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MALARIA AMONG GOLD MINERS IN SOUTHERN PARÁ, BRAZIL: ESTIMATES OF DETERMINANTS AND INDIVIDUAL COSTS

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Abstract—As malaria grows more prevalent in the Amazon frontier despite increased expenditures by disease control authorities, national and regional tropical disease control strategies are being called into question. The current crisis involving traditional control/eradication methods has broadened the search for feasible and effective malaria control strategies—a search that necessarily includes an investigation of the roles of a series of individual and community-level socioeconomic characteristics in determining malaria prevalence rates, and the proper methods of estimating these links. In addition, social scientists and policy makers alike know very little about the economic costs associated with malarial infections. In this paper, I use survey data from several Brazilian gold mining areas to (a) test the general reliability of malaria-related questionnaire response data, and suggest categorization methods to minimize the statistical influence of exaggerated responses, (b) estimate three statistical models aimed at detecting the socioeconomic determinants of individual malaria prevalence rates, and (c) calculate estimates of the average cost of a single bout of malaria. The results support the general reliability of survey response data gathered in conjunction with malaria research. Once the effects of vector exposure were controlled for, individual socioeconomic characteristics were only weakly linked to malaria prevalence rates in these very special miners' communities. Moreover, the socioeconomic and exposure links that were significant did not depend on the measure of malaria adopted. Finally, individual costs associated with malarial infections were found to be a significant portion of miners' incomes.

Key words—malaria, costs, socioeconomic determinants of malaria, measures of malaria, questionnaire response data, itinerant gold miners

1. INTRODUCTION

Waves of migrants into the delicate ecosystems of the Amazon jungle have triggered alarming increases in malaria [1]. These dramatic increases are provoking renewed interest in the individual and environmental factors that influence the disease's transmission, with an eye towards reevaluating the control/eradication methods currently employed. One important component of this research investigates a series of complex interrelationships that link socioeconomic factors to the prevalence and spread of malaria at the individual and household levels [2]. It is hoped that by identifying these relevant and potentially manipulable links that disease control, which currently relies almost exclusively on DDT spraying and the distribution of curative drugs, can be made more flexible to better combat a disease that, until recently, was thought to be well on its way to eradication [3].

Renewed interest in malaria has also produced a polarization among malaria researchers regarding the limitations of different types of field data in addressing the relevant disease transmission and control issues, especially quantifying the disease. One view relies almost exclusively on the laboratory analysis of properly collected blood samples in quantifying the disease. A second line of research makes use of questionnaire response data as a basis for analysis. Researchers from the latter group have been sharply criticized for their heavy reliance on retrospective data that is certain to suffer from errors in self-diagnosis and recall. In what follows, I hope to dispel some of the fears associated with the quality of questionnaire response data, and demonstrate the consistent underlying statistical interrelationships they contain.

This paper addresses four important issues. First, after descriptive statistics and a conceptual discussion of malaria in Sections 2 and 3, respectively, the reliability of questionnaire response data is tested in Section 4. Second, acceptable individual measures of malaria are also derived in Section 4. Third, in Sections 5 and 6, socioeconomic and other sources of the marked differences in malaria prevalence across individuals are investigated. The microeconomic costs of a single case of malaria to an average active gold miner in the area of southern Pará covered by the survey are estimated in Section 7.

2. DATA

Empirical analysis of the socioeconomic determinants of malaria requires detailed information on both the individuals exposed to the disease as well as the micro- and macro-environments they inhabit. In 1984, a field research group from CEDEPLAR (Centro de Desenvolvimento e Planejamento Regional) collected such data in four gold mining communities in the Brazilian state of Pará, an economic and epidemiological frontier receiving thousands of migrants per year and registering substantial

increases in malaria per capita [1]. Data on these four gold mining communities serve as the empirical underpinning for the study.

Sample selection is difficult in the case of small-scale gold mining due to the high rates of itineracy that characterize the profession, the 'life cycles' which characterize the gold mining sites, and the intra-regional environmental diversity that arises when the Amazon jungle area is carefully examined [4].

Small-scale gold mining is a very seasonal and transient occupation [5]. Depending on weather, available infrastructure, and gold discoveries, miners move rapidly from one site to another, or enter and leave the area (and profession) altogether. This constant flux of individuals in and out of mining sites makes estimates of population sizes very difficult. Furthermore, since there is no guarantee that those leaving the sites will be similar to those arriving, it is difficult to ensure that the 'pool' of individual characteristics present on the interview data is representative.

The potential for selectivity biases exists whenever individuals not captured in the sample differ significantly from those in the sample in terms of the variables of interest. It is quite likely that some portion of the mobility in these gold mining communities is directly or indirectly linked to malaria, thereby creating some potentially serious selectivity biases in our sample. These biases can take on several forms. First, miners suffering relatively higher malaria prevalences might have abandoned the survey sites, or even the profession by the time the questionnaires were administered. Second, better-informed individuals might avoid gold mining areas altogether. Since we have no information on those absent on the interview date, it is impossible to statistically control these potential selectivity biases.

