15 The demand for insecticide-treated mosquito nets: evidence from Africa

Christine Poulos, Maureen Cropper, Julian Lampietti, Dale Whittington and Mitiku Haile

15.1 Introduction

Brouwer and Koopmanschap (2000) discuss the differences between what they call the 'welfarist' and 'extra-welfarist' perspectives on economic evaluations of health interventions. The 'welfarist approach', characterized by Harrington and Portney (1987) and Berger et al. (1994), aims to embed evaluations in welfare economics. The 'extra-welfarist' approach, characterized by Cuyler (1991) and Williams (1993), aims to help decision makers maximize health from a given budget by 'replacing utility with health as the outcome of interest for evaluation' (Brouwer and Koopmanschap, 2000: 444). While Brouwer and Koopmanschap take aim at the controversial assumptions underlying welfarist evaluations, this study shows that welfarist approaches convey information about individual behavior, which has implications for both health outcomes and health budgets.

This study bridges the gap between welfarist and extra-welfarist perspectives by estimating a household demand for insecticide-treated bednets (ITNs) that allows policy makers to balance the goal of cost recovery against the desire to guarantee that a certain fraction of the population receives protection from malaria and other vector-borne diseases. ITNs have helped to reduce the incidence of malaria and other vector-borne illness in various parts of Africa (Binka et al., 1997), but their use as a health intervention raises an important policy question: should ITNs be provided privately or publicly? If they were sold privately, how many bednets would be purchased (at various prices)? This information would help public health agents balance the goals of cost recovery – which is necessary for a program to be self-sustaining – against the arguments for government subsidization of the program because of the externalities associated with the control of infectious disease.

We estimate the demand for bednets based on a survey of over 250 households in Tigray, an agricultural area characterized by seasonal, unstable malaria in the north of Ethiopia. At the time of our study, bednets were essentially unknown to households in Tigray as a method of treating malaria.[1] The Tigray Region Malaria Control Department was considering ITNs as an intervention to decrease the risk of malaria and other diseases.

To measure the demand for bednets, we asked the household head (or spouse) how many bednets he or she would purchase if they were available. This modified stated preference method asked respondents to choose the quantity of goods they would purchase at a given price, rather than their willingness to pay for a fixed quantity of good. This modification permits estimation of the household demand for bednets. Given the supply price of ITNs, the demand curve can be used to calculate the subsidy necessary to guarantee that a certain fraction of the population is protected, assuming the bednets are sold as private goods.

The demand curve can also be used to calculate the benefits of such a program if bednets are provided free of charge. While this is not a Hicksian compensated benefit measure, the area under the bednet demand curve between 0 and $n/2$ bednets (each bednet protects at least two people) approximates the compensating variation associated with purchasing n bednets.

The plan of the chapter is as follows. The household demand for bednets is derived in Section 15.2 by combining the health production model of Grossman (1972) with Becker's (1981) benevolent dictator model. Our modified stated preference method is described. Count regression models, in which the number of bednets purchased is constrained to be less than or equal to one-half family size, are used for the econometric representation of bednet demand. Section 15.3 describes the region where our survey was conducted, the status of malaria in the region, and our sample's experience with malaria. Section 15.4 contains estimates of the demand for bednets and uses the demand curve to estimate the benefits of a bednet distribution program. Section 15.5 discusses the extent to which results from Tigray can be generalized to other parts of Africa.

15.2 Theoretical model and study methodology

This section develops a model of ITN demand that combines Becker's (1981) benevolent dictator model and Grossman's (1972) health production model.[2] Becker assumes that a single individual, such as a head of household or their spouse, makes the consumption choices for the entire household. We assume that the decision maker's utility depends on the amount of a numeraire that each family member consumes (X_i), on each person's leisure time (L_i), and on the amount of time each family member is ill with malaria (S_i). Utility also depends on taste variables such as the decision maker's education, age, and gender (Z) that affect the weight he or she places on children's versus adults' consumption and of health versus other goods. Assuming n family members, utility is given by

$$U = u(X_1, \ldots, X_n, L_1, \ldots, L_n, S_1, \ldots, S_n, Z). \tag{15.1}$$

The time each family member is ill with malaria (S_i) is, in turn, a function of preventive care, such as ITNs (A_i), and treatment, such as chloroquine (M_i). How effective these inputs are depends on individual health characteristics (H_i) and, in the case of malaria, on the prevalence of mosquitoes (endemicity), E.

