Journal of Development Economics 75 (2004) 303–318
JOURNAL OF Development ECONOMICS
www.elsevier.com/locate/econbase

# The demand for a malaria vaccine: evidence from Ethiopia☆

Maureen L. Cropper[a,b,*], Mitiku Haile[c], Julian Lampietti[b], Christine Poulos[d], Dale Whittington[e]

[a] *University of Maryland, USA*
[b] *The World Bank, MC2-205, The World Bank, 1818 H Street NW, Washington, DC 20433, USA*
[c] *University College Mekelle, Ethiopia*
[d] *University of Missouri, Columbia, USA*
[e] *University of North Carolina, at Chapel Hill, USA*

Received 1 April 2000; accepted 1 February 2003

**Abstract**

This study measures the monetary value households place on preventing malaria in Tigray, Ethiopia. We estimate a household demand function for a hypothetical malaria vaccine and compute the value of preventing malaria as the household's maximum willingness to pay to provide vaccines for all family members. This is contrasted with the traditional costs of illness (medical costs and lost productivity). Our results indicate that the value of preventing malaria with vaccines is about US$36 per household per year, or about 15% of imputed annual household income. This is, on average, about twice the expected household cost of illness.


*JEL classification:* I12; I18; O10
*Keywords:* Malaria vaccine; Malaria control benefits; Ethiopia

☆ This study was sponsored by the UNDP/World Bank/WHO Special Program for Research and Training in Tropical Disease. We would like to thank Melba Gomes and Oye Meesook for comments and Bill Evans for providing the computer program used to estimate the truncated Poisson model. We also appreciate the comments of two anonymous referees. The paper does not represent the views of the World Bank, its Executive Directors or the countries they represent, nor does it represent the views of the World Health Organization.

* Corresponding author. The World Bank, MC2-205, The World Bank, 1818 H Street NW, Washington, DC 20433, USA. Tel.: +1-202-473-1277; fax: +1-202-522-3230.
*E-mail address:* mcropper@worldbank.org (M.L. Cropper).

0304-3878/$ - see front matter 
doi:10.1016/j.jdeveco.2003.02.006

## 1. Introduction

Malaria is one of the world's most serious infectious diseases, claiming over two million lives and causing five hundred million cases of clinical illness each year. Approximately 90% of these cases occur in sub-Saharan Africa, where malaria is a leading cause of death among children. Malaria also has significant economic impacts. When peak transmission occurs just before harvest, the disease can cause sizable productivity losses. Indirect productivity losses may occur if malaria affects the amount of land cultivated and/or the nature of crops grown. Indeed, Gallup and Sachs (1998) estimate that malaria lowered GDP growth in sub-Saharan Africa by 1–2 percentage points annually between 1965 and 1990.

One of the most promising approaches to controlling malaria in sub-Saharan Africa is through a vaccine.[1] Researchers have worked on developing a vaccine for decades, and it appears that a viable vaccine could be produced within the next 10 years. This raises a host of policy questions. Should the vaccine be provided privately or publicly? If it were sold privately, how many vaccines would be purchased (at various prices) and who would receive them? If, instead, the vaccine were provided free of charge by governments or donor agencies, what would be the benefits of providing the vaccines? Malaria is only one of many diseases that could be targeted by public health programs, and it is important that the net benefits of malaria control programs be compared with the net benefits of other programs, both inside and outside of the health sector.

To help answer these questions we present estimates of the demand for a malaria vaccine based on a household survey conducted in the north of Ethiopia. In Tigray, an agricultural area characterized by seasonal malaria, we asked the household head (or spouse) how many vaccines he or she would purchase if a vaccine were available, and who in the family would be inoculated. We use these responses to estimate a household demand curve for vaccines.

Our estimates of a vaccine demand curve have at least two uses. Kremer (2001) and Glennerster and Kremer (2000) suggest that the R&D necessary to develop a malaria vaccine would be forthcoming if multilateral donors would guarantee a market for the vaccine. Once a vaccine is developed, donors would supply the bulk of revenues and developing countries might be expected to contribute a co-payment of, perhaps, 20 ¢ per vaccine. Our estimates of vaccine demand suggest how many households would purchase a vaccine at such a price, if households were charged a co-payment. Whether households are charged for the vaccine or receive it for free, the household demand curve can be used to calculate the benefits of a vaccine program. Specifically, the area under the inverse vaccine demand curve between 0 and $n$ vaccines approximates the compensating variation associated with providing vaccines to $n$ family members. This provides an estimate of the private benefits from a malaria vaccine program.

[1] In climates less hospitable to the anopheles mosquito, which carries the malaria parasite, the disease can be eradicated by spraying. This is how malaria was controlled in the United States and Southern Europe. In areas of high endemicity, spraying can lower the incidence of the disease, but cannot eliminate it.