The 'life cycle' of gold mining sites presents another source of potential bias. Gold mining camps evolve over time. Each phase can display different environmental, socioeconomic, demographic, and epidemiological characteristics. In an effort to capture several stages in this 'life cycle' and control for this potential bias, the CEDEPLAR group selected four sites at different phases of the 'cycle'. Serrinha was very new, Manelão and Pista do Arraia were in intermediate positions, and Cuca was the oldest and most settled.

Finally, the Amazon region is not environmentally uniform, making site selection even more difficult. There are vast differences in topography, ground cover, drainage patterns, and soil quality even within confined geographic areas. This diversity provokes entomological as well as economic differences that can influence malaria. The presence of gold mining camps can also disrupt natural ecosystems to differing degrees. At the Cuca camp, for example, natural drainage patterns had been rerouted to aid mining activities. A relatively large area had been deforested, creating new mosquito breeding habitats. At the other end of the degradation spectrum covered by our small sample, Serrinha was the least disturbed.

In spite of these and other complications associated with sampling from itinerant miners in ever-changing ecosystems, I believe the CEDEPLAR data are adequate for analytical purposes relating to mining communities in southern Pará. It must be kept in mind that the extent to which the results presented below can be transferred to other endemic areas depends on ecological similarities and the socio-economic characteristics of the specific populations under study.

Descriptive statistics generated by questionnaires administered to samples of all miners present during the July 1984 site visits are presented in Tables 1A–E.

Table 1 Descriptive statistics

Variables	Mean	Median	SD
(A) Cuca $N = 104$			
Cases of malaria* (per individual)	2.53	1.41	3.60
Monthly income (000's of Cruzeiros)	351.0	200.0	702.0
Age (yr)	27.3	23.8	10.5
Exposure (yr)†	2.24	1.27	2.21
Days inactive‡	9.86	6.50	9.74
Days hospitalized‡	1.67	0.33	3.64
Medical expenses‡ (000's of Cruzeiros)	120.0	74.0	173.0
(B) Serrinha $N = 104$			
Cases of malaria* (per individual)	1.99	0.78	3.21
Monthly income (000's of Cruzeiros)	176.0	102.0	215.0
Age (yr)	28.5	25.2	10.1
Exposure (yr)†	2.58	2.00	2.13
Days inactive‡	13.30	10.30	10.00
Days hospitalized‡	1.50	0.13	3.59
Medical expenses‡ (000's of Cruzeiros)	158.0	80.0	206.0
(C) Manelão $N = 142$			
Cases of malaria* (per individual)	2.02	1.05	3.25
Monthly income (000's of Cruzeiros)	217.0	100.0	608.0
Age (yr)	28.1	24.9	9.96
Exposure (yr)†	2.50	1.99	2.17
Days inactive‡	7.71	4.23	7.95
Days hospitalized‡	1.26	0.28	2.67
Medical expenses‡ (000's of Cruzeiros)	100.0	55.0	140.0
(D) Pista do Arraia $N = 30$			
Cases of malaria* (per individual)	2.33	0.94	3.93
Monthly income (000's of Cruzeiros)	775.0	600.0	822.0
Age (yr)	27.50	25.50	8.21
Exposure (yr)†	3.00	2.04	2.51
Days inactive‡	17.60	15.00	13.00
Days hospitalized‡	4.40	4.00	4.56
Medical expenses‡ (000's of Cruzeiros)	271.0	258.0	133.0
(E) Entire sample $N = 388$			
Cases of malaria* (per individual)	2.17	1.06	3.39
Monthly income (000's of Cruzeiros)	279.0	140.0	593.0
Age (yr)	27.9	24.8	10.0
Exposure (yr)†	2.29	2.00	2.20
Days inactive‡	9.84	5.90	9.45
Days hospitalized‡	1.56	0.27	3.28
Medical expenses‡ (000's of Cruzeiros)	123.0	70.0	170.0

*Cases of malaria contracted while living and/or working at any gold mining site.
†Years spent living and/or working at any gold mining site.
‡Refers to last completed malaria infection in gold mining sites.

3. MEASURING MALARIA

A first step in empirically estimating the interrelationships between malaria and a vector of socioeconomic variables is to quantify the disease itself, a difficult task even in controlled clinical and laboratory environments. Due to the methodological, conceptual, and logistical difficulties associated with the widespread use of blood slides [2], I relied on individuals' reports of the number of cases of malaria suffered within a given time period. However, since miners in that area are likely to associate every attack of fever with a distinct case of malaria, a decision had to be made as to the relevant unit of observation, i.e. a clinically discernible case of malaria versus a fever that may or may not have represented a unique case of the disease.

