amount (KSH/day)†	346	185	132	231
Median amount (KSH/day)†	300	115	100	95
Median reported time lost (days)†‡	3	4	4	4

* The first survey was conducted during February–March, 1998, and the second survey was conducted during November–December, 1998. Amounts are by survey and use of insecticide (permethrin)-treated bed nets (ITNs) KSH = Kenyan Shilling.
† The average and median amounts are calculated just from those household reporting payment to non-household members to do household-related activities while household members look after a sick child. We were unable to obtain an estimate of the number of days that the non-household members actually worked. A plausible upper limit would be the number of days reported lost by household members while caring for a sick child.
‡ Median time reported lost by those identified as caring for a sick child < 5 years of age and whose households also reported paying a non-household member to do some of the household-related activities.

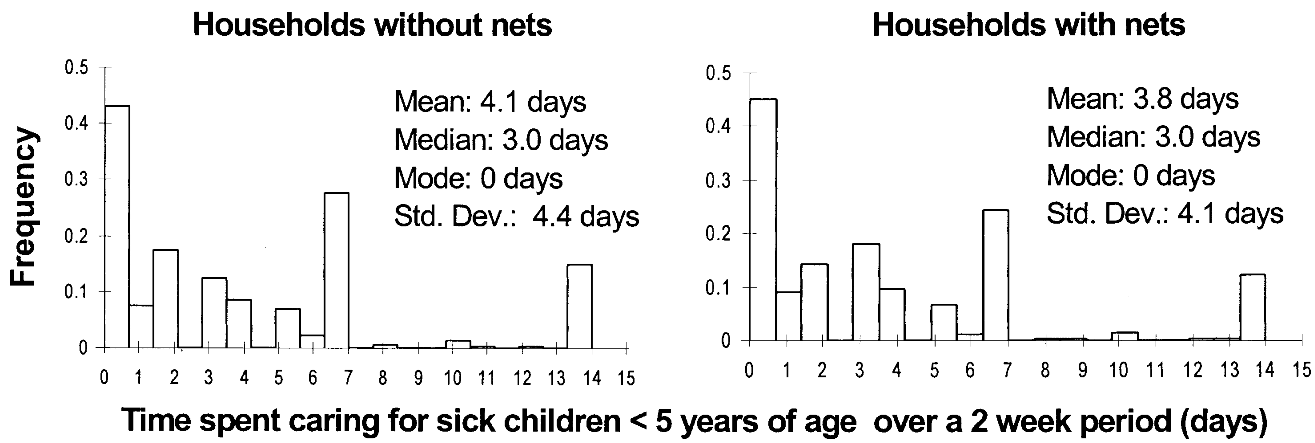

FIGURE 2. Distribution by intervention status of total household time spent taking care of sick children less than five years of age during a two-week period. Std. Dev. = standard deviation.

The review of Brinkmann and Brinkmann[17] found the cost of a net ranged from U.S. $3.00–$72.00, with the annual cost of insecticide impregnation ranging from U.S. $0.50 to U.S. $2.00 (apparently in 1992 and 1993 prices). Nuwaha[28] recently reported that in Uganda, unimpregnated bed nets cost approximately U.S.$6–$12, and impregnated nets cost U.S. $12–$18.

During the trial, each ITN-using household had an average of 2.2 ITNs. Using the prices from our informal survey, this is equivalent to an annual (undiscounted) cost of U.S. $6.49–$12.54 per household if they only use 4′ × 6′ nets. (U.S. $3.80 × 2.2 nets per household)/3-year net life + [U.S. $0.84 per tablet × 2.2 nets × 2 treatments per year] = U.S. $6.49 per year. The U.S. $12.54 per year estimate was calculated in a similar manner using the largest costs. Differences in net size, number of nets, actual net life, and number of annual insecticide treatments may alter actual costs. These estimates are very similar to those estimated by Brinkmann and Brinkmann,[17] who calculated annual household-level costs to range from U.S. $2.98 to U.S. $13.60 (averaged over three years, with nets lasting between 1.3 and 6 years). If one compares these costs to our estimated threshold of U.S. $6.50 per year, the most optimistic assessment of the household-level impact of the ITNs is that, if ITNs saved households money, the savings would likely be less than U.S. $1.00 per year (i.e., approximately breakeven). It is quite probable that the annual household-level cost of bed nets and their maintenance will actually be greater than what a household would save from ITN-induced reductions in malaria-related health care expenditures. The threshold may have been increased (increasing the probability of saving money) if we had measured any reductions in expenditures and time lost due to adults being ill. Conversely, we calculated our threshold using data from a controlled trial. The effectiveness of ITNs in a non-experimental setting may well be lower than what we measured due to lower levels of coverage and adherence to proper use, and less efficient net maintenance and re-impregnation. Lower levels of effectiveness will reduce the threshold level, making savings more unlikely. Seasonal effects may also reduce the threshold.