$$S_i = s(A_i, M_i, H_i, E). \tag{15.2}$$

The amounts of preventive care, medical care and other goods each person consumes are constrained by the household's budget

$$\sum_{i=1}^{n} I_i + \sum_{i=1}^{n} w_i(T - L_i - S_i) = \sum_{i=1}^{n} X_i + p_a \sum_{i=1}^{n} A_i + p_m \sum_{i=1}^{n} M_i, \tag{15.3}$$

where $\Sigma_{i=1}^{n} I_i$ is non-earned income, w_i is the wage of family member i and $\Sigma_{i=1}^{n} w_i(T - L_i - S_i)$ is earned income. (T is total time available to each household member.) The sum of these must equal household expenditures on consumption (the price of which is 1), use of bednets (with price p_a), and treatment (with price p_m).

The decision maker selects values of X, L, A, and M to maximize household utility subject to the budget constraint and to the health production functions. This yields a household demand function for ITNs, where A^* is the number of ITNs chosen by the decision maker

$$A^* = g(I, \mathbf{w}, p_a, p_m, \mathbf{Z}, \mathbf{H}, E). \tag{15.4}$$

This function indicates that demand for ITNs depends on household non-earned income, a vector of wages for each household member, as well as the prices of ITNs and mitigating health care, characteristics of the decision maker, baseline health of each individual, and the prevalence of the malaria vector.

The discrete nature of bednets suggests that equation (15.4) be estimated using a count data model, such as the Poisson. Since at least two people can sleep under each bednet, purchasing more than $n/2$ bednets cannot increase welfare. We estimate a truncated Poisson model which imposes the constraint that the household never purchases more than $n/2$ ITNs.

The count data were collected using a modified stated preference method in which the respondent was asked if he would purchase one or more ITNs at one of five randomly assigned prices. If the respondent answered 'yes', he was asked how many ITNs would be purchased. While this method is different than most stated preference applications, which value a fixed, exogenous quantity of the good, some prior studies have made use of data on quantities chosen by respondents. These studies fall into two categories. The first are travel cost models that estimate count regression models using data on revealed demand for recreation trips (see, Loomis et al., 2000). The second combines revealed demand with stated preference data in a joint estimation of revealed and stated preference models (see, for example, Cameron, 1992; Englin and Cameron, 1996; Jakus, 1994). Most of these applications are found in the travel cost literature.

Only one other study, to our knowledge, has asked respondents to choose quantities in a stated preference approach. Niklitschek and Leon (1996) measure stated preferences for an exogenous environmental quality improvement and stated, rather than revealed, demand for beach trips. They jointly estimate a discrete choice model and a linear travel cost model to measure household preferences for water quality improvements. Their results are used to determine beach user fees that maximize aggregate recreational benefits.

Like Niklitschek and Leon, our study will rely on stated or intended demand, but it will not implement a joint estimation. Also, recognizing the discrete nature of the data, we use count regression models to estimate a Marshallian demand function. The WTP measure from the estimated Marshallian demand function is not a Hicksian benefit measure. Willig (1976) demonstrates that, if the area to the left of the Marshallian demand function is approximately 5 per cent of money income, then the Hicksian benefit measure and the Marshallian benefit measure are within a few per cent of each other.[3]

15.3 Study site and research design

The data used to estimate the demand for ITNs were collected in 1997 in Tigray, a province in northern Ethiopia. The main activity in Tigray is subsistence farming; however, the low productivity of the soil and lack of adequate rainfall have resulted in chronic food shortages.

The climate in most of Tigray is marginally 'suitable' for malaria, meaning that malaria may follow strong seasonal cycles with great inter-annual variation (Ghebreyesus et al., 1996; MARA, 2001). In areas with this transmission pattern, malaria affects adults and children equally. Microdams, which have been constructed in Tigray to provide water for crops, have exacerbated malaria by providing a breeding ground for mosquitoes.

Approximately 900 households in 18 villages were surveyed to assess the demand for malaria prevention and to compute the medical costs and productivity losses associated with the disease.[4] The head of household or their spouse was asked to identify the symptoms associated with malaria and was asked how the disease was transmitted and how it could be prevented and treated. Respondents who were familiar with the disease were asked to describe their family's experience with malaria during the last two years.[5] This included a detailed description of the respondent's most recent malaria episode, as well as the most recent malaria episode experienced by a teenager or child in the family. These descriptions included information about treatment, treatment costs, lost work time, caretakers' time, and intra-household labor substitution.