The recurring nature of the disease caused by potentially long dormant stages within the human host can complicate clinical diagnoses of a unique cases of malaria [6]. In areas where reinfection is likely, differentiating new cases from recurring ones becomes almost impossible * In addition, relapses may occur in cases in which the disease was improperly treated

Not all malaria cases (reinfections, recurrences, or relapses) are of the same intensity, even for a given individual. The effects of a single attack of the disease will depend, among other things, on the type of malaria contracted, the health status of the infected individual, the quickness with which he seeks treatment, the type of treatment received, and the number of previous attacks—all of which, to a certain extent, are interdependent. Intensity variations confound cost estimates, and limit the certainty with which individuals can self-diagnose.

Further complicating malaria measurement issues is the fact that field researchers are often forced to rely almost exclusively on questionnaire responses to quantify the disease, and these responses can suffer from several biases.

The most obvious of these biases stems from the fact that many of the positive responses are likely to be based on self-diagnosis. The validity of these responses will depend on the individuals' abilities to differentiate attacks of malaria from the ill effects prompted by other competing, or complicating ailments. Our field experience has supported the hypothesis that, with the possible exception of ill-informed individuals suffering their first bouts of malaria, the vast majority of people living in the malaria endemic areas of the Amazon frontiers are experienced enough to perform reliable self-diagnoses.

The second major problem associated with response data is recall error. Individuals who have spent long periods of time in endemic areas and those who have suffered many cases may give less reliable accounts of the actual numbers of their respective malarial infections. Long-time residents may forget the earlier cases, and those suffering from seemingly countless infections in relatively short time spans may overestimate the actual number of bouts.

Finally, in judging the relative merits of malaria measures based on laboratory tests and those derived from questionnaire responses, researchers must specify exactly what they are trying to measure. If their work focuses on cases of malaria verified by laboratory techniques, then blood slides are the only certain source of information. If, as is the case in this paper, researchers are interested in the economic consequences of the physical effects produced by an attack of malaria, regardless of the uniqueness of the infection or its exact definition, then verbal responses to questionnaires can be sufficient.

In the final analysis, verbal responses are often our only comprehensive, individual-specific source of information. This is especially true in areas in which malaria can be treated in either the public or private sector, or both. What is proposed in the next section is a scheme for testing the reliability of questionnaire responses, and two methods of numerically representing such data to minimize the effects of the above-mentioned errors.

4. A RELIABILITY TEST AND THREE DIFFERENT MEASURES OF MALARIA

Given clinically demonstrable parasite gestation periods and the extended dosages and effects of curative drugs, there seems to be an upper bound on the number of *treated* cases of malaria that any person can suffer in a specific time period. Any respondent who reports an incidence of malaria above the established upper bound can be assumed to be overestimating the actual number of distinct cases suffered, and/or including the effects of other diseases or infections in his estimates. The upper bound adopted for this test is one case of malaria per month.

An exposure-weighted index of malaria was derived by dividing the number of reported cases of malaria by the number of months each miner claimed to have been in the gold mining area. Any value exceeding one was deemed unreliable. Ninety-seven percent of the cases fell below the established upper bound, but some individuals registered indices as high as six. For the sample as a whole, the mean value of the index was 0.13.

Virtually all of the miners passed this reliability test, indicating that even though the range of their answers was quite wide (0–19), the exposure-weighted responses were not unreasonable.† The first measure of malaria, NUMALGAR, is simply the number of malaria cases each miner reported having suffered since arriving in the mining region. The average number of malarial episodes individual miners

*A possible exception would be the first appearance of a different strain of malaria in an individual having previously suffered from the disease For example, a miner who had suffered three bouts of vivax and then reports a case of falciparum can certainly be counted as having at least two unique infections.

†This simple test captures those individuals who, on average, have suffered an unacceptably high number of malaria episodes since their arrival in the mining area The test cannot detect those miners reporting excessive malaria bouts during sub-intervals of their respective stays in the camps. Nor does this test consider the fact that some individuals could have been infected, but not feverish, when they first arrived at the camps or on the day of the interview.

suffered while in the mining region was 2.2, with a standard deviation of 3.4. This relatively large variance suggests that some responses might be exaggerated. If the measurement error associated with NUMALGAR is random, then confidence intervals will be overly restrictive. If, as I suggest, the errors are heteroskedastic and increase with reported malaria, then confidence intervals will be too liberal [7].*

There are a number of ways to correct for this suspected nonrandom exaggeration. The method I have chosen recodes the reported cases of malaria so as to aggregate unlikely responses and reduce their relative statistical weight. All relatively high responses are treated as equally suspect, and a series of discrete categories are generated to weight these potential over-estimators equally.

The discrete measure of malaria, CATMAL, classifies responses into three categories: zero for those who never suffered a case of malaria; one for those who suffered from one to three cases; and two for those reporting four or more cases while working in the mining area. The immediate appeal of this categorical approach is that it allows researchers to regroup individual responses into more convincing subsets. For example, those responding zero are likely to have reliable recollections. We can also be fairly confident about those registering one to three cases of malaria. The least reliable group, in this case 4–19 reported malarial infections. can be lumped into a single category.†

In the case of strong doubts as to the validity of multiple counts of self-diagnosed malaria, researchers can also adopt a simple dichotomous measure. I have derived such a measure, DIMAL, which takes on the value one for all those who reported suffering at least one case of malaria while working in the gold mining areas, and zero for those who had not. This measure will also be of interest to researchers who choose to focus on the malaria-free population.