The area under the household's inverse demand curve for vaccines could also be used to measure the private benefits of other programs that might prevent malaria, since it captures the benefits to the household of eradicating the disease. Ours is a more comprehensive measure of benefits than what is typically used in the public health literature. Traditionally, the benefits from government-subsidized prevention programs have been equated to the reductions in treatment costs and gains in productivity that occur from preventing disease; i.e., reductions in the cost of illness. Reductions in the cost of illness, however, fail to capture the benefits to parents of preventing malaria in children, the value of resources spent on preventing the disease, and the value of the pain and suffering that malaria causes. These benefits are captured in our estimates of the value of prevention, computed from the demand curve for vaccines. The latter are two to three times the value of traditional cost of illness estimates.

The plan of the paper is as follows. Section 2 of the paper contrasts the cost of illness (COI) approach to valuing the benefits of malaria control with estimates of willingness to pay (WTP) to prevent malaria derived from a vaccine demand curve. Section 3 describes the region where our survey was conducted. We focus on the nature of malaria in the region and present estimates of the treatment costs and lost workdays experienced by households in our sample. Section 4 contains estimates of the demand for a vaccine and uses the demand curve to estimate the benefits of a vaccine distribution program. Section 5 discusses the extent to which results from Tigray can be generalized to other parts of Africa.

## 2. Cost of Illness versus Willingness to Pay approaches to valuing health benefits

In benefit–cost analyses of health and safety programs, avoided medical costs and productivity losses are often used to conservatively estimate the benefits of preventing illness or injury. One goal of our work is to provide a method of estimating the benefits of preventing malaria that is more broadly defined. Specifically, we wish to estimate what a household would pay to avoid the illness not only because of the costs described above, but because the illness involves pain, suffering and, possibly, death.

To put our estimate of household willingness to pay (WTP) to avoid malaria in context, we first review the literature on the cost of illness (COI) associated with malaria. We discuss the methodology used to produce cost of illness estimates, and review COI studies for malaria in Africa that are based (like ours) on household survey data. This is followed by a discussion of the concept of household WTP to avoid illness and the use of stated-preference methods to estimate WTP.

### 2.1. Cost of illness estimates

In the medical economics literature the cost of illness (COI) is the sum of the costs of medical treatment (the "direct" costs of illness) and the value of productive time lost due to illness (the "indirect" costs of illness). Depending on the context, costs may be computed as either private costs or social costs. Private medical costs include only the costs actually incurred by the sick person, whereas social costs include payments by all parties (e.g., the government).

The direct costs of a malaria episode include the costs of medicine and medical treatment, as well as the time and out-of-pocket costs of travel to receive treatment. Ideally, private costs should be estimated based on household survey data. Estimates of the social costs of medical care and drugs, when these are subsidized, requires information on government healthcare expenditures. Expenditure on drugs represents the largest component of private direct costs in most studies conducted in Africa, since there is often no charge for visits to a clinic or community health worker. Estimates of total direct costs per case treated (1997 USD), including the cost of clinic visits, are US$3.61 in Rwanda (Ettling and Shepard, 1991) and US$4.48 in the Congo (Shepard et al., 1991). In Burkina Faso, Sauerborn et al. (1991) estimate direct costs to be US$5.31 for a severe case of malaria and US$1.92 for a mild case. These are average costs per case, given that treatment is sought. To calculate an average direct cost per malaria case, one must know the proportion of cases treated.[2]

The indirect costs of illness include the productive time lost by malaria patients, substitute laborers, and caretakers who do not perform their usual household activities. These time costs are the sum of three items. The first is the number of workdays that the malaria patient loses when ill. The second is the net time lost by a person who foregoes his own duties to substitute for the malaria patient at work. This time may be negative (i.e., it may reduce total time lost) if, for example, the substitute laborer gives up his leisure time. The third item is the workdays a caretaker misses while caring for the ill household member.

There is considerable variation in productive time lost due to malaria depending on the pattern of malaria transmission. In areas where malaria is endemic; i.e., where there is "significant annual transmission, be it seasonal or perennial," adults and children will develop some immunity to the disease (Snow and Marsh, 1998). This is especially true in areas where transmission is perennial (7–12 months per year) and in areas where a large fraction of the population contracts the disease each year.[3] In holo-endemic areas (prevalence >75%) episodes are likely to be less than 1 week. Sauerborn et al. (1991), for example, estimate an average of 5.39 productive days lost per episode in Burkina Faso (holo-endemic). In the Sudan, in an area where malaria is seasonal, Nur (1993) estimated an average of 11 days of productive time lost per episode—9 days of time lost by the patient and 2 days lost due to intra-household labor substitution. In areas where the transmission pattern is "prone to distinct inter-annual variation" malaria is said to be epidemic and, due to lower population immunity, episodes are likely to be even longer.

A measure of the monetary value of lost labor is needed to calculate the indirect COI in monetary terms. Calculation of the value of lost productivity in agricultural economies

[2] Direct costs are sometimes expressed on a per capita basis, which requires an estimate of malaria incidence, as well as of the percentage of cases treated.