TABLE 5

Total household expenditures (KSH) on health care for children < 5 years of age during a two-week period: impact of insecticide (permethrin)-treated bed nets (ITNs), total years of education of caregivers, number and average age of children, and survey period*

Variable†	Type of variable	Impact on cost (KSH)‡	5th, 95th% Confidence intervals	P
Dependent variable				
Total household expenditures children's health care§				
Independent variables				
Baseline¶	Continuous	32	12, 52	<0.0001
Had ITN	Binary	–15	–23, –7	<0.0001
Caregiver plus HH had < 20 years of education	Binary	–25	–43, –7	<0.0001
Had 2 children in household	Binary	20	12, 28	<0.0001
Had 3 children in household	Binary	30	–1, 61	0.06
Had 4 children in household	Binary	62	–96, 220	0.441
Average age of children ≤30 months	Binary	13	5, 21	<0.0001
Expenditure during 1st survey (Feb–Mar 1998)	Binary	25	17, 33	<0.0001

* KSH = Kenyan Shillings. On March 26, 1998, U.S. $1 = KSH 60.11 (KSH 1 = U.S. $0.017). On March 26, 1999, U.S. $1 = KSH 64.75 (KSH 1 = U.S. $0.015). The first survey was conducted during February–March, 1998, and the second survey was conducted during November–December, 1998. Regression coefficients were estimated after 1,500 iterations using 1,495 observations. Raw sum of deviations from the median = 152,997. Minimum sum of deviations from the median = 148,744. "Pseudo" R^2 = 0.03. HH = head of household.

† The following variables were dropped from the final equation: One or more children in household with a critical weight-for-age Z-score, one or more children in household with a critical height-for-age Z-score, one or more children in household with a hemoglobin level < 7 g/dL, indicating marked anemia, household wealth index, and distance from house to clinic. See Results for further details.

‡ Impact refers to the baseline household, with the presence of each subsequent variable adding or subtracting to the value of the baseline.

§ Expenditures related to all illnesses, not just malaria-induced.

¶ Baseline refers to households with no ITNs, one child < 5 years of age, the caregiver and head of household had > 20 years of education between them, using data collected in second survey (Nov–Dec 1998).

TABLE 6

Reported time lost from work and household activities due to caring for a sick child in a two-week period: Impact of insecticide (permethrin)-treated bed nets (ITNs), total years of education of caregivers, number and average age of children, and survey period*

Variable†	Type of variable	Impact on days lost‡	5th, 95th% Confidence intervals	*P*
Dependent variable				
Total time lost due to caring for sick children				
Independent variables				
Baseline§	Continuous	5	3.4, 6.6	<0.0001
Had ITN	Binary	–0.5	–1.4, 0.4	0.262
Caregiver plus HH had ≤ 12 years of education	Binary	1	0.0, 2.0	0.044
Had 2 children in household	Binary	0.5	–0.4, 1.4	0.28
Had 3 children in household	Binary	1	–0.2, 2.2	0.106
Had 4 children in household	Binary	1.5	–0.4, 3.4	0.123
Average age of children ≤30 months	Binary	1	–0.1, 2.1	0.073
Time lost during first survey (Feb–Mar 1998)	Binary	–2.5	–3.7,–1.3	<0.0001

* If respondents reported a sick child in the household during the two weeks prior to the interview, they were asked what activities did the caregiver(s) miss because of the illness and how much total time, in days or half days, was lost from activities. The first survey was conducted during February–March, 1998, and the second survey was conducted during November–December, 1998. Regression coefficients were estimated after 1,500 iterations using 1,182 observations. Raw sum of deviations from the median = 3,797. Minimum sum of deviations from the median = 3,662. "Pseudo" R^2 = 0.04. HH = head of household.

† The following variables were dropped from the final equation: One or more children in household with a critical weight-for-age Z-score, one or more children in household with a critical height-for-age Z-score, one or more children in household with a hemoglobin level < 7 g/dL, indicating marked anemia, household wealth index, and distance from house to clinic. See Results for further details.

‡ Impact refers to the baseline household, with the presence of each subsequent variable adding or subtracting to the value of the baseline.

§ Baseline households had no ITNs, one child < 5 years of age, and the caregiver and head of household had > 12 years of education between them, using data collected during the second survey (Nov–Dec 1998).

Two reasons why we measured such a low threshold cost were that we could not find a significant reduction in time lost from activities, and that the households in the study are very poor. The poverty of the households is demonstrated by the fact that many households have very few, or none, of the items included in the wealth index (see Appendix 1). Poverty is also demonstrated by considering the fact that baseline households typically spent very little, in absolute terms, on children's health care: the baseline household spent U.S. $0.50 (95 CI = U.S. $0.20–$0.87) per household per two-week period.

