Malaria and Growth

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Abstract

Malaria ranks among the foremost health issues facing tropical countries. In this paper, we explore the determinants of cross-country differences in malaria morbidity, and examine the linkage between malaria and economic growth.

Using a classification rule analysis, we confirm the dominant role of climate in accounting for cross-country differences in malaria morbidity. The data, however, do not suggest that tropical location is destiny: controlling for climate, we find that access to rural healthcare and income equality influence malaria morbidity.

In a cross-section growth framework, we find a significant negative association between higher malaria morbidity and the growth rate of GDP per capita which is robust to a number of modifications, including controlling for reverse causation. The estimated absolute growth impact of malaria differs sharply across countries; it exceeds 0.25 percent per annum in a quarter of the sample countries. Most of these are located in Sub-Saharan Africa (with an estimated average annual growth reduction of 0.55 percent).

1. Introduction

Malaria ranks among the major health and development challenges facing some of the poorest economies.[1] Endemic in ninety-one countries, accounting for 40 percent of the world's population, malaria affects an estimated 300 million people. Though in most cases treatable, malaria is responsible for more than 1 million deaths per year. In Sub-Saharan Africa, the most affected region, malaria-related illnesses claim the life of one out of every twenty children below age five. For adults, mortality rates are lower but frequent debilitating attacks reduce the quality of life for chronic sufferers.

The human and economic costs of malaria have been recognised for centuries. The unravelling of the transmission mechanism in the late 19th century opened the way towards systematic antimalarial efforts. Initially, these efforts focussed on controlling the population of anopheles mosquitoes transmitting the parasite. DDT-based eradication programs achieved notable successes in countries with relatively low malaria incidence in the Mediterranean and in some Asian countries, but largely failed in high-incidence regions like Sub-Saharan Africa, and were largely abandoned in the late 1960s. During the last decades, antimalaria efforts have focussed primarily on reducing human exposure for given anopheles populations, primarily through the use of bednets and protective clothing, on reducing the health effects of malaria episodes, and more recently, on developing an effective vaccine.

The partial success of the eradication programs resulted in a sharp spatial concentration of malaria in tropical areas. The same areas also suffer most from a set other illnesses related to the economic development stage (Sachs 1997, 1999 and Gallup and Sachs 1998a,b), including intestinal diseases causes by contaminated water and communicable diseases such as tuberculosis.

Morbidity and mortality rates for this last group of diseases are strongly linked to income per capita levels (table 1). The link is bi-directional: impaired public health restrains economic development, while economic development, by increasing access to clean water and sanitation and by improving housing conditions, reduces the morbidity rates for these diseases (Gallup, Sachs, and Mellinger 1998).

[1] The debate on the development effects of malaria reaches back to the early part of this century. Ross (1911), Carter (1919), Sinton (1935/36) and Macdonald (1950) are among the classic studies. Recent studies include Conley (1975), Aron and Davis (1993), Gomes (1993), Hammer (1993), Mills (1993), Chima and Mills (1998), Gallup and Sachs (1998), Gallup, Sachs and Mellinger (1998) and Goodman, Coleman and Mills (1998a, 1998b, 1999).

Table 1. Malaria Mortality and Loss of DALYs in 1995

	Mortality (1000s)	*Mortality Age 0-4*	*Cases (1000s)*	*DALYs (1000s)*
Total	1,110	793	272,925	39,267
Males	572	417	136,572	20,188
Females	538	376	136,353	19,080
High Income	0	…	…	0
Low Income	1,110	…	…	39,267
Africa	961	745	237,647	34,506
Americas	4	0	2,043	130
Eastern Mediterranean	53	36	13,693	1,854
Europe	0	0	0	0
South East Asia	73	10	15,791	2,185
Western Pacific	20	2	3,751	591

Source: World Health Organization (1999). DALY: Disability Adjusted Life Years (Murray and Lopez 1996).

As a primarily rural parasitic disease transmitted by mosquito bites, malaria is less immediately affected by improved urban sanitation and housing in the course of economic development; indeed, after the failure of the eradication efforts, malaria has at times been portrayed as a largely unavoidable side effect of tropical location. The sizeable differences in malaria morbidity between countries with few geographic differences suggest, however, that location is not entirely destiny.

Economic development may influence malaria morbidity by providing households with the means to invest in antimalaria protection? notably insecticide-impregnated bednets and protective clothing? and in full medical treatment cycles. Furthermore, governmental capacity to provide comprehensive access to rural healthcare and to engage in local mosquito control arguably increases with economic development. To the degree that these channels are operative, malaria is as closely intertwined with development as the other tropical diseases most prevalent at early economic development stages.

The core of this paper is devoted to the empirical analysis of these linkages. Our paper builds on a sizeable prior literature examining the incidence and economic cost of malaria, primarily with a household or site focus. The household/site-specific approach provides an intuitive and attractive cost-assessment methodology based on high quality local data. By construction, it is, however, less suited for exploring other relevant questions, including the impact of macro policy variables on malaria morbidity across countries, and the importance of indirect effects of malaria on total factor productivity. These issues, more readily addressed in a cross-country comparative framework, are the focus of the present paper.

Based on morbidity data for a large group of countries in three five-year periods, we examine two issues. We begin by exploring the cross-country differences in malaria morbidity rates to ask whether such differences are adequately explained by climate differences (the "location as destiny" view), or whether economic variables such as income distribution and health care availability provide important additional explanatory power.