Approximately one-third of respondents (279) living in six of the villages were asked whether they would purchase one or more ITNs for members of their family if ITNs were to become available. The bednet scenario coupled an explanation of how using a bednet reduces the probability of contracting malaria with an actual demonstration of a double-size polyester bednet impregnated with 1 per cent Deltamethrin. Respondents were then presented with information about annual re-impregnation of an ITN over its four-year expected life and were told that they could spread payments for the bednets over four months. After being reminded that other measures could be taken to prevent malaria, such as draining standing water and/or taking medicine as prophylaxis, the respondent was asked if he would purchase one or more ITNs at one of five randomly assigned prices. (Prices ranged from US$1 to US$16 per bednet.) The highest price is based on an estimate of the charge that would be needed for full cost recovery of an imported ITN. If the respondent answered 'yes', he was asked how many ITNs would be purchased. The survey ended with questions about the family's socio-economic circumstances, including education, occupation, income, assets, and housing construction. Table 15.1 shows the sample means.

Table 15.1 Means and standard deviations of variables

Variable	N	Mean	Std. Dev.	Min	Max
Log income (thousand Birr)	279	1.97	1.23	−4	4
Missing wage (1 if no wage)	279	0.39	0.49	0	1
Number of teenagers	279	0.56	0.78	0	4
Number of children	279	1.74	1.33	0	5
Household cost of illness (Birr)	279	22.26	16.45	0	97
Married (1 if married)	279	0.70	0.46	0	1
Gender (1 if female)	279	0.66	0.47	0	1
Read (1 if read easily)	279	0.53	0.50	0	1
Age (years)	279	41.04	15.04	16	80
Alt (hundred meters)	279	16.51	1.89	12	19
Household size	279	4.53	2.03	1	12

The remaining two-thirds of respondents (569) were asked whether they would purchase one or more hypothetical malaria vaccines for members of their family, if such a vaccine were to become available. These responses are analysed in Cropper et al. (1999, 2004).

15.3.1 Malaria in Tigray

Our survey was conducted in villages where malaria follows a seasonal pattern, with peak transmission occurring just before harvest (i.e., after the rainy season) and, to a lesser extent, during the rainy season. Government malaria control activities include spraying in outbreak areas, encouraging communities to drain ditches of standing water, and training volunteer community health workers to recognize and treat malaria with chloroquine.

Seventy-eight per cent of the 848 respondents in our sample said that they had been ill with malaria at some time in their lives, with 58 per cent reporting at least one episode of malaria in the last two years.[6] Fifty-three per cent of respondents said that at least one other adult in the household had experienced malaria in the last two years, and 49 per cent of respondents said that at least one child or teenager in the family had experienced the disease within the last two years.

15.3.2 Cost of illness estimates

The costs of illness (COI) measure the out of pocket expenditures[7] plus the productivity losses (proxied by lost wages)[8] associated with an episode of malaria. The COI associated with an average episode, depending on productivity assumptions, ranges from US$7 to US$24 for an adult and US$7 to US$12 for a child.[9] If we compute the COI for each household and average this value across all households (including those with no malaria), the annual per household COI ranges from US$31 (assuming productivity losses of US$1 per day) to US$9 (assuming productivity losses of US$0.5 per day).

These results are comparable with most of the other published COI estimates from areas like Ethiopia that face an unstable, seasonal malaria transmission pattern. Other studies' estimates range from US$3 in Pakistan (Kahn, 1966) to US$16 in Sri Lanka (Konradsen et al., 1997), and US$18 in Chad (Sauerborn et al., 1991). (The estimates from Pakistan are likely an underestimate because the data on the number of cases and the costs per case are taken from national statistics on the formal health care sector.)[10]

To place these numbers in context, we computed household income as the sum of the value of agricultural output, off-farm earnings, and the annualized value of farm animals. Average income is US$220 per household per year, implying that as much as 14 per cent of income is lost to malaria annually. This figure does not include the cost of activities that are undertaken to prevent the disease.[11]

15.4 Empirical analysis of ITN demand

15.4.1 Description of responses

Table 15.2 shows the number of bednets households which said they would purchase at each price. Quantity demanded is clearly sensitive to price: the percentage of households who declined to purchase nets increases from 19 per cent at a price of US$1 to 63 per cent at a price of US$16. The percentage of families who said they would buy two or more nets also declines monotonically as price rises. A rise in price from US$1 to US$3 and from US$3 to US$6, however, increases the percentage of families purchasing one net. Families who would buy two nets at a lower price would buy only one net at higher prices.