The idea that the use of ITNs would not result in savings is not unique. Aikins and others,[13] using a societal perspective, found that the use of ITNs in The Gambia resulted in a net cost, regardless of the type of outcome used for evaluation (e.g., child-death averted, child-illness averted, life year gained, per capita economic impact). Brinkmann and Brinkmann[17] estimated that the use of ITNs in Malawi and Cameroon would result in a net savings to a household. However, they obtained their estimates from a model that combined data from a variety of sources and contained a number of assumptions. In contrast, we obtained our results from statistical analyses of prospectively acquired data. One assumption that they made that was notably different from our study was that ITNs would reduce the average number of episodes of malaria in a Malawian household (average size = 3 adults and 1.3 children) from 21.4 to 8.6 episodes per year (4.6 fewer cases in children and 1.9 fewer cases in adults). We did not measure the impact of the ITNs on adults in the households. Furthermore, although we measured a statistically significant, ITN-associated reduction in clinical malaria of approximately 44%, that measurement had 95% CIs of 6–66%.[8] Brinkmann and Brinkmann did not allow for such a large variance in reduced morbidity. Another assumption that they made was that each reduced episode would save the household from losing 1.2 days of activities due to caring for a sick child. We did not find, by direct measurement, any statistically significant, ITN-induced reduction in the time lost from activities due to caring for sick children.

Perhaps one of our most important economic findings was that the use of the ITNs did not impact the time lost from household-related activities due to caring for a sick child. There could be a variety of reasons for this result, including the fact that the use of ITNs was associated with rather small reductions in parent-perceived episodes of all-cause illness in children.[8]

Compared with the November–December period (the second survey), parents were willing and able to spend almost double (an additional KSH 25 or U.S. $0.42) on health care in February–March (Table 5). Additionally, in February–March, they cut in half (by 2.5 days) the amount of time spent caring for sick children in November–December (Table 6). Thus, compared with November–December, during the February–March period, households substituted resources spent on health care for time lost from activities such as working in the fields. The reason for this substitution is that January–March is when household members, both male and female, are busy preparing the land (plowing) and planting crops in anticipation of the long rainy season that typically occurs from March through May.[29] During the two periods surveyed, households thus allocated their resources in a manner that indicated that returns to labor in the field were likely to be greater in February–March. Note that this argument does not rely on actual productivity, which may be affected by variations in rainfall, and income from the field (which we did not measure). Rather, the argument rests on the potential for returns from labor-based investment. In agricultural production, farmers have to invest a great deal of labor in terms of preparing the field, etc., before they know what the returns will be. Mwabu,[30] who collected data on the impact of malaria in eastern Kenya, also noted a seasonal difference in the value of time, with labor in the wet season being valued three times more than labor in the dry season.

Another important aspect of the seasonal effect is that it was larger than any ITN-related impact on household economics. Furthermore, there may be more than one seasonal effect. Although malaria is transmitted year-round in the Asembo area,[31] the risk of contracting malaria decreases (but does not disappear) during the drier seasons (e.g., June and July). We did not conduct a survey during the drier season, but it is possible that there may be a decrease in the household-level impact of malaria during the drier season. If this were true, then the estimated threshold value of $6.50 (annual equivalent) may be too high, making it even more probable that households will not save resources if they use ITNs.

Notable seasonal variations in the household-level impact of malaria can have important policy implications. For example, Mills and others,[21] when conducting a willingness-to-pay study for insecticide used to impregnate bed nets in The Gambia, noted that ". . . . where malaria transmission is seasonal, impregnation is required just before the rainy season, which is when households are likely to be most short of cash." Public health policy makers may have to concede, therefore, that the amount that households can pay for any malaria intervention is likely to vary with the seasons. Thus, large-scale marketing of ITNs and other malaria interventions will probably have to adjust the prices of the intervention(s) to match the amount that the parents will be willing (or able) to pay in the drier season (i.e., subsidize the bed nets or the insecticide or some combination). Other investigators have also noted the need for some subsidization to improve the adoption rate of insecticide-impregnated bed nets.[12,13,15,18,19,21,28,32,33]

In summary, the ITN trial in Asembo, western Kenya has demonstrated that permethrin-treated bed nets can significantly reduce malaria-related mortality and morbidity in children.[8,9] The data in this report have shown that most of the people living in Asembo are very poor, and spend very little, in absolute terms, on children's health care. Thus, there is very little opportunity for the households to save money by using ITNs. National and international public health agencies should acknowledge that the widespread adoption and appropriate use of the ITNs will probably require a subsidy, allowing for seasonal effects.