We then turn to the effect of malaria on economic growth in a standard cross-section growth framework. The cross-section methodology allows us to explore not only the net effect of malaria on growth, but also the transmission channels. Adding a malaria variable to a standard growth equation allows the identification of any residual effect on productivity. Such effects may arise from a variety of sources, including the effect of repeated worker absences on production patterns and specialization, malaria-prevention motivated reductions in internal and external labor mobility, and the potential loss of investment projects in tourism and infrastructure.[2]

Our approach to the second question is most closely linked to a series of papers exploring the link between geography, economic development and diseases by Bloom and Sachs (1998), Gallup, Sachs, and Mellinger (1998), and Gallup and Sachs (1998a,b). The papers employ a malaria exposure index, defined as the product of the land area subject to malaria and the fraction of malaria cases attributable to the most serious malaria variant, to explore the growth and income effect of malaria in a cross-country regression framework. Gallup, Sachs, and Mellinger (1998b) detect both a significant negative correlation between the 1994 malaria exposure index and the 1995 (log) income per capita level, and a significant positive association between declines in malaria exposure between 1966[3] and 1994 and the 1965 to 1990 per capita growth rate. Gallup and Sachs (1998) put the negative growth effect of malaria at more than 1 percentage point a year.[4]

[2] Many of these effects involve hypothetical alternative histories; their empirical importance is very hard to establish. Examples abound, though, ranging from the perceived need to combat malaria as a prerequisite for the construction of the Panama Canal to the positive effect of malaria eradication on Mediterranean tourism.

[3] The fraction of falciporum cases in total cases is available only for 1990. Under the assumption that the fraction is time invariant, malaria maps for 1966 and 1994 are digitized to derive the land share and create exposure indices for 1966 and 1994.

[4] For the exposure index to fall to zero, it must either be the case that the population of parasite carrying mosquitoes drops to zero, or that the fraction of the most serious parasite among all cases drops to zero. Our estimates, reported below, instead define the counterfactual as zero malaria morbidity, regardless of the malaria variety.

We extend this research in three directions, elaborated below. First, we use a panel data set on malaria morbidity rather than exposure as our malaria measure. Second, we formally explore whether, controlling for climate, other variables principally susceptible to intervention are useful in determining differences in malaria morbidity between countries sharing the same climate characteristics.[5] Third, we explicitly distinguish between the effects of malaria on total factor productivity and indirect effects of malaria on growth operating through lower growth elasticities of human and physical investment.

The remainder of the paper divides into five sections. Section two continues with a brief summary of the transmission mechanism and of the effects of malaria. Sections three and four describe the data before turning to classification rule analysis to examine the relative incidence of malaria across countries as a function of spatial, climatic and social factors. Section five examines the direct and indirect effect of malaria on growth. Section six concludes.

2. Background

Malaria is a parasitic disease transmitted by anopheles mosquitoes.[6] The human malaria exposure rate is determined by the fraction of the mosquito population carrying the parasite[7]; the life-expectancy of the mosquito relative to the parasite's incubation period; the use of night-time protection, in particular bednets (most mosquito bites occur between sunset and sunrise); the location of human populations relative to mosquito breeding grounds (the mosquito flight range is about 2 miles) and temperature.[8] The interplay of these factors results in significant cross-country differences in human exposure rate. Estimates suggest that the number of infective bites per person per year ranges from zero in nontropical areas to the low single digits in subtropic areas, and to between 40 and more than a 100 bites in some tropical areas. For a variety of reasons, including climate and the spatial distribution of parasite and anopheles species, Sub-Saharan Africa suffers the highest exposure rates, followed by parts of Asia and Latin America.

[5] Straus and Thomas (1998) provide a broad review of the links between health, nutrition, and economic development.

[6] For a detailed description of malaria, see Bruce-Chwatt (1985). Brinkmann and Brinkmann (1991) provide a concise treatment of malaria and health in Africa.

[7] Plasmodium falciparum, Plasmodium malariae, Plasmodium ovale and Plasmodium vivax. Plasmodium falciparum is associated with the most serious effects.

[8] At temperatures below 22 degrees Celsius, the ratio of the parasite's incubation period relative to the expected mosquito lifetime increases rapidly. At 18 degrees Celsius, the incubation period, at 55 days, exceeds the lifespan of 99.7 percent of a mosquito cohort (Snow et al. 1999).

Over time, the human immune system adjusts to combating the malaria parasite. Adult mortality in endemic areas is hence fairly low. Malaria mortality is concentrated among children between the age of 6 months and 5 years (the age at which the immunity inherited from the mother wanes and at the age at which children develop their own immunity), among travellers and migrants from nonmalarial into malarial regions, among populations in previously nonmalarial regions undergoing climatic change, and among populations with repressed immune system, including pregnant women and individuals suffering from HIV.

A typical bout of malaria lasts from about 10 to 14 days,[9] with 4 to 6 days of near complete incapacitation, and recuperation periods of 4 to 8 days characterised by fatigues and weakness. Mild malaria is characterised by one or two episodes of malarial fever per year, coupled with headache, nausea, fatigue and diarrhea, with relatively few side effects between episodes. Severe malaria, primarily in Plasmodium falciporum infections most prevalent in Sub-Saharan Africa, results in impaired consciousness, weakness and jaundice, and accounts for most fatal cases.

Antimalaria efforts have been four-pronged: targeting the reduction of the mosquito population, minimizing the number of infective bites for a given mosquito population, developing antimalarial drugs and an effective vaccine. The control of the anopheles populations dominated in the early postwar period. Widespread use of DDT coupled with the coating and draining of breeding grounds resulted in a substantial reduction in mosquito populations and malaria morbidity in the subtropics, notably southern Europe (Spain, Greece) and parts of Asia (Malaysia, Singapore) from 1940 to the late 1960s, in turn fueling optimism that malaria could be rapidly eradicated. “For the first time it is economically feasible for nations, however underdeveloped and whatever the climate, to banish malaria completely from their borders.” (Russell 1955)[10]

The optimism proved premature. While substantial inroads were achieved in the subtropics, controlling malaria in the tropics proved far more challenging. The effectiveness of the eradication effort was reduced through a combination of far higher human and mosquito parasite carrying rates, the prevalence of anopheles species particularly suited to malaria transmission, a climate conducive to all-year exposure and the gradual development of insecticide resistance, and evidence that increasingly pointed to significant adverse side effects with the pervasive use of insecticides. In consequence, eradication plans were largely abandoned in the late 1960s. Malaria prevention efforts have since shifted towards more easily implementable local protection methods, focussing on partial controls of breeding grounds and in particular, on the use of insecticide impregnated mosquito bednets to minimise infective bites for a given mosquito population (table 2).