One reason for analysing bednet demand is to predict the number of households who would purchase bednets at various prices. For example, Table 15.2 can be used to predict the fraction of households who would buy a bednet at a price that would permit cost recovery. It can also be used to determine what price would induce a desired fraction of households to purchase nets. Figure 15.1 illustrates the number of bednets that would be purchased in a village of 200 households, assuming that these households have the same characteristics as those in our sample (e.g., average household size is five). At a price of US$6 per net, for example, 166 nets would be purchased. Calculating the number of people in the village who would be covered at this price requires an assumption about the number of people who sleep under a net. If this is two, then one-third of the population of the village would sleep under insecticide-treated nets at a price of US$6 per net.

15.4.2 Estimation of household demand functions for bednets

Count data models are appropriate in this case, since households buy a non-negative integer quantity of bednets. Table 15.3 presents estimates of Poisson, Negative Binomial, and Truncated Poisson models of the demand for bednets. The Truncated Poisson model imposes on the Poisson model the constraint that a household will never purchase more than $n/2$ bednets.

Table 15.2 Number of bednets purchased by price

Price (1997 US$)	0 nets	1 net	2 nets	3 or more nets
1	19%	21%	43%	17%
3	22%	33%	32%	13%
6	41%	37%	20%	2%
10	52%	23%	19%	6%
16	63%	25%	11%	2%

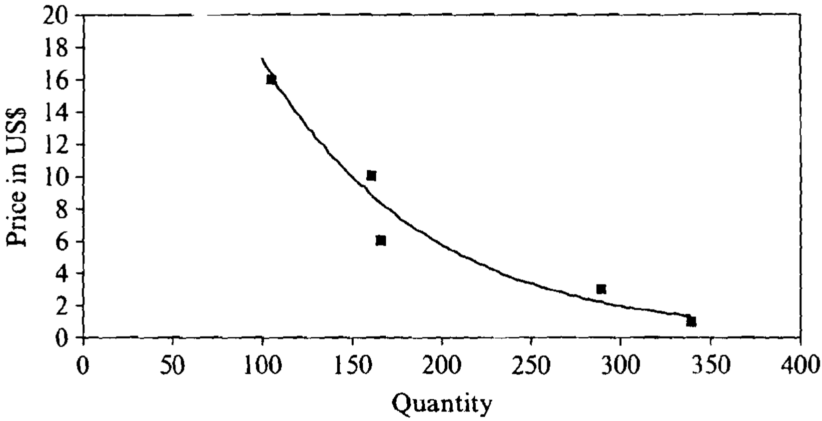

Figure 15.1 *Demand for bednets in 200 household villages in Tigray, Ethiopia*

The theoretical model described in Section 15.2 suggests that the number of vaccines purchased should depend on vaccine price, household income, and family size. It might also depend on family composition, i.e. on the number of adults, children, and teenagers in the family, and on the characteristics of the respondent – gender, age, marital status, and education – which may influence his taste for health-related goods. We measure education by whether the respondent can read a newspaper. Income, which enters the demand function in log form, is made up of three components: annual gross crop income, the annualized value of livestock holdings, and reported annual off-farm wages. Since 28 per cent of observations on off-farm wages are missing, we replace missing values with zero and then include a 'missing wage' dummy variable, equal to one if off-farm income is not reported.

The demand for the vaccine should also depend on the incidence of malaria in the area and on family members' susceptibilities to the disease. We proxy malaria incidence by village altitude. We proxy household susceptibility to malaria with a variable that measures past experience with the disease. Specifically, we sum the number of malaria episodes that members of the household experienced during the last two years, weighting each episode by the average age-specific cost of treatment. This is the household's direct COI. Household size is measured by a series of dummy variables, because the number of bednets respondents say they will purchase does not increase linearly with household size.

The only variables whose coefficients are significantly different from zero are price, income, and age of the respondent. Price is strongly significant in all three models. Income is marginally significant in the

Table 15.3 Parameter estimates for bednet models (n = 279)