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REFERENCES

1. Gallup JL, Sachs JD, 2001. The economic burden of malaria. *Am J Trop Med Hyg 64(Suppl):* 85–96.
2. The World Bank, 2000. *African Development Indicators 2000.* Washington, DC: The World Bank.
3. Habluetzel A, Diallo DA, Esposito F, Lamizana L, Pagnoni F, Lengler C, Trarore C, 1997. Do insecticide-treated curtains reduce all-cause child mortality in Burkina Faso? *Trop Med Int Health 2:* 855–862.
4. Nevill CG, Some ES, Mung'ala VO, Mutemi W, New L, Marsh K, Lengeler C, Snow RW, 1996. Insecticide-treated bednets reduce mortality and severe morbidity from malaria among children on the Kenyan coast. *Trop Med Int Health 1:* 139–146.
5. Binka FN, Kubaje A, Adjuik M, Williams LA, Lengeler C, Maude GH, Armah GE, Kajihara B, Adiamah JH, Smith PG, 1996. Impact of permethrin impregnated bednets on child mortality in Kassena-Nankana district, Ghana: a randomized controlled trial. *Trop Med Int Health 1:* 147–154.
6. D'Alessandro U, Olaleye BO, McGuire W, Langerock P, Bennett S, Aikins MK, Thomson MC, Cham MK, Cham BA, Greenwood BM, 1995. Mortality and morbidity from malaria in Gambian children after introduction of an impregnated bednet programme. *Lancet 345:* 479–483.
7. Phillips-Howard PA, ter Kuile FO, Nahlen BL, Alaii JA, Gimnig JE, Kolczak MS, Terlouw DJ, Kariuki SK, Shi YP, Kachur SP, Hightower AW, Vulule JM, Hawley WA, 2003. The efficacy of permethrin-treated bed nets on child mortality and morbidity in western Kenya. II. Study design and methods. *Am J Trop Med Hyg 68 (Suppl 4):* 10–15.
8. ter Kuile FO, Terlouw DJ, Phillips-Howard PA, Hawley WA, Friedman JF, Kolczak MS, Kariuki SK, Shi YP, Kwena AM, Vulule JM, Nahlen BL, 2003. Impact of permethrin-treated bed nets on malaria and all-cause morbidity in young children in an area of intense perennial malaria transmission in western Kenya: cross-sectional survey. *Am J Trop Med Hyg 68 (Suppl 4):* 100–107.
9. Phillips-Howard PA, Nahlen BL, Kolczak MS, Hightower AW, ter Kuile FO, Alaii JA, Gimnig JE, Arudo J, Vulule JM, Odacha A, Kachur SP, Schoute E, Rosen DH, Sexton JD, Oloo AJ, Hawley WA, 2003. Efficacy of permethrin-treated bed nets in the prevention of mortality in young children in an area of high perennial malaria transmission in western Kenya. *Am J Trop Med Hyg 68 (Suppl 4):* 23–29.
10. Goodman CA, Coleman PG, Mills A, 1999. Cost-effectiveness of malaria control in sub-Saharan Africa. *Lancet 354:* 378–385.
11. Picard J, Aikins M, Alonso PL, Armstrong Schellenberg JRM, Greenwood BM, Mills A, 1993. Cost-effectiveness of bed net impregnation alone or combined with chemoprophylaxis in preventing mortality and morbidity from malaria in Gambian children. *Trans R Soc Trop Med Hyg 87(Suppl 2):* 53–57.
12. Binka FN, Mensah OA, Mills A, 1997. The cost-effectiveness of permethrin impregnated bednets in preventing child mortality in Kassena-Nankana district of northern Ghana. *Health Policy 41:* 229–239.
13. Aikens MK, Fox-Rushby J, D'Alessandro U, Langerock P, Cham K, New L, Bennett S, Greenwood B, Mills A, 1998. The Gambian national impregnated bednet programme: Costs, consequences and net cost-effectiveness. *Soc Sci Med 46:* 181–191.
14. Goodman CA, Mnzava AEP, Dlamini SS, Sharp BL, Mthembu DJ, Gumede JK, 2001. Comparison of the cost and cost-effectiveness of insecticide-treated bednets and residual house-spraying in KwaZulu-Natal, South Africa. *Trop Med Int Health 6:* 280–295.
15. Evans DB, Azene G, Kitigia J, 1997. Should governments subsidize the use of insecticide-impregnated mosquito nets in Africa? Implications of a cost-effectiveness analysis. *Health Policy Plann 12:* 107–114.
16. Goodman CA, Mills AJ, 1999. The evidence base on the cost-effectiveness of malaria control in Africa. *Health Policy Plann 14:* 301–312.
17. Brinkmann U, Brinkmann A, 1995. Economic aspects of the use of impregnated mosquito nest for malaria control. *Bull World Health Organ 73:* 651–658.
18. Onwujekwe O, Chima R, Shu E, Nwagbo D, Okonkwo P, 2001. Hypothetical and actual willingness to pay for insecticide-treated nets in five Nigerian communities. *Trop Med Int Health 6:* 545–553.
19. Cropper ML, Haile M, Lampiett JA, Poulos C, Whittington D, 2001. *The Value of Preventing Malaria in Tembien, Ethiopia.* Washington, DC: The World Bank.