Before going on to test the robustness of the three measures presented above, the role of exposure to malaria vectors should be reemphasized. To state simplistically that three cases of malaria is a more reliable answer than eight is to reject the role that exposure to risk is known to play If we control for exposure, it will be possible to more closely discriminate between the reliable responses and those in need of deletion or recoding. Continuing with the example of three and eight responses, I would associate far more accuracy to eight cases occurring over the course of 10 years in a high-risk area, than to three cases reported by a miner who had arrived from a zero-risk area just 30 days before the interview date In a cursory way, the simple test outlined at the beginning of this section identifies the highly unlikely suspect cases, which, in this analysis, were excluded before the process of recategorization was undertaken.

In the analysis that follows, I use each of the measures of malaria derived above (NUMALGAR, CATMAL, and DIMAL) in examining the links between a series of socioeconomic and environmental characteristics and the number of malaria cases suffered by individual gold miners. The absence of significant differences in the results generated by the three different measures of malaria will, I believe, strengthen the case for the continued use of questionnaire response data in future malaria research.

5. MODEL SPECIFICATION

The individual and environmental factors suspected of directly influencing the reported number of cases of malaria are included in the following equation:

$$\begin{aligned} \text{EQ1: } \text{MEASURE}_{ji} = {} & \text{CONSTANT} \\ & + a1\text{EXPOSURE}_i + a2\text{EXPOSURE2}_i \\ & + a3\text{CUCA}_i + a4\text{SERRINHA}_i \\ & + a5\text{MANELÃO}_i + a6\text{INCOME}_i \\ & + a7\text{AGE}_i + a8\text{PREMAL}_i \\ & + a9\text{RURAL}_i + a10\text{PARA}_i \\ & + a11\text{MARANHÃO}_i + a12\text{GOIAS}_i + e_i \end{aligned}$$

where 'i' represents the ith individual, $a1$ through $a12$ are the coefficients to be estimated, 'j' stands for one of the three measures of malaria being used, and e_i is the error term assumed to display all the standard properties. A complete list of the variables included in this analysis is presented in Table 2.

5.1. Dependent variables

As noted in Section 4, three different measures of malaria suffered by individual miners are used in this analysis. Three separate equations are estimated, one for each measure. The independent variables included in each equation are identical to facilitate comparisons across models. The variable MEASURE_j appears in the following order of increasing levels of aggregation: actual questionnaire responses (NUMALGAR), a categorical measure (CATMAL), and finally the dichotomous treatment (DIMAL).

NUMALGAR is the number of cases of malaria an individual claimed to have suffered, i.e. the actual questionnaire response. Of the 388 miners interviewed, 255 (66%) reported having suffered at least one case of malaria while working in the mining area, and the majority of those, 62%, claimed to have had more than one bout with the disease.

CATMAL is a discrete measure of malaria, taking on the values zero to two. Miners who never experienced a case of malaria fall into category zero. Category 1 is for those who suffered between one and three cases. Category 2 contains miners who suffered four or more cases while working in the mining area.

DIMAL is a dichotomous measure of malaria, registering zero for those who never suffered a case of malaria while working in the gold mining area, and

*Recent work by Mariano *et al* [8] on measurement error suggest possible statistical tests and sample size criteria in determining the proper treatment of limited dependent variables.

†In the absence of skewed heteroskedastic disturbances, the categories chosen by the researcher will not affect underlying statistical relationships [7].

Table 2. Variable list

Variable	Description
AGE	Years
CUCA MANELÃO SERRINHA	Gold mining sites: 1 = if interviewed at that site 0 = interviewed elsewhere
EXPOSURE	Months of exposure in high risk mining areas
EXPOSURE2	Exposure squared
INCOME	Estimate of last month's income
MEASURE (a) NUMALGAR (b) CATMAL (c) DIMAL	Measures of malaria: Reported number of malaria cases 0 = 0 malaria, 1 = 1 to 3 cases, 2 = 4 or more cases 0 = 0 malaria, 1 = 1 or more cases
PARA MARANHÃO GOIAS	State where miner grew up 1 = raised in that state 0 = raised elsewhere
PREMAL	Previous experience with malaria 0 = never suffered malaria before coming to gold mining camps 1 = suffered at least 1 case
RURAL	Origin 1 = rural origin 0 = urban

one for those who had, regardless of the number of infections.

5.2. Independent variables

The independent variables have been placed in four categories reflecting their expected influence on the dependent variables, $MEASURE_j$. The first category explores the influences of exposure to the malaria vector. The second captures the effects of income on malaria prevalence among individual miners. The last two categories focus attention on proxies for individuals' understanding of the transmission process, and experience in diagnosing, treating, and avoiding malarial infections.