Variable	Poisson	Negative binomial	Truncated poisson
Price	−0.014[a]	−0.014[a]	−0.016[a]
(Birr)	0.002	0.002	0.003
Log household income	0.093[b]	0.093[b]	0.097
(thousands of Birr)	0.059	0.059	0.075
Missing wage	0.019	0.019	0.265
(1 if no wage)	0.188	0.188	−0.132
Number of teenagers	0.116	0.117	0.118
(number)	0.109	0.109	0.147
Number of children	0.044	0.044	0.032
(number)	0.099	0.099	0.142
Household dir. cost of illness	−0.005	−0.005	−0.006
(Birr)	0.005	0.005	0.006
Married	0.045	0.045	0.022
(1 if married)	0.195	0.195	0.271
Gender	0.012	0.012	0.009
(1 if female)	0.146	0.146	0.213
Read	0.022	0.022	−0.010
(1 if read easily)	0.160	0.160	0.224
Age	−0.010[a]	−0.010[a]	−0.012
(years)	0.005	0.005	0.008
Altitude	0.067	0.067	0.082
(hundreds of meters)	0.038	0.038	0.049
Intercept	−0.541	−0.541	0.461
	0.844	0.846	1.116
Lnα		−17.323	

Notes: Dichotomous variables for household size and enumerators are reported in the Appendix. Standard errors in small font.
[a] Significant at the 5 per cent level.
[b] Significant at the 10 per cent level.

Poisson and Negative Binomial models, as is respondent age. The income elasticity of demand for bednets is low: a 10 per cent increase in income increases the demand for bednets by only 1 per cent. Older respondents have lower demand than younger respondents do.

The lack of significance of so many explanatory variables in these models is due in part to small sample size (279 households). Nevertheless, we believe Table 15.3 indicates that we probably have accurate estimates of the impact of price on the purchase of bednets, which is most likely the variable of greatest policy significance.

Table 15.4 Goodness of fit criteria for bednets

	Actual	Poisson	Negative binomial	Truncated poisson
Log likelihood	N/A	−322.30	−322.30	−311.75
Mean $Y\|\mathbf{X}$	1.07	1.07	1.07	1.09
Variance of $Y\|\mathbf{X}$	1.63	0.56	0.56	0.57
$Y >$ (household size)/2	0%	2%	2%	0%
Frequency				
0	39%	54%	54%	52%
1	28%	37%	37%	38%
2	25%	8%	8%	8%
3	6%	1%	1%	1%
4	0%	0%	0%	0%
5	0%	0%	0%	0%
6 or more	1%	0%	0%	0%

Table 15.4 compares the performance of the three models in predicting within-sample behavior. A likelihood ratio test fails to reject the null hypothesis that the data follow a Poisson distribution. Since the Poisson model is a special case of the Negative Binomial model and the Truncated Poisson model, it is not surprising that the three models produce similar results. All models over-predict the number of households purchasing zero bednets or one bednet and underpredict the number of households purchasing two or more bednets. This suggests that, for purposes of predicting bednet purchases, it is better to rely on the raw data in Table 15.2.

15.4.3 Willingness to pay for bednets

Our estimates of bednet demand can also be used to compute the household's total willingness to pay for a given number of nets. To illustrate, suppose that a donor were to provide enough bednets to protect all persons in a village. What are the economic benefits of such a program? The value to a household of owning x nets (its total WTP for the nets) is the area under its demand curve between 0 and x nets. Thus, the value of the program would be the sum of each household's total WTP for the nets it received. Assuming that each household received $n/2$ nets, mean and median household WTP for bednets are given in Table 15.5.[12]

These benefit estimates are difficult to compare with the other two benefit estimates measured in this study: COI and WTP for a hypothetical malaria vaccine. While WTP for ITNs lie in the range of annual household COI associated with malaria, these values are difficult to compare because COI indicates the benefits of eliminating malaria for one year, while ITNs

Table 15.5 Willingness to pay for bednets in US$ (n =279)

	Poisson	Negative binomial	Truncated poisson
Willingness to pay			
Mean	20	20	22
Median	18	18	19
Standard deviation	11	11	13
Minimum	3	3	1
Maximum	74	74	95

reduce, but do not eliminate, risk for four years. Average household WTP for a hypothetical malaria vaccine that is 100 per cent effective for one year is estimated to be US$36 per year (Cropper et al., 2004). Thus, mean WTP for ITNs (US$22 for Truncated Poisson) is 60 per cent of mean WTP for vaccines. The difference between these estimates may be partially explained by the fact that, although bednets are a durable good with a four year expected lifetime, they provide only partial protection against malaria. Moreover, they require some effort to use.[13]

15.4.4 Policy implications of the results

These results can assist decision makers seeking to maximize health given a fixed budget by illustrating the tradeoff between public expenditures and bednet coverage. It has been estimated that the supply price of an ITN is about US$16. At this price, however, 63 per cent of households in Tigray would buy no bednets. Figure 15.1 plots the number of ITNs purchased at each of our sample prices, and connects these points. The figure shows that only 200 persons in a village of 200 households (1000 persons) would be protected by bednets. At a price of US$1, about 340 bednets are sold and 680 persons (68 per cent of the population of the village) would sleep under a bednet. Since the revenue from selling 100 bednets at US$100 per ITN is almost four times as great as the revenue from selling 340 bednets at US$1 per ITN, there is clearly a tradeoff between coverage and profit maximization, were ITNs to be sold as private goods. Indeed, our estimates of demand for ITNs imply that the possibility of distributing the bednets through the private sector is slim.