20. Messonnier M, Meltzer MI, 2002. Cost-benefit analysis. Haddix A, Teutsch S, Corso P, eds. *Prevention Effectiveness.* Second edition. Oxford, United Kingdom: Oxford University Press, 127–155.
21. Mills A, Fox-Rushby J, Aikins M, D'Alessandro U, Cham K, Greenwood B, 1994. Financing mechanisms for village activities in The Gambia and their implications for financing insecticide impregnation. *J Trop Med Hyg 97:* 325–332.
22. Mills A, 1998. Operational research on the economics of insecticide-treated mosquito nets: lessons of experience. *Ann Trop Med Parasitol 92:* 435–447.
23. Shepard DS, Ettling MB, Brinkmann U, Sauerborn R, 1991. The economic cost of malaria in Africa. *Trop Med Parasitol 42 (Suppl 1):* 199–203.
24. Sauerborn R, Shepard DS, Ettling MB, Brinkmann U, Nougtara A, Diesfeld HJ, 1991. Estimating the direct and indirect economic costs of malaria in a rural district of Burkina Faso. *Trop Med Parasitol 42 (Suppl 1):* 219–223.
25. Ettling M, McFarland DA, Schultz LJ, Chitsulo I, 1994. Economic impact of malaria in Malawian households. *Trop Med Parasitol 45:* 74–79.
26. Kennedy P, 1992. *A Guide to Econometrics.* Third edition. Cambridge, MA: The MIT Press.
27. Koenker R, Hallock K, 2000. Quantile regression: An introduction. Available online at: www.econ.uiuc.edu/~roger/research/intro/intro.html.
28. Nuwaha F, 2001. Factors influencing the use of bed nets in Mbarara municipality of Uganda. *Am J Trop Med Hyg 65:* 877–882.
29. Alaii JA, van den Borne HW, Kachur SP, Shelley K, Mwenesi H, Vulule JM, Hawley WA, Nahlen BL, Phillips-Howard PA, 2003. Community reactions to the introduction of permethrin-treated bed nets for malaria control during a randomized controlled trial in western Kenya. *Am J Trop Med Hyg 68 (Suppl 4): 128–136.*
30. Mwabu GM, 1988. Seasonality, the shadow price of time and effectiveness of tropical disease control programs. Herrin AN, Rosenfield PL, eds. *Economics, Health and Tropical Diseases.* Manilia, The Philippines: School of Economics, University of the Philippines, 259–270.
31. Beier JC, Oster CN, Onyango FK, Bales JD, Sherwood JA, Perkins PV, Chumo DK, Koech DV, Whitmire RE, Roberts CR, 1994. *Plasmodium falciparum* incidence relative to entomologic inoculation rates at a site proposed for testing malaria vaccines in western Kenya. *Am J Trop Med Hyg 50:* 529–536.
32. Schellenberg JR, Abdulla S, Nathan R, Mukasa O, Marchant TJ, Kikumbih N, Mushi AK, Mponda H, Minja H, Mshinda H, Tanner M, Lengeler C, 2001. Effect of large-scale social marketing of insecticide-treated nets on child survival in rural Tanzania. *Lancet 357:* 1241–1247.
33. Cham MK, Olaleye B, D'Alessandro U, Aikins M, Cham B, Maine N, Williams LA, Mills A, Greenwood BM, 1997. The impact of charging for insecticide on the Gambian national impregnated bednet programme. *Health Policy Plann 12:* 240–247.

APPENDIX: THE CONSTRUCTION OF A WEALTH INDEX

INTRODUCTION

In observing the impact of insecticide-impregnated bed nets upon household-level healthcare expenditures, the level of household income may dictate the level of initial, or non-bed net, healthcare expenditures. We hypothesized that relatively poorer people may save less as a result of using bed nets simply because they are too poor to spend very much on healthcare without the bed nets. Thus, in our statistical analysis of the data recording the levels of healthcare expenditure with and without bed nets, we wished to control for differing levels of household income. A rural household in Africa, however, typically receives "income" in the form of cash and bartered goods and services. Further, the sources of cash, goods, and services can vary widely by household and season. The seasonal and irregular nature of this income make it very difficult to actually measure a household's income. Faced with difficulties in recording income, we chose to construct an index representing the wealth of a household. We then used this index as a proxy for measuring the impact of available income upon healthcare expenditures in households with and without bed nets.[1]

METHODS

Objectives. For a variety of reasons, we did not have the resources to conduct an exhaustive inventory of each household's possessions. Thus, our objective in constructing a wealth index was to record the presence of a limited number of items owned by a household. The presence of these items in a household would represent the relative, but not absolute, level of wealth at the time of the interview. We wanted the items on the list, as a group, to fulfill the following criteria: 1) represent medium-to-long term investments (i.e., 3–≥10 years) with a relatively wide range of acquisition costs; 2) reflect the different decisions and opportunities regarding priorities that a household will have to make whenever they have resources to invest in household items; and, 3) have the potential for a "wide" amount of variance between each household.