5.2.1. Risk of exposure. I expected the number of reported cases of malaria to be directly related to the amount of time a miner spent in the gold mining area. Once the other included variables have been controlled for, EXPOSURE (measured in months) will capture the effects of the risk associated with simply living and working in gold mining areas for extended periods of time. EXPOSURE2, the square of EXPOSURE, will shed some light on the risk of spending additional time in these areas. A negative and significant coefficient on EXPOSURE2, for example, would suggest decreasing marginal risk as a function of time spent in mining camps. A negative coefficient on EXPOSURE2 would also support the acquired immunity hypothesis that the body's immune system adjusts to repeated malarial infections in such a way as to minimize the adverse effects of subsequent malarial attacks. In the long run, miners may be unaware they are parasite carriers and ignore the minor fevers they suffer [6, pp. 59–61]. Such cases represent an under-reporting of actual malaria attacks, though *not* an under-reporting of debilitating malarial fevers, which are of primary concern here.

CUCA, SERRINHA, and MANELÃO are three of the four mining sites included explicitly in this analysis. They appear in the equations as 0/1 dummy variables to capture the site-specific effects of income, price and environmental differences. Pista do Arraia was unique in terms of its isolation and strict government-controlled migration, and was therefore chosen to be the omitted reference site.

5.2.2. Income. The effects of income on the number of cases of malaria reportedly suffered by individual miners are likely to work in opposite ways. First, standard consumer theory suggests that individuals with higher incomes should be better able to adjust their consumption baskets in ways that protect them from the disease. Better housing and increased use of repellents, for example, would reduce vector contact thereby reducing the risk of contracting malaria. However, given the precarious and very homogenous nature of lifestyles within these mining camps, it is unlikely that consumption differences (via income differences) will provoke any malaria-reducing changes.

On the other hand, a mining-site selection process might be at work if some miners choose to accept higher malaria prevalence rates in some sites in return for higher income. For example, miners in Serrinha averaged 1.99 cases of malaria per year and earned approx. CR$176,000 per month, while their peers in Pista do Arraia suffered 2.33 cases per year but earned over 4 times more (CR$775,000 per month). A positive coefficient on monthly income in these models would suggest such a process is at work.

5.2.3. Individual characteristics. An individual's age (AGE) is expected to serve as a proxy for accumulated experience in dealing with malaria and relative risk aversion. Age, in and of itself, is not known to affect the probability of contracting the disease. Older individuals are assumed to be better informed

regarding techniques of reducing contact with infected mosquitos, either through modern or traditional means, and to seek timely and more effective treatment. In addition, risk aversion generally increases with age. I expect this pattern to be present even in gold mining, a highly risky profession, and I also expect these differences in risk aversion to influence the lifestyles of miners and affect their respective chances of contracting malaria.

Experience in diagnosing and treating malaria *prior* to arriving at the mining camps is also expected to influence the number of cases of malaria suffered by miners. For example, individuals with previous experience with the disease are also more likely to be familiar with its transmission process, and act to avoid contracting the disease. Field experience has convinced me that the learning curve for malaria is initially quite steep, which suggests that previous experiences with the disease should decrease the probability of subsequent malaria attacks. A dummy variable (PREMAL) was included to capture the importance of previous malaria experience. PREMAL takes on the value of one if a miner reported contracting at least one case of malaria *before* coming to the gold mining area. If he had not, PREMAL takes on the value zero.

The final independent variable in this category (RURAL) was included to reflect the predominance of malaria in rural areas of Brazil. Persons migrating from rural communities or farms are expected to be better informed as to disease diagnoses and transmission processes, as well as better acquainted with a series of home remedies and modern curative drugs. For miners whose declared occupation prior to arriving at the mining camps was agriculture, RURAL took on the value one, and zero otherwise.

5.2.4. Origin. The last group of explanatory variables was included to capture the regional nature of the distribution of malaria in Brazil. The states of Pará, Maranhão, and Goias all have high Annual Parasite Indices relative to most of the other states represented in the sample [1]. Varying state-specific disease prevalence rates are expected to provoke changes in behavior patterns of former residents that might decrease the number of cases suffered. The three states appear dichotomously in the model; with all other states of origin aggregated to form the omitted case.

6. EMPIRICAL RESULTS

Equation EQ1 was estimated three times; once for each measure of malaria. Because of the censored nature of the original data, the first equation including actual questionnaire responses was estimated using a TOBIT—Maximum Likelihood technique [9]. The equation containing the three-group categorical dependent variable was estimated using an Ordered Probit—Maximum Likelihood technique. Finally, the equation containing the dichotomous dependent variable was estimated using a simple Probit model [10]. Results of the estimation procedures appear in Tables 3–5, and are discussed below.

Recall that all three versions of equation EQ1 represent efforts to explore the influence of a series of individual and environmental factors on the number of cases of malaria suffered by each respondent. One important exclusion criterion was that the average exposure-weighted malaria responses could not exceed one case per month for any miner. An unfortunately high number of missing values for some independent variables further reduced our usable sample size to 237.