These results are due to a relatively steep demand curve – implying that, as the price of ITNs fall, the number purchased increases, but gradually. Households' mean WTP for $n/2$ bednets as a percentage of income (8 per cent) is twice as large as intended bednet expenditures as a percentage of income (4 per cent or less). The policy implications of this result are that, while the benefits from allocating resources to bednets are large, it will be difficult to achieve significant market penetration unless the price is subsidized.

To compute the private benefits of free ITNs, we compute the consumer surplus that each household would receive if it were given x bednets. This is approximated by the area under the household's demand function between 0 and $n/2$ bednets. The average annual household benefits from bednets are US$20–22. Summing these benefits over the 279 households in our sample yields total annual benefits of US$5580–6138. The costs of this program to the public health agency would equal the number of bednets provided (i.e., one-half of the number of people protected, since ITNs protect at least two people) times the subsidy per bednet. If the subsidy is set so that the price per bednet is about US$9 or less, then the program yields positive net benefits.

15.5 Conclusions and generalizability of the results

This chapter illustrates how the results of a welfare economic study can assist decision makers seeking to maximize health given a fixed budget. The study is one of the first to use a stated preference method asking respondents to choose the quantities of good that they would demand. Typically, stated preference methods measure respondents' preferences for a fixed quantity of a good. The modified stated preference approach permits straightforward estimation of the market demand function.

Our estimates of the household demand for ITNs have three policy implications. First, the estimated ITN demand curve is such that, even at low prices, many households would not purchase bednets. For example, at a price of US$1, one-fifth of all households in Tigray would purchase no bednets. Second, there is a sharp trade-off between cost recovery and assuring that a significant fraction of the population receives protection from bednets. Third, the shape of the demand curve implies that, even though few bednets are purchased, consumer surplus from bednets is high. This implies that the net benefits from donor-sponsored bednet distribution could be positive, even though few households would privately purchase ITNs.

To what extent are these results likely to apply in other parts of Africa? Malaria is a disease that varies widely in its incidence and in its pattern of transmission. In many parts of Africa, malaria is endemic: transmission is perennial and most adults experience at least one episode of the disease each year. In these areas morbidity and mortality from malaria are highest among groups having low immunity, such as infants and children. In areas where malaria follows an unstable, seasonal transmission pattern, such as Tigray, the working age population suffers more episodes of malaria relative to perennial transmission, and the income losses due to malaria are greater. For these reasons, one must be cautious in transferring results from Ethiopia to the rest of sub-Saharan Africa.

Notes

Christine Poulos, Research Triangle Institute, 3040 Cornwallis Road, Research Triangle Park, North Carolina, 27709, email: cpoulos@rti.org. Maureen Cropper, The World Bank and Professor of Economics, University of Maryland-College Park. Julian Lampietti, The World Bank. Dale Whittington, Professor of Environmental Sciences and Engineering and City and Regional Planning, University of North Carolina at Chapel Hill. Mitiku Haile Dean, Mekelle University College, Mekelle, Ethiopia.
This investigation received financial support from the UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Disease. The authors would like to thank Melba Gomes for comments and Bill Evans for providing the SAS code used to estimate the multivariate model. Carol Jenkins conducted the initial ethnographic survey. The field work would not have been possible without the help of Kristin Komives, Zarai, Amare, Gebremedhin, Gebremichael and the members of the enumeration teams. Special thanks are also due to Tedros Ghebreyesus and the Tigray Malaria Control Office and to staff at University College Mekelle.