The latter criterion is very important because an index without much household-to-household variance is unlikely to be statistically significant in any analysis of the impact of bed nets upon healthcare expenditures. For example, because most houses in the study area have thatch roofs, an index consisting only of a valuation of the roofing material would have almost no difference between households, and thus would not likely be statistically related to differing levels of healthcare expenditures. Roofing material is, however, a good "candidate" for inclusion in a multi-item index because it does reflect a relatively large household-level investment (criterion 1). Further, the amount spent on roofing (e.g., metal versus thatch) is a choice that can impact other important household investment decisions—save money on the roof and purchase some goats is an example of such decisions.

Data sources. At the beginning of 1996, a large-scale trial in the Asembo Bay area of western Kenya was started to test the impact of insecticide-impregnated bed nets on malaria-associated morbidity and mortality among children < 5 years of age.[2] One of the first tasks of the project team was to conduct a baseline census. This census was conducted in February–March 1996, and included questions that can be used to construct an index of relative wealth.

Definition of household and compound: units of analysis. Because bed net use by children is likely to be overseen by the child's mother, the bed net project's primary unit of observation was the subunit within a family compound termed "household." This household is usually a wife and her children and any other children in her care. A family compound, then, is made up of a number of households. When considering the resources available to a family to prevent and treat malaria in children, both household and compound are of interest. In the initial census, 6,751 compounds comprising 18,218 households were identified and included.

Variables used to construct the index. The first two indicators used in the wealth index recorded the materials of the walls and roof of the house in which the respondent lived (e.g., brick, mud, metal, thatch). The respondent was then asked to enumerate the number of radios, televisions, bed nets, bicycles, and sofas owned (the term sofa usually means a set of furniture consisting of a small settee and two armchairs; however, some respondents may have given the number of individual armchairs). The final set of data used in the wealth index concerned the numbers of cattle, goats, sheep, and donkeys owned by the respondent's family on the day of the interview. This group of items satisfied our criteria 1 and 2 for inclusion into the wealth index.

Since 98.5% of households did not own a television set, the data collected regarding television ownership were excluded from the index (i.e., the item failed criterion 3). The census survey collected data on two different types of radios, differentiating between those with one or two speakers. Because the latter are more expensive, it is assumed that ownership of the two-speaker radio was an indicator of status and wealth. However, since less than 8% of households reported owning a two-speaker radio, ownership of both types of radios were combined into a single variable.

The questionnaire also included questions concerning the ownership of the house (rented, owned, "borrowed"), and if rented, for how long. However, less than 5% of households reported renting their houses, with over 95% of respondents stating that they either owned or "borrowed" their houses. Since occupancy and ownership of land and dwellings in rural Africa are often not clearly defined by the exchange of monetary instruments and legal documents such as title deeds, valuing ownership of dwelling was excluded from the analysis. Instead, we included in the wealth index the equivalent cost of constructing a dwelling.

Valuing roofs and walls. A local building contractor (Omir M, personal communication, February 1997) was asked to provide separate estimates for placing a metal or thatch roof on a 12′ by 15′ dwelling, as well as constructing the exterior walls, with one internal partition, using either brick and cement or wooden poles and mud. The contractor supplied lists and local market prices of materials for each job using February 1997 prices (Kenya shillings [KSH]). Also supplied were estimates of the amount of labor required for each job, broken down into skilled worker-days and helper days. An owner wanting a metal roof or a brick walled house will typically employ a skilled local contractor (a "fundi" in local terms) and his helpers, often in the ratio of two skilled workers to one helper. Labor inputs for these jobs were valued at February 1997 local market prices.

An informal survey of some local residents confirmed that, as is typical in much of sub-Saharan Africa, most thatch roofs, wooden pole, and mud walls are constructed by the owner with help from friends, family, and neighbors. Friends and neighbors donate their time in the expectation of reciprocal help in the future, or as "payment" for help given to them earlier. The person whose roof or walls are being built is also typically expected to provide food and drink to the helpers, often in a post-construction party setting. Given the difficulty of finding convincing alternative "shadow prices" for the labor used in these constructions, it was decided to value the labor used in these projects using the same rate for the metal roof and brick walls.

Valuing household goods. A brief survey of shops in Kisumu, the nearest substantive-sized town to the Asembo area, was conducted to provide a range of prices for radios (one speaker with cassette-tape player), Kenyan-made bicycles, and locally made sofa sets. To avoid being quoted inflated prices, a local employee was used to obtain most of the quotes.

Valuing livestock. From July through December 1997, and in January and February 1998, four local markets in the Asembo area were surveyed once each month to obtain a list of local prices for produce, including the market price for one adult female goat and one adult cow. The average price of a cow was then used to value each cow and donkey reported in the bed net census, and the average price of the goat was used to value each recorded goat and sheep.