The results of three models are presented jointly to facilitate comparisons across models, and to underscore the very consistent interrelationships identified by the different measures of malaria. The absolute values of the estimated coefficients are, of course, different, but the signs and the levels of significance are very similar, adding credibility to the use of questionnaire responses in this type of study.

The amount of time a miner spent in a gold mining area (EXPOSURE) was directly related to

Table 3. Determinants of malaria, TOBIT–Maximum Likelihood estimates, dependent variable = NUMALGAR

Independent variables	Estimated coefficient	t-ratio[a]
RISK		
EXPOSURE	0.24	5.33***
EXPOSURE2	−0.002	3.97***
CUCA	1.02	0.68
SERRINHA	0.48	0.31
MANELÃO	0.84	0.55
INCOME		
MONTHLY INCOME	0.0009	0.79
EXPERIENCE		
AGE	−0.06	1.60
PREMAL	−0.56	0.66
RURAL	−0.62	1.00
ORIGIN		
PARA	−0.24	0.23
MARANHÃO	−0.43	0.47
GOIAS	−0.60	0.52
INTERCEPT.		
CONSTANT	−0.51	0.24
LOG-LIKELIHOOD	−475.02	
N	237	

[a]Absolute value of t-ratios are asymptotic and *, ** and *** indicate coefficients are significant at the 10, 5 and 1% levels, respectively.

Table 4. Determinants of malaria, Ordered Probit—Maximum Likelihood estimates, dependent variable = CATMAL

Independent variables	Estimated coefficient	t-ratio[a]
RISK		
EXPOSURE	0.08	5.80***
EXPOSURE2	−0.001	4.45***
CUCA	0.24	0.66
SERRINHA	0.05	0.12
MANELÃO	0.16	0.44
INCOME:		
MONTHLY INCOME	0.0001	0.51
EXPERIENCE:		
AGE	−0.02	2.17**
PREMAL	−0.13	0.63
RURAL	−0.11	0.66
ORIGIN		
PARA	0.16	0.50
MARANHÃO	−0.14	0.46
GOIAS	−0.02	0.07
INTERCEPT:		
CONSTANT	−0.01	0.02
CHI-SQUARE (12)	73.5	
N	237	

[a]Absolute value of t-ratios are asymptotic and *, ** and *** indicate coefficients are significant at the 10, 5 and 1% levels, respectively.

Table 5 Determinants of malaria, Probit—Maximum Likelihood estimates, dependent variable = DIMAL

Independent variables	Estimated coefficient	t-ratio[a]
RISK		
EXPOSURE	0 09	5.62***
EXPOSURE2	−0 001	4.25***
CUCA	0 13	0.32
SERRINHA	−0 21	0.49
MANELÃO	0 12	0 29
INCOME		
MONTHLY INCOME	0 0008	0.72
EXPERIENCE		
AGE	−0.03	2 45**
PREMAL	−0 0008	0 00
RURAL	−0 07	0 34
ORIGIN		
PARA	−0 26	0 73
MARANHÃO	−0 38	1 24
GOIAS	−0 17	0 51
INTERCEPT		
CONSTANT	0 16	0 26
CHI-SQUARE (12)	62 6	
N	237	

[a]Absolute value of t-ratios are asymptotic and *, ** and *** indicate coefficients are significant at the 10, 5 and 1% levels, respectively

the number of cases of malaria he suffered This anticipated result, in that it supports the notion that exposure to vectors in a high risk area, is a good predictor of malaria prevalence. The more time a man spends in any mining community, *ceteris paribus*, the more cases of malaria he is likely to contract. The square of EXPOSURE (EXPOSURE2) tests for increases or decreases in the rate of risk of exposure. The significant negative coefficient on EXPOSURE2 indicates that the initial months of exposure carry the highest marginal risks. The combined coefficients on EXPOSURE and EXPOSURE2 suggest that although prolonged exposure increases the chances of catching additional cases of malaria over a relevant range, the marginal risk decreases. I believe these decreased relative risks reflect a selectivity bias inherent in the sample population and/or the importance of acquired immunity among miners.

Individuals whose natural immune systems have adjusted to the constant presence of parasites in their blood streams and tissues are less likely to suffer debilitating bouts of malaria. These so-called asymptomatic carriers almost certainly exist in the gold mining communities under study, and are very difficult for disease control officials to locate. They therefore pose a serious threat to attempts to interrupt disease transmission since, although they do not react to malarial infections in the normal way, they are still capable of transmitting the disease to others via vector contact.

None of the mining camp dummy variables (CUCA, SERRINHA, MANELÃO) were significantly different from the omitted camp (Pista do Arraia) in any of the equations This result suggests that, although significant intraregional ecological differences exist, the macro-environment of the Amazon frontier is generally conducive to malaria transmission.

Income was not linked to individual malaria prevalence rates, thereby lending no support to the hypothesis that miners willing to switch sites in search of higher returns do so at the risk of an increased number of malarial attacks. However, more detailed time-series data on miners' earnings and disease patterns is needed to test the relationship thoroughly.