[9] Hempel and Nájera (1996) and Snow (1999) provide detailed discussions.

[10] See also Pampana (1969).

Table 2. Malaria Mortality Rates
(per 100,000 population/annum)

	1900	*1950*	*1970*	*1997*
Sub-Saharan Africa	223	184	107	165
Rest of World	192	39	7	1

Source: World Health Organization (1999).

Better medical treatment of infected individuals has been the second prong of the attack on malaria. A range of antimalarials (Gilles 1991)[11] are effective in eliminating parasites in the blood (though not in the liver) within a short time, at a cost of US$1-5 per bout. Significant challenges remain, however, as selection pressures, coupled with incomplete treatment and eradication cycles, tilt parasite and carrier populations towards strains with greater resistance to commonly used antimalarials and insecticides. Longer term, vaccination is viewed as the next significant step forward in reducing malaria morbidity and mortality.

Over the course of the century, malaria mortality and, to a lesser extent, morbidity has sharply declined outside Sub-Saharan Africa, though at a decelerating rate. Sub-Saharan Africa, only partially involved in the global eradication efforts, has not witnessed a commensurate decline in either mortality or morbidity; indeed, both absolute cases and mortality rates have recently trended upward (table 2).[12] The sustainability of the decline outside of Sub-Saharan Africa remains in question. While medical advances, notably the expected advent of an effective vaccine, promise further reductions, natural climatic changes[13] coupled with the increasing mobility of the human hosts and, as a side effect, mosquitoes,[14] raises the likelihood of more frequent malaria epidemics.[15]

3. Data

The incidence of malaria, like most tropical diseases, is measured rather imprecisely, placing particular value on consistency in cross-country data. We rely on a recent data set

[11] Including Quinine, Chloroquine, Malarone™, Amodiaquine, Mefloquine™, Proguanil and Artenisnin.

[12] It is possible that the increase partly reflects an increase in the fraction of cases reported.

[13] Sharp increases in malaria in South America have been attributed to changes in mosquito habitats caused by El Niño.

[14] "Airport malaria," the infection of individuals living close to airports, is perhaps the best known instance of the mobility effect, though the number of cases is very small relative to the worldwide incidence. Relatively little is known about the quantitative effect of the exposure of local noninfected mosquito populations to infected human hosts. See also Singhanetra-Renard (1993) on the mobility-malaria link.

[15] See Nájera, Kouznetzsov and Delacollette (1998), Kondrashin (1987), Veeken (1993), inter alia.

on malaria.[16] As malaria outside the 0-5 age group primarily takes the form of repeated incapacitating but nonfatal episodes, we focus on total population morbidity per 100,000 population. The incidence of malaria varies sharply over time, depending on the particular climatic situation in a given year and other factors. As a single year's cross section may thus not be representative, we employ five-year averages covering the years 1983-87, 1988-92 and 1993-97.[17] Table 3 presents the joint frequency distribution of malaria morbidity per 100,000 population for all three periods, revealing the large spread between near-zero morbidity rates at the bottom, and morbidity rates above 10 percent (and for Sub-Saharan Africa above 20 percent) for the top decile.

Table 3. Country Distribution of Malaria Morbidity
(cases per 100,000 population)

Median all years	*All*	*Africa*	*Year*	*Median*
10th	7.5	47.5		
25th	75.9	1,358.4	1983	495.9
50th	576.7	5043.3	1988	485.1
75th	4,236.2	10,155.2	1993	751.5
90th	11,365.9	23,354.6		

Source: Computed based on WHO (1999). The percentile distribution is based on all available five-year averages (a maximum of three per country).

We complement the malaria data with information on climate and location, public health expenditures, access to clean water and sanitation, and a range of socioeconomic indicators taken primarily from World Bank and WHO sources. Some of these data are only available at infrequent intervals. To match the malaria morbidity data and reduce endogeneity problems, observations for the years 1983, 1988, and 1993 (the starting years of the malaria five-year averages) were used where possible, or the closest data point within the five-year period was selected.[18]

[16] Published by the World Health Organization (WHO) in its Weekly Epidemiological Record, 8/13/99, www.who.int/wer.

[17] The exposure index used by Gallup, Sachs and Mellinger (1998) and Gallup and Sachs (1998a) is based on two individual data points, multiplying the fraction of a country's area which is exposed to malaria in 1994 with the fraction of falciparum cases in total cases in 1990. We do not distinguish between Plasmodium varieties. The use of actual morbidity ratios rather than exposure has the advantage of controlling for differing uses of protective measures (and thus for the possibility that actual morbidity ratios differ sharply between countries with similar exposure), while the averaging over multiple years reduces the importance of year-to-year fluctuations.

[18] The quality of the underlying data unavoidably differs across sources, as well as across countries for given sources. To reduce sensitivity to extreme measurements, all data were plotted, and obvious outliers removed, typically one or two per variable, with outliers often twenty to thirty times larger than the cluster of observations (see appendix).

4. Incidence

Endemic malaria has been depicted as an unavoidable side effect of a tropical location. A first look at the data supports this view; malaria, not surprisingly, is concentrated in the tropics. Yet, a closer look within the tropics reveals substantial differences in malaria morbidity and mortality rates between countries sharing similar locations and climates, suggesting the possibility of important additional determinants. We hence begin the exploration of the malaria-growth nexus by asking whether knowledge of climate is sufficient to explain the spatial pattern of malaria. If so, malaria can be viewed as an exogenous variable in growth regressions. If, in contrast, other variables, including some potentially influenced by economic development, play an additional independent role, a simultaneity problem arises.

The linkages are likely to be subject to threshold effects, for example the temperature-malaria link discussed above. In addition, the linkages may be subject to context-dependence. In particular, even if a cold average temperature is sufficient to infer low malaria morbidity, temperatures above this level may only be necessary but not sufficient to infer high malaria morbidity. To allow for these nonlinearities, we turn to classification rule analysis to explore the determinants of different malaria morbidities. Box 1 provides a brief exposition of this methodology.