[3] Areas where the prevalence of malaria >75% are characterized as holo-endemic; between 51% and 75% as hyper-endemic; between 11% and 50% as meso-endemic and < 10% as hypo-endemic. MARA (Mapping Malaria Risk in Africa) Project. http://www.mara.org.za.

should allow for seasonal variation in the marginal product of labor, and should distinguish the value of time lost by age and gender. Better studies (Sauerborn et al., 1991) attempt to calculate an average product of labor by season and gender. Most COI studies, however, assume that daily productivity is equal to the market wage rate, or some fraction thereof. The average indirect cost of a malaria episode (1997 USD) is US$17.90 for Chad (Shepard et al., 1991), US$12.94 for Rwanda (Ettling and Shepard, 1991) and US$7.80 for the Congo (Shepard et al., 1991).

### *2.2. Willingness to pay to avoid illness*

It is widely recognized that the direct and indirect costs of illness capture only part of the value of preventing a case of malaria. As Mills (1992) notes, the COI approach ignores the pain and discomfort associated with malaria, as well as the longer-term productivity consequences of the disease—changes in type of crops grown, unwillingness to take risks, impacts on human capital through reduced child schooling. It also ignores the value of measures taken to prevent malaria—such as draining areas of standing water, or spraying homes to kill mosquitoes—and the value of leisure time lost to the illness.[4]

A household's demand for a malaria vaccine that would prevent the disease with certainty should reflect the value the household places on preventing all of the consequences of the disease, as it perceives them.[5] In our survey, we put the respondent in the role of a unitary decision-maker, asking him or her to maximize his own utility function (which may reflect altruistic preferences towards other family members), subject to household income. This yields a stated demand for the malaria vaccine that reflects the impact of the vaccine on the time spent ill by each family member and on his or her risk of dying, as well as the impact of the vaccine on the cost of treatment and productivity loss.

The number of vaccines that a respondent would purchase ($q$) should depend on the price of the vaccine ($p_v$), household income ($y$), household size and composition ($H$)—specifically, the number of children, teenagers and adults in the household—respondent characteristics such as age, gender, marital status and literacy ($Z$) and a vector of malaria-related variables ($M$). The latter include measures of the prevalence of malaria in the respondent's village and the respondent's experience with the disease.

The vaccine demand curve can also be used to measure the value of protecting $n$ household members from the disease for 1 year. The total value the decision-maker places on preventing malaria in him or herself and members of the household (WTP

---

[4] Harrington and Portney (1987) and Freeman (1993) prove in a household production framework that willingness to pay to avoid exposure to a disease-causing agent (e.g. mosquitoes) exceeds the sum of treatment costs and productivity losses.

[5] In studies where value is inferred from observed behavior—for example, the use of compensating wage differentials to value risk of death on the job—the researcher must often make assumptions about how individuals perceive the commodity valued. For example, it is usually assumed that perceived risk of death on the job coincides with objectively measured risk of death.

for prevention) is the area under the inverse demand curve between 0 and $n$ vaccines.

$$\mathrm{WTP} = \int_0^n p_\mathrm{v}(q, y, H, Z, M)dq \qquad (1)$$

Since an effective malaria vaccine does not exist, the only way to estimate the household's vaccine demand curve is using stated-preference techniques. The use of stated-preference methods to value health outcomes is well-established in the literature (Evans and Viscusi, 1991; Loehman and De, 1982; Smith and Desvousges, 1987; Viscusi and Evans, 1990, 1998). In most studies, respondents are asked whether they would pay a stated price for a fixed quantity of some health-related good; e.g., a reduction in risk of death or injury or the avoidance of an episode of illness. Our work differs from the literature in asking how many units of a health-related commodity the respondent would purchase at a stated price. The advantage of asking such questions directly is that the researcher can fix the nature of the commodity valued and can vary the price offered to the respondent at random. The disadvantage of the stated-preference approach is that the questions asked are hypothetical.

Because the vaccine demand question is hypothetical, we provide two tests of the validity of survey responses. The first is to see if stated vaccine demand varies with price and income as predicted by economic theory. Respondents faced with a high vaccine price should, on average, purchase fewer vaccines than respondents faced with a lower price. A second test is whether a respondent's willingness to pay to prevent his or her family from contracting malaria is correlated with the expected loss in income and cost of medical treatment associated with malaria. We would expect that each respondent's WTP to prevent malaria, as measured by the area under the vaccine demand curve, should exceed the household's expected cost of illness, but that the two quantities should be positively correlated across respondents.

## 3. Study site and research design

The data used to estimate the demand for a malaria vaccine 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. Microdams have been constructed to provide water for crops, but this has exacerbated malaria by providing a breeding ground for mosquitoes.

A total of 889 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.[6] The respondent (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 unfamiliar with malaria (41 of 889) were dropped from the analysis. The 848 respondents familiar with the disease were asked to describe their family's experience with malaria during the last 2 years. This included a detailed description of the respondent's most recent

[6] A detailed description of the project and its results may be found in Cropper et al. (2000).