An individual's age (AGE), controlling for time spent in mining camps, was negatively related to the number of cases of malaria he suffered. In other words, older gold miners, regardless of their accumulated exposure, registered significantly fewer attacks of malaria than their younger peers. This may be due to their greater relative risk adversity vis-a-vis their junior miners.

The remaining variables in the experience group indicated consistent but statistically loose relationships between the number of cases of malaria and previous experience with the disease. Consistently negative coefficients across the three models suggest that previous experience with malaria before coming to the mining (PREMAL) camps did tend to reduce the number of malaria cases suffered, though the data did not establish a definite link.

Finally, a miner's origin, especially in the cases of Maranhão and Goias seemed to influence the number of malaria cases he reported. One potential reason for this weak result is that malaria in Brazil is endemic in relatively few limited geographic areas, even within states registering high aggregate prevalence rates. Since we do not know the exact municipality of origin of each miner, the potentially important impact of this information is lost in state-level aggregation.

7. COSTS OF MALARIA

The short-run costs to an individual gold miner of a case of malaria will depend on the number of days he is rendered inactive, the arrangements for distribution of proceeds within his working group, and his out-of-pocket expenses on medicine and medical treatment, including travel

The most difficult aspect of measuring the microeconomic impact of malaria is estimating its debilitating physical effect. Individual reactions to malaria depend on the physical health of the newly infected man, as well as his previous disease and treatment history. Differences in physical stamina and socioeconomic status may also confound efforts to capture empirically productivity losses due to malaria. For example, two men who are 'equally ill' by laboratory standards can display vastly different productive capacities, as well as respond differently to economic incentives.

All of these factors help explain the very wide distribution of reported days of inactivity due to malaria (Table 1E). I chose the median value of this distribution as a representative datum for calculating costs, thereby limiting the importance of those cases involving long periods of inactivity—up to 45 days in one instance—which are unlikely to reflect the effects of a single, treated case of malaria. Reported days of inactivity may also be greater than days 'sick' if miners leave the camps and do not return until they are completely cured. The median number of days of inactivity reportedly due to malaria, inclusive of days spent in hospitals, was 5.9. The mean value was 9.8.

Deriving estimates of individual income losses caused by absences from work required insight into current small-scale gold mining practices in rural Brazil [5]. Contemporary gold-mining activities have switched from a generally individual manual panning technique to one involving suction pumps, carried out by teams of 5–6 men whose sustenance is provided by a 'patrão'. For each dig, lasting 7–20 days, the output of the team depends on the efforts of each individual. The 'patrão' gets the lion's share of the gold—relatively larger if he provides pumps and other capital equipment— and each worker is guaranteed a certain percentage of the remainder. Camaraderie and team experience certainly enhance productivity. When a member of the team contracts malaria, he can guarantee receipt of his share of the proceeds of the particular dig by providing a substitute laborer, to whom he pays a fixed daily wage

Field data indicate that the median individual monthly monetary income from gold mining was approx. Cr$ 140,000, or Cr$ 4,667 per day,* with a mean value of Cr$ 279,000 Short-term labor to replace ill miners could be hired at the rate of Cr$ 10,000 per day †

Finally, median total medical expenses gold miners reported for their last malarial infection, including hospital fees, etc., was Cr$ 70,000 Mean value of total medical expenses was Cr$ 123,000

We are now in a position to estimate the average total July 1984 Cruzeiro cost of a single case of malaria suffered in the four gold mining communities under study Since monthly production shares are guaranteed to those who begin each dig, share losses due to malaria are zero if a substitute worker is provided ‡ The median number of inactive days was 5 9, during which time sick workers had to pay a substitute at the daily rate of Cr$ 10,000. Median out-of-pocket expenses totalled Cr$ 70,000. Thus, the estimated total cost or income loss of a single bout of malaria to an average gold miner would be Cr$ 59,000 + Cr$ 70,000 = Cr$ 129,000, or 9.73 ORTNs (inflation-free government bonds) per case of malaria.§ This sum represents approx. 12% of the median annual salary (8 working months of dry season).

Extending this analysis, a miner at the mid-point of our sample distribution contracts roughly one case of malaria per year, which for the entire 338-man sample, represents a total annual estimated cost of 338 × 9.73 ORTNs = 3775.24 ORTNs, or approx. U.S.$ 25,379.‖

Replicating the above calculations using mean, as opposed to the median, values for all variables raises the cost of malaria substantially. 9.8 days × Cr$ 10,000 = Cr$ 98,000 in replacement labor. Using average medical expenses, total cost to an individual miner is now Cr$ 98,000 + Cr$ 123,000 = Cr$ 221,000 or 16.67 ORTNs. Extrapolating the expected costs for the sample now generates a total annual group cost of 16.67 ORTNS × 388 × 2 (attacks per year) = 12,936 ORTNs or U.S.$ 86,962. Though the median values were initially used to control for potential response exaggerations, the true cost probably lies somewhere between the mean and median estimates.