We use three groups of potential discriminants. The first covers spatial and climate variables capturing the suitability of the country as an anopheles habitat. It includes elevation, average annual temperature, average annual rainfall, the absolute latitude (proportional to the distance from the equator) and a dummy for adjacency to an ocean.[19] The second group of variables, proxying for the quality and accessibility of the public health system, includes the fraction of GDP spent on health care; the fraction of the population with ready access to health care (in the aggregate and separately for rural and urban areas); access to clean water and sanitation (in the aggregate and separately in rural and urban areas) and, as an alternative measure of exposure to water born diseases, mortality from intestinal infectious diseases. The third group? aiming to capture any remaining individual or societal effects? comprises GDP per capita,[20] the percentage of the population living below the poverty line[21] and the Gini coefficient[22] as measures of household ability to invest in protective measures and medicine.

[19] As climatic conditions often vary strongly within a country, elevation, temperature, absolute latitude and rainfall are averaged across the 3 largest cities for the 10 largest countries. The other data are for the capital city.

[20] To the extent that a high malaria incidence reduces growth prospects, the causality is of course two-sided, a point to which we return below.

[21] Based on UNDP, Human Development Report.

[22] Based on Deininger and Squire (1996), in a few cases updated from the World Bank World Development Indicators. The definition is standard; a higher coefficient denotes reduced income equality.

Box 1: Classification Tree Methodology

Classification trees consist of a sequence of rules for predicting the value of a binary dependent variable based on a vector of independent variables. For the present purpose, the binary variable is defined as high (1) and low (0) malaria morbidity. We convert the continuous data into binary form by sorting the morbidity rates by size into three groups. The middle group is dropped, and observations in the top and bottom group are coded respectively as "1" (high morbidity) and "0" (low morbidity).

The objective of classification tree analysis is to determine the set of rules (consisting of a discriminant variable and a threshold) which permits the best sorting of the dependent variable into its two constituent groups. At each branch of the tree, the sample is split into two sub-branches based upon a threshold value of one of the explanatory variables. The splitting is repeated until a terminal node is reached. Suppose, for example, that in all countries falling into the "high" group, the average annual temperate is above 27° Celsius, while in all countries falling into the "low" group, the average annual temperature is below 27°. In this case, the rule *average annual temperature is below 27° ® low morbidity* perfectly discriminates between the two groups, and the resulting decision tree would have a single branching with two nodes. In practice, perfectly discriminating rules are rare, and rules have associated type I and type II errors. In this case the algorithm selects the rule (consisting of the variable and the associated threshold) which minimizes a weighted sum of type I and type II errors. For the present purpose, equal weights are used. By construction, any additional sub-branch reduces the overall error rate of the classification scheme. Akin to an adjusted R^2 criterion, the algorithm terminates at a node if the reduction in the overall error rate falls short of a penalty on the number of branches.

Binary classification trees possess a number of advantages for the problem at hand. First, the algorithm establishes a priority ordering among the potential discriminants, discarding secondary variables and thus reducing the need for subjective preparsing. Second, the procedure permits subsamples to be described by different rules, thus allowing for context dependence. Third, because the procedure will typically split on an interior threshold, it is quite robust to outliers.

The resulting classification rules are graphed in table 4. The distance from the equator, as measured by the absolute latitude, is the single best and clearly exogenous discriminant between the high and low malaria morbidity group: 73 percent of the countries close to the equator fall into the high malaria group, contrasted with only 14 percent of the countries located further away from the equator.

Yet, while geography clearly matters (Gallup, Sachs, and Mellinger 1998), it is not destiny: among the countries sharing a location close to the equator, income distribution makes a small but noticeable difference: poverty ratios below 18 percent are associated with a lower probability of belonging to the high malaria group (0.667 versus 0.745 for countries with larger poverty ratios). The interpretation of this link is however impeded by potential simultaneity. For a given GDP per capita, lower poverty ratios enable even

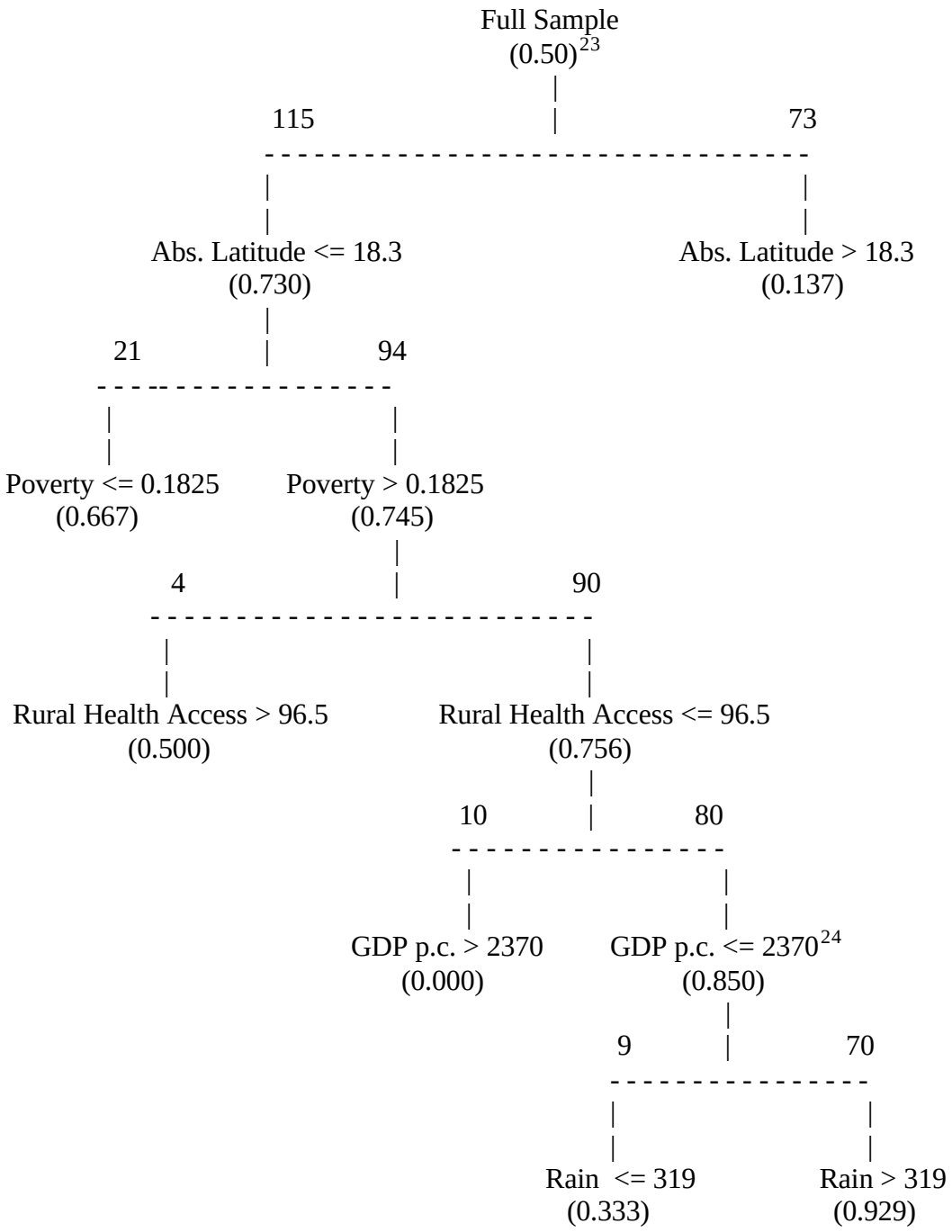
poorer households to invest in antimalaria measures, generating a causal link from lower poverty ratios to reduced malaria morbidity. Yet malaria itself reduces household incomes of those affected, and thus may increase poverty ratios in the absence of comprehensive social security systems.