Constructing an index of relative wealth. The list of items included in the wealth index owned by each household were valued and then summed together to provide the wealth index for that household. Note that we did not adjust the value of any item for age and condition, since that would have required additional interview time and enumerator training. The indices for individual households were then aggregated to a compound level. Descriptive statistics for individual items as well as the indices were then calculated.

Ethical considerations and informed consent. The project protocol was reviewed and approved by the institutional review boards of the Kenya Medical Research Institute (Nairobi, Kenya) and the Centers for Disease Control and Prevention (Atlanta, GA). Written, informed consent was obtained from caregivers for each participating individual and household.

RESULTS

Livestock. The most notable feature regarding livestock ownership is that a large percentage of the livestock counted in the census is owned by a relatively small proportion of households. Of the 36,296 head of livestock reported on the day of census (Table 1), approximately 46% of these animals were owned by 5.4% of households surveyed. The 75th percentile was two head of livestock per household, which was also the mean (Table 1), and approximately 64% of households reported owning none of the four species recorded (median and mode of "all livestock" = 0 head, Table 1).

The distribution of livestock was also very skewed at the compound level. Although the mean number of head per compound was 5.38 head, the median and the mode are 3 and 0 head, respectively (Table 2). Seventy-five percent of the compounds own seven or less head of livestock, and account for approximately 29% of all livestock in Asembo (Table 3). Approximately 14% of the compounds owned 48% of all livestock (Table 3).

Dwellings. Sixty-five percent of all households had a house made with mud walls and a thatch roof, 20% had mud walls

TABLE 1

Number of livestock per household in Asembo, Kenya, 1996: descriptive statistics*

Type	Total all HH†	Numbers per household				
		Mean	Median	Mode	SD	Maximum
Cattle	18,697	1.03	0.00	0.00	2.37	45
Goats	10,521	0.58	0.00	0.00	1.74	30
Sheep	6,035	0.33	0.00	0.00	1.43	33
Donkeys	1,043	0.00	0.00	0.00	0.35	8
All livestock‡	32,926	1.99	0.00	0.00	4.49	78

* N = 18,218.
† HH = households.
‡ All livestock = sum of cattle, goats, sheep, and donkeys.

and a tin roof, and 14% had brick walls and a tin roof. Less than 1% had brick walls and a thatch roof. The mean number of dwellings per compound was 2.7 (SD = 1.81), with the median and mode both equal to 2. The 25th and 75th percentiles of the number of dwellings were equal to 1 and 3, respectively (Table 4). Note that the storehouses and other buildings were not recorded.

Household goods. Seventy percent of all households and 46% of all compounds reported owning no radios. Thirty-two percent of all compounds reported owning one radio, and an additional 14% owned two radios. Sixty-eight percent of all compounds reported owning no sofas, while 6% and 8% had one and two sofas, respectively. Some 0.5% of the compounds reported owning seven or more sofas; the maximum reported was 20 sofas. Thirty-one percent of all compounds reported owning one bicycle, while 12% reported owning two or more bicycles, and 76% reported owning no bicycle.

Wealth index. Table 5 provides the valuations of the items used to construct the wealth index. Note that the KSH 15,000 value of a metal roof is approximately equal to the value of an entire traditional house (thatch roof and mud and wooden pole house) (Table 5). The 15,200 total index value of a traditional house is equal to the mode of the wealth index for both the household and compound level (Table 6). For both household and compound levels, there is approximately a 7.5 fold difference between the 20th and 90th percentiles of the wealth index (Table 6).

DISCUSSION

The most striking feature from this data set is the relative poverty of a large proportion of households and compounds. The median number of houses per compound was approximately 2 (Table 4), which have a minimum index value of KSH 30,400 (wooden poles, thatch roof, Table 5). This would leave a maximum of KSH 47,200, from the median compound-level index of KSH 77,600 (Table 6). This is less than the value of four cows (Table 4), demonstrating that many compounds do not have a great number of items included in the index.

It is true that the wealth index did not include a number of other items, such as beds and lanterns, that could have met the three criteria for inclusion (listed earlier). The wealth index could have also been refined by making adjustments for age and condition of each item included in the index. Expanding the list of items and adjusting their values for age and condition, however, would have considerably lengthened the time needed for interviewing a household. Adjusting values for age and condition for a wide variety of items (e.g., cattle and radios) would have required extensive additional training of the enumerators and a validation procedure to ensure that such adjustments were being conducted in a uniform manner.

Perhaps the most important limitation of the wealth index is that it does not measure a family's cash flow, which may be the single most important factor affecting a household's decision to purchase health care. Nonetheless, anecdotal evi-

TABLE 2

Number of livestock* per compound in Asembo, Kenya, 1996: descriptive statistics†

Item	Head
Mean	5.38
Median	3.00
25th percentile	0.00
75th percentile	7.00
Mode	0.00
Standard deviation	8.03
Maximum	103.00

* Livestock = sum of cattle, goats, sheep, and donkeys.
† N = 6,751 compounds.