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 two-thirds of respondents (569) were asked whether they would purchase one or more malaria vaccines for members of their family if such a vaccine were to become available. The remaining respondents (279) were asked whether they would purchase insecticide treated bednets.[7] We use the responses of households receiving the vaccine scenario to estimate the vaccine demand curve and the responses of all 848 households to characterize the nature of malaria in the region.

Households who received the vaccine scenario were told that the vaccine would prevent malaria with certainty for a period of 1 year.[8] Respondents were reminded that other measures could be taken to prevent malaria, such as draining standing water and/or sleeping under bednets. The respondent was asked if he would purchase one or more vaccines at a price randomly drawn from a set of five possible prices (prices ranged from US$0.80 to US$32.00 per vaccine). If the respondent answered "yes," he was asked how many vaccines would be purchased and to whom they would be given. The survey ended with questions about the family's socio-economic circumstances, including education, occupation, income, assets and housing construction.

### 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 (see Fig. 1). 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.[9]

Table 1 summarizes the incidence of malaria, as reported by 848 respondents in our sample.[10] Seventy-eight percent of respondents said that they had been ill with malaria at some time in their lives, with 58% reporting at least one episode of malaria in the last 2 years. Fifty-three percent of respondents said that at least one other adult in the household had experienced malaria in the last 2 years, and 49% of respondents said that at least one child or teenager in the family had experienced the disease within the last 2 years.

### 3.2. Cost of illness estimates

The productivity losses associated with an episode of malaria are reported in Table 2. The average number of workdays lost during an episode of malaria was 18 for an

[7] These responses are analyzed in Cropper et al. (2000).

[8] A real malaria vaccine would consist of a series of inoculations that, once completed, would protect the individual for many years. In a poor community with poorly functioning credit markets, it makes more sense to ask about annual payments for a vaccine.

[9] Eighty-four percent of respondents said that they drained areas near their home of standing water to prevent malaria transmission. Seven percent of respondents took chloroquine prophylactically.

[10] These figures measure self-reported malaria. Only 164 respondents said that they had ever had their malaria diagnosed with a blood test.

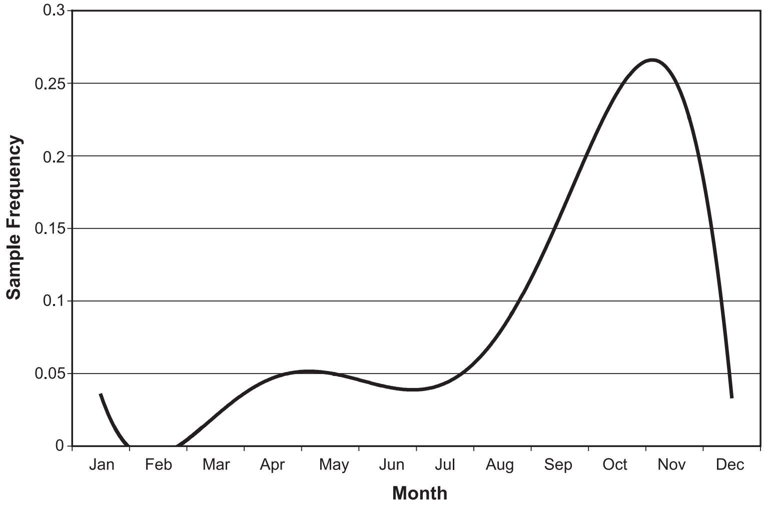


Fig. 1. Malaria transmission pattern in Tigray region of Ethiopia.

adult or teenager and 2 days for a child. The total number of workdays lost by all family members during a malaria episode may, however, exceed the number of workdays lost by the patient. Other family members may forego their normal activities to take care of the sick patient. On average, caretakers gave up 11 days to take care of adults or children and 13 days to care for teenagers. Other family members may give up their leisure time to substitute for the sick patient at work. Although this may represent lost utility to the substitute laborer, the net effect is to reduce workdays lost by the family. This figure, labeled intra-household labor substitution, must be subtracted from the patient's and caretaker's lost workdays to arrive at the net number

Table 1
Household malaria incidence (in last 2 years unless otherwise specified)

| Variable | *N* | Mean (trimmed mean)[a] | Median |
|---|---|---|---|
| Respondent had malaria in lifetime | 848 | 0.78 | 1 |
| Respondent had malaria | 848 | 0.58 | 1 |
| Households where other adults had malaria | 842 | 0.58 | 1 |
| Households where children/teens had malaria | 845 | 49% | 0 |
| Households where somebody died of malaria (lifetime) | 803 | 7% | 0 |
| Number of times the respondent had malaria | 656 | 2.7 (1.8) | 2 |
| Number of other adults who have had malaria | 451 | 1.5 | 1 |
| Number of children/teenagers who have had malaria | 415 | 2.0 | 2 |

[a] Trimmed means are obtained by setting all values greater than the ninety-fifth percentile equal to the ninety-fifth percentile.