1. In response to the question, 'What are the best ways to avoid getting malaria?', only four respondents mentioned sleeping under a bednet (either unimpregnated or impregnated).
2. Our model ignores risk of death from malaria, which, in Tigray, is low relative to risk of death from other causes. In Tigray, eight persons out of every 10 000 die each year from malaria (Ethiopian Ministry of Health, 1996). By contrast, risk of death from other causes is 160 per 10 000 people.
3. There is a distinction between (1) the economic value of an exogenous change in malaria exposure (e.g., vector control program) that causes a risk reduction equivalent to the risk reduction achieved by the ITN and (2) the economic value of the risk reduction achieved by the ITN. The former can be measured by the change in expenditure on a private good that is a pure substitute for malaria exposure (i.e., the area *under* the price and to the left of quantity). However, this substitution method is invalid for non-marginal changes in exposure (Freeman, 1993). The latter, which is measured in this study, is the area *above* the price and to the left of quantity.
4. A detailed description of the project and its results may be found in Cropper et al. (2004).
5. Of 889 respondents who received our questionnaire, 41 were not familiar with malaria. These households were dropped from the sample.
6. These figures measure self-reported malaria. Only 164 respondents said that they had ever had their malaria diagnosed with a blood test.
7. These include the costs of medicine, fees paid to health care providers, and the costs of traveling to health care providers.
8. The total number of workdays lost by all family members during a malaria episode equals the number of workdays lost by the patient, plus the number of days other family members stopped their normal activities to take care of the sick patient, minus the number of days other family members substitute for the sick patient at work. The net number of workdays lost to the family is, on average, 21 days for an adult episode of malaria, 26 days for a teenager's episode of malaria, and 12 days for a child's episode of malaria.

   To compute the average private cost of an episode of malaria, workdays lost must be valued and added to the private costs of treatment. A workday lost by an adult is valued at the daily wage of an unskilled laborer (US$1). Teenagers are assumed to be half as productive as adults, and children half as productive as teenagers.
9. At the time of the study, US$1 = Birr 6.3.
10. See Hammer (1993), Gomes (1993), and Mills (1991) for thorough reviews of COI due to malaria.
11. Eighty-four per cent of respondents (712/848) said that they drained areas near their home of standing water to prevent malaria transmission. Seven per cent of respondents took chloroquine prophylactically.

12. When not an integer, $n/2$ was rounded down to the nearest integer.
13. Mills (1998) reviews studies of both expenditures and WTP for other preventive goods. These values are also difficult to compare to our ITN results because preventive goods offer various levels of risk reduction and durations of effectiveness.

References

Becker, G., (1981), 'Altruism in the family and selfishness in the market place', *Economica*, **48** (189), 1–15.

Berger, M., G. Blomquist, D. Kenkel and G. Tolley (1994), 'Framework for valuing health risks', in Tolley et al. (eds), *Valuing Health for Policy: An Economic Approach*, Chicago: The University of Chicago Press.

Binka, F., O. Nensah and A. Mills (1997), 'The cost effectiveness of ermethrin impregnated bednets in preventing child mortality in Kassena-Nankana district of northern Ghana', *Health Policy*, **41**, 229–39.

Brouwer, W. and M. Koopmanschap (2000), 'On the economic foundations of CEA: Ladies and gentleman, take your positions!', *Journal of Health Economics*, **19**, 439–59.

Cameron, T.A. (1992), 'Combining contingent valuation and travel cost data for the valuation of nonmarket goods', *Land Economics*, **68** (3), 302–17.

Cropper, M., J. Lampietti, C. Poulos, H. Mitiku and D. Whittington (1999), 'The value of preventing malaria in Tigray, Ethiopia', Report to the World Health Organization.

Cropper, M.H. Mitiku, J. Lampietti, C. Poulos and D. Whittington (2004), 'The demand for a malaria vaccine: evidence from Ehiopia', *Journal of Development Economics*, **75**, 303–18.

Cuyler, A. (1991), 'The normative economics of health care finance and provision', in A. McGuire, P. Fenn and K. Mayhew (eds.), *Providing Health Care: The Economics of Alternative Systems of Finance and Delivery*, Oxford: Oxford University Press.

Englin, J. and T. Cameron (1996), 'Augmenting travel cost models with contingent behavior data', *Environmental and Resource Economics*, **7**, 133–47.

Ethiopia Ministry of Health (1996), 'Burden of Disease', *Ethiopia Social Sector Study Report*, September.

Freeman. A. (1993), *The Measurement of Environmental and Resource Values: Theory and Practice*, Washington, DC: Resources for the Future.

Ghebreyesus, T., T. Alemayehu, A. Bosman, K. Witten and A. Teklehaimanot (1996), 'Community participation in malaria control in Tigray region Ethiopia', *Acta Tropica*, **61**, 145–56.

Gomes, M. (1993), 'Economic and demographic research on malaria: a review of the evidence', *Social Science and Medicine*, **37**, 1093–108.