TABLE 3

Frequency of livestock* by compound† in Asembo, Kenya, 1996

Number of head per compound	Cumulative % of compounds	Cumulative % of livestock
0	32.7	0.0
1	39.1	1.2
2	48.1	4.5
3	55.6	8.7
4	62.3	13.7
5	67.7	18.7
6	72.4	23.9
7	76.1	28.8
8	79.2	33.4
9	81.9	37.9
10	84.9	43.0
11	86.2	52.0
>12	100.0	100.0

* Livestock = sum of cattle, goats, sheep, and donkeys.
† N = 6,751 compounds.

TABLE 4

Descriptive statistics and frequency of number of houses by compound* in Asembo, Kenya, 1996

Item	Statistic
Mean number of houses	2.7
Mode number of houses	2.0
Standard deviation	1.8
Maximum number of houses	24.0
Frequency of houses	Cumulative %
1	26.5
2	56.1
3	76.5
4	88.0
5	93.3
6	96.4
7	97.9
8	98.7
9	99.2
>10	100.0

* N = 6,751 compounds.

TABLE 5

Equivalent values in Kenyan shillings (KSH)* used to construct a wealth index in the Asembo area, Kenya, 1997

Item	Subtotals KSH	Totals KSH
Roofs†		
Thatch		6,030
Material	3,730	
Labor‡	2,280	
Metal (tin)		15,000
Material	9,000	
Transport	1,550	
Labor	4,000	
Walls§		
Mud plus wood poles		9,200
Material	3,100	
Labor¶	6,100	
Brick plus cement		85,500
Material	71,500	
Transport	3,500	
Labor#	10,500	
Household goods		
Bicycles		3,750
Radio		2,500
Sofas		9,500
Livestock		
Cattle (one head, female)		8,000
Goats (one head, female)		1,000
Sheep (one head)**		1,000
Donkeys (one head)††		8,000

* On March 26, 1998, U.S. $1 = KSH 60.11 (KSH 1 = U.S. $0.017).
† Thatch and metal roof sufficient to cover a house 12′ times 15′.
‡ Roofs require 18 labor days, 12 days of expert labor ("fundis") at KSH 150/day and 6 days of an unskilled helper at KSH 80/day.
§ Walls to build a house 12′ × 15′ with one internal partition.
¶ Mud and wood pole houses require 30 expert labor days + 15 unskilled labor days, at KSH 150/day and KSH 80/day, respectively. This valuation includes values of food and entertainment traditionally provided by owner to friends and family who volunteer to help.
\# Brick and cement houses require three experts ("fundis") for 45 labor days + 15 unskilled helper days, at KSH 150/day and KSH 80/day, respectively, for a sub-total of KSH 7,950. Plastering the walls with cement requires 11 skilled ("fundi") days and 11 unskilled helper days, for a subtotal of KSH 2,530, and a total of approximately KSH 10,500.
** The value of a sheep was considered equivalent to that of a goat.
†† A donkey was valued equivalent to a female cow.

dence from the Asembo area strongly suggests it is a common practice for households to invest any surplus cash in the type of items used to construct the index. This would be typical for many parts of east and southern Africa. Thus, low levels of investment are considered indicative of compounds having relatively little "surplus" cash with which to invest. Consequently, households may not consider investments in bed nets to be their highest priority. A "typical" family has many unfilled basic needs, and purchasing those needs will compete with spending any "surplus" income on bed nets.

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TABLE 6

Calculated wealth index for Asembo, Kenya: descriptive statistics at household and compound levels

Item	Household level KSH*	Compound level KSH†
Mean	42,982	115,886
Mode	15,200	15,200
Standard deviation	43,088	126,089
Minimum	15,200	15,200
Maximum	429,200	2,554,940
Percentiles		
10th	15,200	18,950
20th	15,200	32,900
25th	15,200	39,400
30th	15,200	46,400
40th	17,700	60,370
50th	24,200	77,600
60th	28,200	100,500
70th	40,200	129,205
75th	49,450	149,413
80th	64,700	172,840
90th	107,310	247,295

* N = 18,218 households.
† N = 6,751 compounds.

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REFERENCES

1. Meltzer MI, Terlouw DJ, Kolczak MS, Odhacha A, ter Kuile FO, Vulule JM, Alaii JA, Nahlen BL, Hawley WA, Phillips-Howard PA, 2003. The household-level economics of using permethrin-treated bed nets to prevent malaria in children less than five years of age. *Am J Trop Med Hyg 68(Suppl 4):* 149–160.
2. Phillips-Howard PA, ter Kuile FO, Nahlen BL, Alaii JA, Gimnig JE, Kolczak MS, Terlouw DJ, Kariuki S, Shi YP, Kachur SP, High-tower AW, Vulule JM, Hawley WA, 2003. The efficacy of permethrin-treated bed nets on child mortality and morbidity in western Kenya: II. Study design and methods of evaluation. *Am J Trop Med Hyg 68(Suppl 4):* 10–15.