Table 2
Productivity losses per malaria episode, by age group (average number of days)

| | Age group | | |
|---|---|---|---|
| | Adult | Teens | Children |
| (1) Patient's lost work days | 18 | 18 | 2 |
| (2) Gains in household productivity due to intra-household labor substitution | 8 | 5 | 0 |
| (1) – (2) | 10 | 13 | 2 |
| (3) Caretaker's lost work days | 11 | 13 | 11 |
| Net number of work days lost [(1) – (2)+(3)] | 21 | 26 | 12[a] |

[a] This column does not add up because of rounding errors.

of workdays lost to the family. The latter 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.[11]

To compute the private cost of an episode of malaria, workdays lost must be valued and added to the private costs of treatment. Table 3, which shows average per episode cost of illness (COI), values a workday lost by an adult at the daily wage of an unskilled laborer (US$1 US) (high productivity assumption) and, alternately, at 50% of the daily wage (low productivity assumption). Teenagers are assumed to be half as productive as adults, and children half as productive as teenagers. Average treatment costs, per episode, are shown in the third column of the table. These include the costs of medicine, fees paid to a health care provider and the costs (including time costs) of traveling to the health care provider.

The COI associated with an average episode (last column of Table 3), depending on productivity assumptions, ranges from US$7 to US$24 for an adult and US$7 to US$12 for a child. These figures are in the range of estimates for the Congo, Chad and Rwanda.[12] 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$9 (low productivity assumption) to US$31 (high productivity assumption).

To place these numbers in context, we computed household income as the sum of the value of agricultural output and off-farm earnings. Average income is US$200 per household per year, implying that as much as 15% of income is lost to malaria annually. This figure, of course, does not include of the value of the discomfort associated with the disease, the value to parents of preventing the disease in their children, or the cost of activities that are undertaken to prevent the disease. In the next section, we examine the

[11] To examine the effect of the length of the recall period on cost of illness estimates, we computed Table 2 separately for malaria episodes that occurred within 4 months of the interview and those that occurred 5 or more months before the interview. Average cost of illness figures differed by no more than 10% between the two tables.

[12] Shepard et al. (1991) report a COI of US$12.28 per case for the Congo, US$16.55 per case for Rwanda and US$18.20 per case for Chad.

Table 3
Average cost of illness per episode, using high and low productivity assumptions (1997 USD)

| Age group | Productivity loss | | Treatment costs | Total Cost of Illness (Range) |
|---|---|---|---|---|
| | 100% Wage | 50% Wage | | |
| Adults | 22 | 6 | 1.6 | 24–8 |
| Teenagers | 22 | 6 | 1.1 | 23–7 |
| Children | 12 | 3 | 0.8 | 13–4 |

demand for a hypothetical malaria vaccine, which should capture these items as well as the traditional COI.

## 4. Empirical analysis of vaccine demand

### 4.1. Description of responses

Table 4 shows the number of vaccines respondents stated that they would purchase at various prices. Quantity purchased is clearly sensitive to price. The percentage of households who say that they would buy no vaccines increases from 24% at a price of US$0.80 per vaccine to 91% at a price of US$32 per vaccine. The average quantity purchased also declines as price rises.

An important issue for policy is who within families would receive vaccines if they were available. Table 5 presents the percentage of adults, teenagers and children who would receive the vaccine by income category (the percentage of persons receiving the vaccine in each case represents an average across sample prices). Two facts about the table are striking. The first is that the percentage of adults, teenagers and children receiving the vaccine increases very slowly with income. The second is that the percentage of adults receiving the vaccine is, on average, higher than the percentage of teenagers and children. This result, which is confirmed by our multivariate results

Table 4
Number of hypothetical vaccines purchased by price

| Vaccine price (US$) | Vaccines | | | |
|---|---|---|---|---|
| | 0 | 1–3 | 4–6 | ≥ 7 |
| 0.80 | 24% | 35% | 33% | 8% |
| 3.00 | 48% | 25% | 22% | 6% |
| 6.00 | 68% | 21% | 10% | 2% |
| 16.00 | 81% | 10% | 6% | 3% |
| 32.00 | 90% | 6% | 4% | 0% |

Table 5
Coverage with vaccines by income group and demographic category

| Annual income | Adults | Teenagers | Children |
|---|---|---|---|
| Low ( < US$125) | 27% | 21% | 23% |
| (*N*) | (409) | (131) | (322) |
| Middle | 28% | 25% | 31% |
| (*N*) | (448) | (141) | (395) |
| High (>US$250) | 29% | 31% | 24% |
| (*N*) | (470) | (187) | (394) |

below, suggests that productivity concerns may motivate the allocation of vaccines among family members.

The data underlying Tables 4 and 5 can also be used to predict the number of vaccines that would be purchased in a hypothetical village of 200 households, assuming that these households have the same characteristics as those in our sample (average household size = 5). Fig. 1 plots the number of vaccines purchased at each of our sample prices, and connects these points. At a price of US$16 only 150 people would receive the vaccine. This number increases to 400 persons at a price of US$3 and to 600 persons at t price of US$0.80. Fig. 2 clearly suggests the need for subsidizing vaccine cost in order to ensure broad coverage with a vaccine.