Grossman, M. (1972), 'On the concept of health capital and the demand for health', *Journal of Political Economy*, **80**(2), 223–55.

Hammer, J. (1993), 'The economics of malaria control', *The World Bank Research Observer*, **8**, 1–22.

Harrington, W. and P. Portney (1987), 'Valuing the benefits of health and safety regulations', *Journal of Urban Economics*, **22**(1), 101–12.

Jakus, P. (1994), 'Averting behavior in the presence of public spillovers: household control of nuisance pests', *Land Economics*, **70**, 273-85.

Khan, M.J. (1966), 'Estimate of economic loss due to Malaria in West Pakistan', *Pakistan Journal of Health*, **16**, 187–93.

Konradsen, F., W. Van Der Hoek, P.H. Amerasinghe and F.P. Amerasinghe (1997), 'Measuring the economic cost of malaria to households in Sri Lanka', *American Journal of Tropical Medicine and Hygiene*, **56**, 656–60.

Loomis, J., S. Yorizane and D. Larson (2000), 'Testing significance of multi-destination and multi-purpose trip effects in a travel cost method demand model for whale watching trips', *Agricultural and Resource Economics*, **29**, 183–91.

MARA (Mapping Malaria Risk in Africa) Project (2001), Updated 7 May, http://www.mara.org.za, accessed 14 October 2001.

Mills, A. (1991), 'The economics of malaria control', in G. Targett (ed.), *Malaria: Waiting for the Vaccine*, Chichester: John Wiley & Sons.
Mills, A. (1998), 'Operational research on the economics of insecticide-treated mosquito nets: lessons of experience', *Annals of Tropical Medicine and Parasitology*, **92** (4), 435–47.
Niklitschek, M. and J. Leon (1996), 'Combining intended demand and yes/no responses in the estimation of contingent valuation models', *Journal of Environmental Economics and Management*, **31**, 387–402.
Sauerborn, R., D.S. Shepard, M.B. Ettling, U. Brinkmann, A. Nougtara and H.J. Diesfeld (1991), 'Estimating the direct and indirect economic costs of malaria in a rural district of Burkina Faso', *Tropical Medicine and Parasitology*, **42**, 219–23.
Williams, A. (1993), 'Cost–benefit analysis: applied welfare economics or general decision aid', in A. Williams and E. Giardina (eds.), *Efficiency in the Public Sector*, Cheltenham: Edward Elgar.
Willig, R. (1976), 'Consumer's surplus without apology', *American Economic Review*, **66**, 589.

Appendix

Table A1 Household size and enumerator effects for bednet models

Variable	Poisson	Negative binomial	Truncated poisson
DIhh_2	−0.227	−0.227	−0.971
	0.446	0.447	0.732
DIhh_3	0.230	0.230	−0.626
	0.442	0.443	0.709
DIhh_4	−0.239	−0.239	−1.256
	0.482	0.483	0.733
DIhh_5	0.101	0.101	−0.914
	0.523	0.523	0.794
DIhh_6	0.367	0.367	−0.628
	0.563	0.563	0.866
DIhh_7	0.296	0.296	−0.714
	0.641	0.641	0.959
DIhh_8	0.110	0.110	−0.876
	0.732	0.730	1.089
DIhh_9	0.885	0.885	−0.039
	0.802	0.802	1.192
Iname_2	−0.203	−0.203	−0.202
	0.319	0.319	0.409
Iname_3	0.500b	0.500b	0.588b
	0.278	0.277	0.347
Iname_8	0.126	0.126	0.126
	0.302	0.302	0.373
Iname_9	0.430	0.430	0.439
	0.303	0.304	0.386
Iname_10	−0.064	−0.064	−0.123
	0.331	0.332	0.430

Table A1 (continued)

Variable	Poisson	Negative binomial	Truncated Poisson
Iname_12	−0.784a	−0.784b	−0.838a
	0.368	0.367	0.408
Iname_13	−0.059	−0.059	−0.090
	0.333	0.333	0.460
Iname_14	0.412	0.412b	0.512
	0.266	0.266	0.337
Iname_16	−0.916a	−0.916a	−1.052a
	0.408	0.407	0.463
Iname_18	−0.135	−0.135	−0.185
	0.336	0.337	0.405
Iname_19	−0.032	−0.032	−0.091
	0.305	0.305	0.445

Notes:
Standard errors in small font.
[a] Significant at the 5 per cent level.
[b] Significant at the 10 per cent level.