Moving down two nodes reveals that among countries located in close proximity to the equator, having high poverty ratios and relatively low access to rural healthcare, a real GDP per capita above US$2,370 is associated with a sharply lower (indeed, zero) probability of belonging to the high malaria group. The result is not surprising: the link between GDP per capita and malaria is well documented (Gallup, Sachs, and Mellinger 1998), indeed, it motivated much of the early work on malaria. Yet, again the interpretation is ambiguous as higher income (if associated with greater administrative capacity) enables improved antimalaria efforts, while malaria itself undermines productivity and thus reduces income per capita.

The small set of classification rules correctly classifies 78 of the 94 high malaria cases and 71 of the 94 low malaria cases. Overall, 149 out of 188 observations were correctly identified (79 percent), compared to an expected 94 correct classifications (50 percent) using a purely random allocation.

The classification rule methodology can also be used to rank variables by their overall power as a discriminant. The score for each variable is based on the difference in discriminatory power between the best discriminant at a particular node, and the discriminatory power of the variable in question, summed over all nodes. Good alternative rules are thus credited relative to bad alternative rules. As the score is computed over all nodes, it will in general not overlap with the ordering of splits in the tree, nor is it even necessary for a variable to appear in any rule in order to be important as a discriminant, provided it is a close competitor to the best rule at several nodes. Table 5 reports the resulting ranking of variables by their power as discriminants. The second column provides a numerical measure of the power, scaled relative to the best discriminant.

Table 4. Classification Tree: Incidence of High Versus Low Morbidity



[23] In brackets: Fraction of observations at the node belonging to the high malaria incidence group. The numbers at the branches refer to the number of observations at each branch.

[24] One additional node conditional on the Gini coefficient (<32.7) separates just a single (low mortality) observation and is not plotted for space reasons. The number of observations at the last split is thus 79 rather than 80.

Table 5. Ranking of Variables by Overall Discriminatory Power

Variable	*Power*
GDP per capita	100
Poverty ratio	62
Access to rural healthcare	55
Absolute latitude	47
Average annual rainfall	29
Average annual temperature	17
Gini coefficient	14

GDP per capita emerges as the best overall discriminant (it appears as a strong competitor at the first three nodes); followed by the poverty ratio and access to rural healthcare, while the unambiguously exogenous discriminants? latitude, temperature and rainfall? enter lower, at ranks four to six. While the methodology does not address causality, and indeed GDP per capita itself may be partly endogenous to location (Gallup, Sachs, and Mellinger 1998); the negative link between malaria and more equal income distribution and in particular access to rural health care is suggestive.

5. Growth Effects of Malaria

Malaria potentially affects both the volume and the productivity of inputs. On the most direct level, malaria incapacitates part of the labor force. This loss of labor input has been the primary focus of the classic aggregate studies of malaria (Ross 1911, Sinton 1935/36), and has been refined in several careful case studies. The consensus estimates suggest that attacks, depending on severity, typically entail a loss of four or more working days, followed by additional days with reduced work capacity (Brohult et al. 1981, Shephard et al. 1991, Picard and Mills 1992, and Hempel and Nájera 1996). The output effect of the lost work time depends both on the degree to which other family-members can increase work effort and, in agricultural areas, on the overlap between malaria episodes and harvest periods.[25] A second effect operates longer term: malaria attacks are a major cause of school absenteeism (McDonald 1950, Wernsdorfer and McGregor 1988) and appears to negatively impact long term learning capacity; reducing the accumulation of human capital over time.

These direct effects are augmented by more indirect links between malaria and productivity. Frequent absenteeism reduces the efficiency of networks, requiring greater redundancy and reducing the scope for specialization. Malaria motivated limits on

[25] Malaria fevers tend to overlap with planting season in spring, while malignant tertian in autumn overlaps with the harvest season [Hempel and Nájera (1996)].

mobility (both intra- and international) reduce the quality of skill matching. Malaria induced changes in planting patterns to minimise the overlap between malaria episodes and peak agricultural work times reduce agricultural productivity (Conly 1975). Endemic malaria also reduces the growth potential for some industries, notably tourism, and sharply raises the cost of infrastructure projects and other collective enterprises.[26]

These indirect costs? education never received, tourism and infrastructure projects never undertaken, specialization patterns never pursued? are harder to estimate directly. They can however be indirectly captured in the residual of growth regressions: to the degree that malaria, controlling for other factors, exerts a significant adverse effect on growth, one would expect to find a significant explanatory role for malaria in standard growth regressions (Gallup and Sachs 1998a and Gallup, Sachs, and Mellinger 1998).