### 4.2. Estimation of vaccine demand function

To see how quantity demanded varies parametrically with price and with co-variates, we estimate a model of vaccine demand. This also provides a test of the internal validity of our responses: quantity demanded should increase with income and education, holding other variables constant. The discrete nature of vaccines suggests that the demand function be estimated using a count data model, such as the Poisson. Since purchasing more than *n* vaccines cannot increase welfare, we estimate a

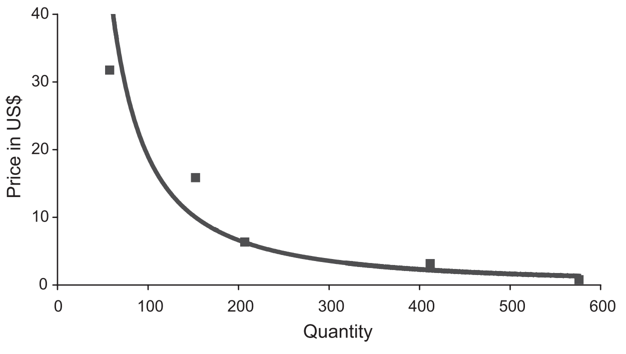


Fig. 2. Malaria vaccine demand for hypothetical 200 household village in Tigray, Ethiopia.

truncated Poisson model, which imposes the constraint that the household never purchases more than $n$ vaccines,

$$P[q_i^* = k_i \mid q_i^* \le n_i] = \frac{e^{\lambda_i} \lambda_i^k / k_i!}{\Pr[q_i^* \le n_i]} \text{ where } k_i = 1 \text{ to } n_i \tag{2}$$

where $\lambda_i = \exp(\boldsymbol{X}_i \beta)$ and $\boldsymbol{X}_i$ is a vector of regressors. This model yields convenient expressions for WTP for prevention, which is the area under the household's inverse demand curve between zero and $n$ vaccines. More formally:

$$\mathrm{WTP}_i = -\frac{e^{\boldsymbol{X}_i \boldsymbol{B}}}{\beta_p} \text{ if } p_{n_i} \le 0 \text{ and } \mathrm{WTP}_i = \frac{n_i}{-\beta_p} + p_{n_i} n_i \text{ otherwise,} \tag{3}$$

where $p_{n_i}$ is the price at which the decision-maker buys vaccines for all household members, and $\beta_p$ is the coefficient of price.[13]

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 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 the sum of the value of agricultural output and off-farm earnings. Since 28% of observations on off-farm income are missing, we replace missing values with zero and then include a "missing income" 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. Other things equal, mosquitoes should be less prevalent at higher altitudes. 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 2 years, weighting each episode by the average age-specific cost of treatment.[14] This is labeled the household's direct COI. Household size is measured by a series of dummy variables since the number of vaccines respondents say they will purchase does not increase linearly with household size. Finally, we add a series of dummy variables to capture interviewer effects.

Table 6 presents parameter estimates for the truncated Poisson model, together with summary statistics for the independent variables.[15] The results for the hypothetical vaccine model are generally consistent with economic theory. The number of vaccines that the respondent agrees to purchase decreases with price, respondent age and altitude. Other things equal, older respondents may perceive themselves to be at lower risk of contracting

[13] Elsewhere (Cropper et al., 2000), we report the results of estimating an untruncated Poisson model and a negative binomial model. A likelihood ratio test allows us to reject the untruncated Poisson model.

[14] The weights are those reported in Table 3, rather than the household's actual expenditure on treatment.

[15] Coefficients of the household size dummy variables and the interviewer dummy variables are reported in Appendix A.

Table 6
Parameter estimates and summary statistics, truncated Poisson model ($n=569$)

| Variable | Mean | Standard Deviation | Coefficient |
|---|---|---|---|
| Price (Birr) | 68.30 | 68.22 | – 0.016[a] (0.001) |
| Log household income (thousands of Birr) | 2.40 | 0.84 | 0.402[a] (0.052) |
| Missing wage (1 if no wage) | 0.28 | 0.45 | 0.059 (0.106) |
| Number of teenagers (number) | 0.81 | 0.91 | 0.001 (0.058) |
| Number of children (number) | 1.95 | 1.35 | – 0.222[a] (0.047) |
| Household direct COI (Birr) | 18.25 | 16.48 | 0.016[a] (0.002) |
| Married (1 if married) | 0.82 | 0.39 | 0.475[a] (0.135) |
| Gender (1 if female) | 0.53 | 0.50 | – 0.281[a] (0.072) |
| Read (1 if read easily) | 0.38 | 0.49 | 0.291[a] (0.072) |
| Age (years) | 42.56 | 14.25 | – 0.021[a] (0.003) |
| Altitude (hundreds of meters) | 16.80 | 1.54 | – 0.082[a] (0.021) |
| Intercept | 1.00 | 0.00 | 2.137[a] (0.725) |

Dichotomous variables for household size and enumerators are not included in Appendix A.
Standard errors in parentheses.
[a] Significant at the 5% level.

malaria than younger respondents. Respondents at higher altitudes, whose families are less exposed to the vector, should have a lower demand for the vaccine.