8. CONCLUSIONS

There has been some confusion regarding the wisdom and feasibility of empirical studies of tropical diseases, as well as a general tendency among physicians and laboratory scientists to shun attempts at quantifying malaria, especially on the basis of field data collected via questionnaires. The pros and cons associated with available laboratory measures of malaria are discussed elsewhere [2] The goal of this paper was threefold: (a) to add statistical credibility to questionnaire response data; (b) to simultaneously test a series of hypotheses regarding the determinants of malaria prevalence rates among a group of itinerant gold miners; and (c) to generate estimates of the microeconomic costs of malaria for this specific subset of the frontier population.

From a methodological point of view, the vast majority of miners' responses regarding malaria prevalence could not be rejected as unreasonable, and the statistical interrelationships presented here were not significantly affected by the measure of malaria employed as the dependent variable. The latter underlines the fact that statistical 'noise' associated with dependent variables that is not concentrated at cut-off points in the categorization process does not affect parameter estimates; a reconfirmation that will hopefully boost the reliability of questionnaire responses in the minds of some researchers, and provide incentive for continued work on collecting, refining, and analyzing such data.

Several interesting relationships consistently linked the number of malarial infections suffered while working in the gold mining areas to a list of included variables serving as proxies for exposure to vector contact, and the means and experience necessary for individuals to limit malaria prevalence rates effectively. As expected, living and working in a high risk

*Miners' incomes are subject to wide variations across individuals and over time, primarily due to luck in striking gold My estimates of miners' incomes are based on their stated incomes for the month preceding the interview date No systematic response bias is expected, but the estimates should be interpreted with care

†It should come as no surprise that short-term workers earn a higher daily wage than their full-time counterparts The Cr$ 4,667 per day wage represents a median value, and is not corrected for age, experience, or the type of work performed In addition, the part-time wage can have a real value of zero during periods of unemployment, in which case the *expected* daily wage will certainly be lower

‡I assume that total group production will not fall when a potentially less experienced substitute laborer takes the place of a full-time miner For the present analytical purposes, this is an innocuous assumption in that its violation will lead to an understatement of the actual microeconomic costs of malaria

§The ORTN (inflation-free government bond) for July 1984 was Cr$ 13,254 67 These figures reflect short-term estimates of the out-of-pocket costs incurred by gold miners suffering from malaria They do not encompass any of the potentially serious long-term individual or joint productivity losses attributable to the disease, nor do they include the important non-economic costs in the form of human suffering, etc.

‖In July 1984, 1 ORTN equalled approx. U.S.$ 6 7725.

area was the most powerful determinant of the likelihood of contracting the disease. Income was not found to be associated with malaria prevalence, indicating the absence of any mining-site mechanism trading off increased income for more malarial infections across the mining camps selected for study. Finally, the hypothesized negative relationship between age and reported malaria was substantiated, providing support for the role of accumulated experience and risk aversion in malaria avoidance.

Inconclusive evidence suggests that information about, and/or experience with, malaria prior to arrive at the mining area was influential in reducing the number of cases a given individual contracted. Similarly weak, but consistently negative correlations surfaced between malaria prevalence, and miners' origins and previous occupations. Since all of these variables served as proxies for access to information about the disease, there seems to be limited scope for information campaigns as a policy tool for decreasing the malaria prevalence rates in the very special case of the gold mining communities investigated here.

Special caution should be taken in interpreting these results and extrapolating them to other populations outside mining areas. All empirical results are derived from a unique subset of the Brazilian frontier population. Besides displaying atypical age and sex distributions, the sample is very likely to depict a highly skewed picture of the socioeconomic matrix of more heterogeneous frontier settlements. In addition, as noted above, the scope for modifications of these particular micro- or macro-environment to reduce the indices of malaria is very limited The same is definitely *not* true in other frontier communities.

Estimates of the out-of-pocket costs of malaria represented a substantial proportion (12%) of miners' incomes. I suspect the median value underestimates the true cost of malaria in these areas, primarily because of the sample selectivity biases which almost certainly omit the individuals who had suffered, or were currently suffering, severe bouts of malaria and were therefore not present at the camps at the time of the interviews. In addition, these estimates do not include the indirect and long-term costs associated with repeated malarial infections.

Interestingly, the cost estimates do include some of the socioeconomic adjustments (for example, guaranteed shares and hired labor markets) made in the gold mining communities that seem to accommodate malaria, and therefore limit its economic impact on infected individuals. Fruitful research remains to be done on the evolution of social structures and production schemes in endemic areas. This would be especially rewarding in light of current anti-malaria campaigns which focus on disease control, especially at the community level, rather than wholesale disease eradication.

Finally, while several authors have identified wide interpersonal differentials in malarial prevalence rates, and firmly linked these differentials to a series of socioeconomic and environmental factors, many of these relationships were not replicated in this study [2, 11]. This reemphasizes the importance of a flexible set of disease control measures that can be altered to fit the socioeconomic and ecological realities of specific endemic areas, as well as react to changes in the disease environments and other circumstances as frontier settlements evolve.

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