Table 6 provides some background information on important growth factors, based on sorting observations by malaria morbidity into three equal-sized groups (low, medium, and high). For each group, the median value for each variable is reported. The third of countries with the highest malaria morbidity rates has not only the lowest initial GDP per capita? a result brought out by the classification trees reported above? but also the lowest growth rates of output per capita, and levels of human and physical capital.

Table 6. Medians

	Low malaria morbidity	*Medium malaria morbidity*	*High malaria morbidity*
Malaria morbidity (per 100,000)	30	574	6,697
GDP per capita (Start of Period)	3,595	2,193	1,267
Average GDP p.c. growth rate (5Y)	1.45	1.51	0.22
Investment ratio	22.7	20.0	18.3
Primary enrollment ratio	104	99	76
Secondary enrollment ratio	49	35	16
Absolute latitude	25.5	14.0	9.4

Source: See section three.

[26] As mentioned above, early antimalaria measures in Panama were partly motivated by the perceived negative impact on the building of the canal. Malaria has also been cited as a major obstacle in the building of the trans-amazonian highway, of major dams and of tourism projects (Hempel and Nájera 1996).

Table 7 reports a set of standard growth regression for the three periods (1983-88, 1988-93, and 1993-98). The dependent variable for the core regressions presented in this table and for the robustness tests reported in table 8 is the average per capita growth rate in the three five-year periods. The top two rows denote sample and regression technique. We report results both for pooled data and for seemingly unrelated regressions (SUR). The sample either comprises all observations or is limited to Sub-Saharan Africa.

The coefficient pattern of the standard determinants is familiar: investment enters positive and is mostly significant. Primary and secondary education enter positive with one exception, though only secondary education is significant in some cases. Initial income per capita enters negatively, indicating conditional convergence; openness is positive and significant, while higher government consumption ratios enter negatively, and, for the full sample regressions, significant. Greater political freedom and stability, measured by the standard set of proxies—the number of revolutions and assassinations and an index of political freedom[27]—are associated positively, and in most cases significantly, with growth.

Malaria enters negatively and significantly in all six regressions. The coefficient is very similar for all six regressions, specifically; there is no sizeable difference between the pooled regression and the SUR.

It might of course be the case that the malaria variable simply proxies for other growth retardants common to the high-malaria countries. To test for this possibility, we restrict the sample to Sub-Saharan Africa, and add dummies for Sub-Saharan Africa and Latin America to the full sample regression. Neither modification substantially alters the coefficient on malaria morbidity.

[27] The political freedom index is from Freedom House; a higher value indicates lower freedom. The revolution and assassination data were kindly provided by Bill Easterly, the original source is Arthur S. Banks Cross-National Time-Series Data Archive.

Table 7. Regression Results

Estimation technique	*Pooled all countries*	*Pooled Africa*	*Pooled all Countries*	*SUR all Countries*	*SUR Africa*	*SUR all Countries*
Constant	10.063**	16.212**	9.719**	10.283**	14.179**	10.349**
Investment ratio	0.101**	0.017	0.054	0.092**	0.051	0.048
	(0.044)	(0.029)	(0.045)	(0.030)	(0.048)	(0.032)
Primary enrollment	0.001	0.001	0.010	0.0004	–0.003	0.007
	(0.013)	(0.013)	(0.012)	(0.012)	(0.016)	(0.012)
Secondary enrollment	0.033*	0.078**	0.015	0.036**	0.076**	0.016
	(0.019)	(0.037)	(0.018)	(0.015)	(0.033)	(0.016)
Ln GDP p.c. (initial)	–1.272**	–2.339*	–0.952**	–1.302**	–2.025**	–1.018**
	(0.433)	(1.210)	(0.467)	(0.397)	(0.865)	(0.401)
Openness (trade/GDP)	0.013*	0.033**	0.017**	0.016**	0.030**	0.021**
	(0.007)	(0.014)	(0.007)	(0.008)	(0.012)	(0.008)
Gov. cons. (% GDP)	–0.124**	–0.058	–0.137**	–0.128**	–0.076	–0.140**
	(0.044)	(0.042)	(0.039)	(0.036)	(0.054)	(0.035)
Political freedom	–0.228**	–0.312**	–0.298**	–0.195	–0.327*	–0.263**
	(0.113)	(0.151)	(0.120)	(0.123)	(0.181)	(0.123)
Revolutions per year	–0.865**	0.184	–0.849**	–0.810**	0.316	–0.862**
	(0.427)	(0.469)	(0.408)	(0.380)	(0.621)	(0.371)
Index of assassinations	–0.012	–2.039*	–0.004	0.004	–2.523	–0.008
	(0.071)	(1.134)	(0.080)	(0.179)	(1.503)	(0.178)
Sub-Saharan African dummy			–1.281**			–1.612**
			(0.534)			(0.594)
Latin American dummy			–2.101**			–2.098**
			(0.557)			(0.647)
Malaria morbidity (per 100,000)	–0.000062**	–0.000073**	–0.000062**	–0.000064**	–0.000062*	–0.000061**
	(0.000028)	(0.000035)	(0.000028)	(0.000029)	(0.000031)	(0.000028)
R^2	0.27	0.24	0.32	–	–	–
Obs.	187	81	187	59, 62, 66	22, 29, 30	59, 62, 66

Note: Dependent Variable: Average per capita growth. Standard errors (in brackets) are corrected for heteroskedasticity and correlation within country clusters for pooled regressions. *(**) denote significance at the 10 percent and 5 percent level.