Demand increases with income, susceptibility to the disease and being married. The income elasticity of demand, 0.4, suggests that the vaccine is not viewed as a luxury good, a result that is consistent with the literature on willingness to pay to avoid illness.[16] Price elasticity of demand ranges from – 0.08 at a price of US$0.80 to – 1.0 at a price of US$10.00.

The results for gender and family composition deserve some discussion. The coefficients on Married and Female indicate that women who are single heads of household have significantly lower demands for vaccines than single male heads of household or married women.[17] It is also the case that, holding household size constant, the demand for vaccines is lower the larger the number of children in the household. This result makes sense from an economic perspective, since children contribute less to the household economically than do adults. It is also consistent with respondents' statements as to who in the family would receive a malaria vaccine. The percentage of children and teenagers who would receive the vaccine is slightly lower than the percentage of adults who would receive the vaccine.

As an additional test of the reasonableness of our results, we use the truncated Poisson model to predict the amount that each household would spend on vaccines, at each price. Regardless of price, mean household expenditure (expressed as a percentage of income) is never more than 4%. Median household expenditure on the vaccine (as a percentage of income) is never greater than 1.5%.

[16] The income elasticity of willingness to pay to avoid illness, a related, but different concept from elasticity of demand, is typically between 0.3 and 0.6 (Loehman and De, 1982; Alberini et al., 1997).

[17] If gender is interacted with all covariates, one can reject the null hypothesis that the vector of interaction coefficients is zero. See Lampietti (1999).

### 4.3. Policy implications of the results

Our estimates of demand for a malaria vaccine underscore the importance of a vaccine purchase commitment scheme (Glennerster and Kremer, 2000; Kremer, 2001). Although an actual malaria vaccine would work differently from the simplified vaccine in our survey, the reluctance to purchase our hypothetical vaccine, even at low prices, suggests that subsidies would be necessary to ensure widespread distribution of a vaccine.

To compute the private benefits of free vaccine distribution, we compute the consumer surplus that each household would receive if it were given $n$ vaccines. This is approximated by the area under the household's inverse demand function between 0 and $n$ vaccines. The average annual household benefits from the vaccine are US$36, roughly twice the value of the annual household COI associated with malaria, assuming that an adult workday is valued at 75% of the wage of an unskilled laborer (US$17). Our results thus suggest that the traditional COI approach to valuing prevention understates the value that individual households place on preventing malaria.[18] Summing these benefits over the 569 households in our sample yields total annual benefits of US$20,484. The costs of this program would equal the number of people vaccinated (2845) times the annualized cost of the vaccine. If the annualized cost per vaccine is US$7 or less, the program yields positive net benefits.

## 5. Conclusions and generalizability of the results

Our estimates of household demand for a malaria vaccine have three policy implications. First, the estimated vaccine demand curve is such that, even at low prices, few vaccines are purchased. For example, at an annualized price of US$3, half of all households in Tigray would purchase no vaccines. This reinforces the importance of subsidizing vaccine purchases, as would be the case under a donor vaccine commitment program. Second, the shape of the demand curve implies that, even though few vaccines are purchased, consumer surplus from the vaccine is high. This means that the net benefits from donor-sponsored vaccine distribution could be positive, even though few households would privately purchase the vaccine. Third, as we note above, the consumer surplus from providing free vaccines to a household is, on average, at least twice the value of the productivity losses and treatment costs that a household would expect to incur because of the disease. This suggests that conventional cost of illness estimates of the value of preventing malaria understate the private welfare gains from malaria prevention. This is true not only for vaccine programs, but for other programs to control malaria. We emphasize that our estimates of the benefits of a vaccine program apply equally well to other malaria control

[18] The fact that WTP exceeds the cost of illness provides some evidence of the reliability of our responses. We also note that the correlation between WTP and the COI across households (0.1424) is statistically significant at the 0.001 level.

programs (such as insecticide-treated bednets or vector spraying), assuming that they could eliminate the disease. If they could not, then our benefit estimates serve as an upper bound to the benefits of such programs.

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 transmission is more intense than in Tigray: 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.