Table 8 reports a set of robustness tests. To allow for the possibility that results are driven by outliers, columns two and four report the results obtained by replacing the malaria morbidity rate by a dummy set equal to one for the one-third of observations with the highest morbidity rates. The dummy enters negatively, barely insignificant for the pooled regression (the p-value is 0.11) and significant for the SUR.

The results reported in the previous section suggest a possible two-sided causality between malaria and economic growth, operating through the ability of the population to invest in antimalaria protection in addition to the adverse growth effects described above. If so, the parameter estimates presented in table 7 are subject to simultaneity bias. To examine this possibility, the first column of table 8 substitutes current with lagged malaria. The substitution comes at the cost of losing the first sample period; the number of observations hence drops from 187 to 128. The coefficient on malaria is slightly larger in absolute terms and remains highly significant, consistent with a causal effect of malaria on growth. The results of using SUR rather than pooled estimation (reported in column 3) are similar. The two right-most columns report the results obtained for the growth rate over the entire 15-year period for OLS (column 5) and for TSLS (column 6), using absolute latitude, average rainfall, temperature and an Africa dummy as instruments.[28] The fit of the first stage equation is fair, with an R2 of 0.40. With this caveat, the coefficient on malaria remains negative and significant at the 10 percent level. While larger in absolute terms, a Hausman test fails to reject the null hypothesis of parameter equality for the OLS and TSLS regressions.

Overall, the robustness tests do not suggest that either the potential endogeneity of malaria morbidity or outliers drive the results. Beyond this direct effect, malaria might also indirectly affect growth through some of the standard growth determinants, notably physical and human capital accumulation.

To examine these effects, we estimate SURs of investment and the enrollment ratios[29] on a constant, the log of GDP per capita and malaria (t-statistics in brackets):

Primary enrollment ratio	= –50.06	+ 18.36 Log(GDPpc)	– 0.00014 Malaria
	(–3.02)	(8.53)**	(0.90)
Secondary enrollment ratio	= –100.21	+ 17.87 Log(GDPpc)	– 0.00021 Malaria
	(–7.39)	(10.19)**	(–1.56)
Investment ratio	= –0.12	+ 2.80 Log(GDPpc)	–0.000033 Malaria
	(0.01)	(2.90)**	(0.38)

[28] To reduce endogeneity issues for the standard determinants, notably the investment ratio, we use beginning of period values. The set of instruments passes an overidentification test. The significance values are based on White-robust standard errors.

[29] The enrollment ratios are only available for 1985, 1990, and 1995. The investment ratio is the average of the five-year period.

Table 8. Robustness Tests
(all countries)

Estimation technique	*Pooled lagged malaria*	*Pooled malaria dummy*	*SUR lagged malaria*	*SUR malaria dummy*	*OLS 1983–98*	*TSLS 1983–98*
Constant	8.365**	10.094**	8.257**	10.355**	10.764**	15.331**
	(2.756)	(2.594)	(3.314)	(3.037)	(3.378)	(5.368)
Investment ratio	0.088*	0.096**	0.099**	0.087**	0.119*	0.120
	(0.046)	(0.045)	(0.036)	(0.031)	(0.071)	(0.073)
Primary enrollment	0.0002	–0.002	–0.001	–0.005	–0.002	0.011
	(0.013)	(0.012)	(0.013)	(0.011)	(0.021)	(0.028)
Secondary enrollment	0.033*	0.034*	0.034**	0.036**	0.044	0.011
	(0.018)	(0.019)	(0.017)	(0.015)	(0.033)	(0.043)
Ln GDP p.c. (initial)	–1.053**	–1.221**	–1.064**	–1.247**	–1.425**	–2.123**
	(0.468)	(0.429)	(0.446)	(0.393)	(0.498)	(0.713)
Openness (trade/GDP)	0.015**	0.011	0.016*	0.015*	0.006	0.032
	(0.007)	(0.008)	(0.008)	(0.008)	(0.012)	(0.024)
Gov. cons. (% GDP)	–0.133**	–0.121**	–0.139**	–0.125**	–0.059	–0.056
	(0.047)	(0.046)	(0.041)	(0.036)	(0.061)	(0.074)
Political freedom	–0.104	–0.197*	–0.095	–0.166	–0.380**	–0.387
	(0.120)	(0.114)	(0.141)	(0.124)	(0.182)	(0.281)
Revolutions per year	–0.721	–0.822*	–0.692	–0.762**	0.135	0.258
	(0.520)	(0.437)	(0.425)	(0.379)	(0.657)	(1.003)
Index of assassinations	–0.058	–0.027	–0.083	–0.021	–0.704	–0.640
	(0.079)	(0.073)	(0.182)	(0.180)	(2.100)	(2.277)
Malaria morbidity	–0.000089**	–1.0541#	–0.000090**	–1.180**	–0.000058**	–0.000287*
	(0.000026)	(0.660)	(0.000035)	(0.585)	(0.000027)	(0.000162)
R^2	0.28	0.26	–	–	0.42	–
Obs.	128	187	0, 61, 67	59, 62, 66	54	53

Note: Standard errors for OLS are computed using White's robust procedure. #: p-value is 0.11. If a dummy is included for Africa and Latin America, then all malaria measurements (except malaria dummy) remain significant at 10 percent level.

For all three variables, malaria enters with a negative coefficient, though only the effect on secondary enrollment comes close to statistical significance at the 10 percent level. The results thus provide only muted support for an indirect negative effect of malaria on growth. The weak evidence may however reflect data problems; specifically the lack of quality adjusted human and physical investment data. A child suffering from malaria, and consequently receiving a less effective education due to absences and reduced learning capacity, would still be counted in enrollment figures; while shifts in the composition of investment allowing for greater redundancy in endemic areas at the cost of reduced overall investment productivity would not necessarily be captured in the volume of investment. To the extent that these quantity/quality data problems are present, the malaria dummy in the regressions reported in tables 7 and 8 would also pick up the indirect effect. A formal test of this possibility—introducing interactive effects between morbidity and the accumulation factors into the regression—however does not yield a significant effect for either human or physical capital accumulation.