## Appendix A

Table A1
Household size and enumerator effects for hypothetical vaccine model, truncated Poisson model (see Table 6 for other parameters)

| Variable | Mean | Standard Deviation | Coefficient |
|---|---|---|---|
| HHSIZE2 | 0.07 | 0.25 | 0.298 (0.594) |
| HHSIZE3 | 0.12 | 0.32 | – 0.106 (0.581) |
| HHSIZE4 | 0.17 | 0.38 | 0.218 (0.588) |
| HHSIZE5 | 0.20 | 0.40 | 0.110 (0.592) |
| HHSIZE6 | 0.17 | 0.37 | – 0.174 (0.608) |
| HHSIZE7 | 0.14 | 0.34 | – 0.684 (0.623) |
| HHSIZE8 | 0.06 | 0.24 | – 0.094 (0.635) |
| HHSIZE9 | 0.04 | 0.21 | – 0.339 (0.660) |
| INAME_2 | 0.03 | 0.18 | – 0.309 (0.434) |
| INAME_3 | 0.04 | 0.20 | 1.689[a] (0.200) |
| INAME_4 | 0.09 | 0.29 | – 1.043[a] (0.192) |
| INAME_5 | 0.08 | 0.27 | – 0.767[a] (0.221) |
| INAME_6 | 0.09 | 0.28 | 1.381[a] (0.185) |
| INAME_7 | 0.08 | 0.27 | – 0.875[a] (0.222) |
| INAME_8 | 0.03 | 0.18 | 0.122 (0.268) |
| INAME_9 | 0.04 | 0.20 | – 0.094 (0.293) |
| INAME_10 | 0.04 | 0.19 | 1.176[a] (0.224) |
| INAME_11 | 0.09 | 0.28 | – 0.526[b] (0.206) |
| INAME_12 | 0.04 | 0.20 | – 0.324 (0.248) |
| INAME_13 | 0.04 | 0.19 | 1.260[a] (0.211) |
| INAME_14 | 0.14 | 0.19 | 0.863[a] (0.192) |
| INAME_16 | 0.04 | 0.20 | – 1.721[a] (0.338) |
| INAME_17 | 0.10 | 0.30 | 0.064 (0.196) |
| INAME_18 | 0.05 | 0.22 | 0.138 (0.212) |
| INAME_19 | 0.04 | 0.20 | 1.036[a] (0.188) |

Standard errors in parentheses.

[a] Significant at the 5% level.

[b] Significant at the 10% level.

## References

Alberini, A., Cropper, M., Fu, T., Krupnick, A., Liu, J., Shaw, D., Harrington, W., 1997. Valuing health effects of air pollution in developing countries: the case of Taiwan. Journal of Environmental Economics and Management 34, 107–126.

Cropper, M., Haile, M., Lampietti, J., Poulos, C., Whittington, D., 2000. The value of preventing malaria in Tembien, Ethiopia, World Bank, Policy Research Working Paper 2273.

Ettling, M., Shepard, D., 1991. Economic cost of malaria in Rwanda. Tropical Medicine and Parasitology 42, 214–218.

Evans, W., Viscusi, W., 1991. Estimation of state-dependent utility functions with survey data. Review of Economics and Statistics 73, 94–104.

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

Gallup, J., Sachs, J., 1998. The Economic Burden of Malaria Harvard University, Center for International Development, Cambridge, MA.

Glennerster, R., Kremer, M., 2000. A better way to spur medical research and development. Regulation 23, 34–39.

Harrington, W., Portney, P., 1987. Valuing the benefits of health and safety Regulations. Journal of Urban Economics 22, 101–112.

Kremer, M., 2001. Creating markets for new vaccines: Part II. Design issues. In: Jaffe, A.B., Lerner, J., Stern, S. (Eds.), Innovation Policy and the Economy. MIT Press, Cambridge, MA, pp. 73–118.

Lampietti, J., 1999. Do husbands and wives make the same choices? Evidence from northern Ethiopia. Economics Letters 62, 253–260.

Loehman, E., De, V., 1982. Application of stochastic choice modeling to policy analysis of public goods: a case study of air quality improvements. Review of Economics and Statistics 64, 474–480.

MARA (Mapping Malaria Risk in Africa) Project. Updated May 7, 2001. http://www.mara.org.za. Accessed November 23, 2001.

Mills, A., 1992. The economics of malaria control. In: Targett, G. (Ed.), Malaria: Waiting for the Vaccine. Wiley, Chichester, pp. 141–168.

Nur, E., 1993. The impact of malaria on labour use and efficiency in the Sudan. Social Science & Medicine 37, 1115–1119.

Sauerborn, R., Shepard, D., Ettling, M., Brinkmann, U., Nougtara, A., Diesfeld, H., 1991. Estimating the direct and indirect economic costs of malaria in a rural district of Burkina Faso. Tropical Medicine and Parasitology 42, 219–223.

Shepard, D., Ettling, M., Brinkmann, U., Sauerborn, R., 1991. The economic cost of malaria in Africa. Tropical Medicine and Parasitology 42, 199–203.

Smith, V., Desvousges, W., 1987. An empirical analysis of the economic value of risk changes. Journal of Political Economy 95, 89–114.

Snow, R., Marsh, K., 1998. New insights into the epidemiology of malaria relevant for disease control. British Medical Bulletin 54, 293–309.

Viscusi, W., Evans, W., 1990. Utility functions that depend on health status: estimates and economic implications. American Economic Review 80, 353–374.

Viscusi, W., Evans, W., 1998. Estimate of revealed probabilities and utility functions for product safety decisions. Review of Economics and Statistics 80, 28–33.