Pulling these findings together, how much lower is the growth rate in endemic areas because of malaria? Under the very stringent assumption that the same growth elasticity of malaria morbidity applies to all countries and at all malaria morbidity rates, the product of the elasticity and the actual malaria morbidity in a country provides an estimate of the negative growth effect. Table 9 reports the results of this exercise, using the –0.000064 coefficient from the SUR regression for all countries reported in column four of table 7. To provide a conservative estimate, we used the median morbidity observation for countries with three observations, and the lower morbidity rate for countries with only two observations. The year noted specifies the beginning of the five-year period used. Thus, considering the first row, for Malawi the predicted growth effect of reducing malaria to zero for the 1993 to 1998 period is 3.22 percent per annum.

Taken at face value, the results suggest that for many countries the growth cost of malaria is pronounced. Even disregarding the tails of the distribution, the estimated growth reduction due to malaria exceeds 0.25 percent per year for about a quarter of the sample. The findings compares with earlier point GDP cost estimates for all of Sub-Saharan Africa of 0.6 percent (predicted to rise to 1 percent) by Shephard, Ettling, Brinkman and Sauerborn (1991) and of 1.3 percent by Gallup and Sachs (1998a) and Gallup, Sachs and Mellinger (1998). As the elasticity of growth with respect to malaria is unlikely to be invariant across countries, if only because the nonlinear effects examined above in studying the incidence of malaria may also affect its economic costs, the point estimates should be viewed with caution.

Table 9: Hypothetical Growth Effect of Eliminating Malaria Morbidity

Country	*Year*	*Loss*	*Country*	*Year*	*Loss*
Malawi	1993	3.22	Guatemala	1988	0.035
The Gambia	1988	2.22	Suriname	1983	0.035
Solomon Islands	1993	1.81	Ecuador	1988	0.029
Sao Tome Principe	1983	1.79	Thailand	1988	0.029
Togo	1988	1.76	Ethiopia	1988	0.023
Namibia	1993	1.56	Bolivia	1988	0.023
Zambia	1988	1.52	Brazil	1993	0.017
Kenya	1983	1.28	Swaziland	1983	0.017
Vanuatu	1983	1.26	Vietnam	1988	0.017
Tanzania	1993	1.12	Colombia	1983	0.017
Guinea-Bissau	1993	0.98	India	1983	0.017
Rwanda	1993	0.90	Haiti	1988	0.017
Burundi	1988	0.70	Myanmar	1993	0.017
Ghana	1988	0.61	Malaysia	1983	0.017
Angola	1988	0.59	Peru	1983	0.012
Niger	1988	0.51	Philippines	1988	0.012
Gabon	1983	0.46	U.A.E.	1988	0.012
Cameroon	1988	0.42	El Salvador	1988	0.012
Liberia	1983	0.38	Yemen	1988	0.012
Cote d'Ivoire	1983	0.38	Sudan	1988	0.006
Burkina Faso	1988	0.37	Nepal	1988	0.006
Benin	1983	0.37	Iran	1993	0.006
Senegal	1983	0.35	Turkey	1983	0.006
Zimbabwe	1993	0.31	Saudi Arabia	1993	0.006
Equatorial Guinea	1983	0.30	Venezuela	1983	0.006
C.A.R.	1988	0.27	Costa Rica	1988	0.006
Papua New Guinea	1993	0.26	Pakistan	1983	0.006
Guyana	1988	0.26	Mexico	1988	0.006
Mauritania	1983	0.24	Paraguay	1983	0.006
Chad	1988	0.24	Indonesia	1993	0.006
Madagascar	1988	0.22	Somalia	1983	0.006
Bhutan	1988	0.19	Bangladesh	1988	0.006
Comoros	1993	0.19	Cape Verde	1983	0.000
Eritrea	1993	0.15	Congo	1988	0.000
Mali	1993	0.14	Iraq	1988	0.000
Belize	1983	0.13	Dominican Republi	1993	0.000
French Guyana	1983	0.13	Panama	1993	0.000
Sri Lanka	1983	0.12	South Africa	1988	0.000
Uganda	1988	0.09	Tajikistan	1988	0.000
Afghanistan	1983	0.09	China	1988	0.000
Guinea	1988	0.09	Maldives	1993	0.000
Botswana	1988	0.09	Mauritius	1983	0.000
Oman	1988	0.09	Armenia	1983	0.000
Congo, Dem. Rep.	1988	0.08	Argentina	1993	0.000
Cambodia	1983	0.08	Algeria	1983	0.000
Nigeria	1988	0.07	Morocco	1983	0.000
Honduras	1993	0.07	Syria	1988	0.000
Nicaragua	1988	0.06	Korea	1983	0.000
Lao PDR	1988	0.05	Azerbaijan	1988	0.000
Djibouti	1993	0.05	Egypt	1988	0.000

From a policy perspective, the economic and noneconomic benefits of reducing malaria must be weighted against the costs of antimalaria measures and contrasted with the cost-benefit calculus for other prevalent diseases. Detailed case studies suggest that substantial reductions can be obtained by fairly simple, low-cost measures (table 10) such as prepackaging complete treatments, better education regarding the need to complete treatment cycles, better availability of second- and third-line drugs in areas with building resistance against currently used drugs, and the widespread use of bednets.

Table 10. Cost Per DALY Averted
(US$, Midpoints)

Intervention	*Percent per DALY saved*	*Percent increase of health budget*
Better access to 2nd and 3rd line drugs	1.4	0.3
Better compliance with drug therapy	4	0.5
Insecticide treatment of existing nets	6	3.0
One spraying round per year	22	27
Chloroquine prophylaxis	43	0.2
Distribution and treatment of nets	44	24.0

Source: WHO (1999:57). DALY: Disability Adjusted Life Year. The health budget baseline is the public sector health budget for a typical low-income Sub-Saharan country.

6. Conclusions

Malaria ranks among the major health problems facing many developing countries, notably in Sub-Saharan Africa. Fighting malaria requires significant financial and organizational resources, yet malaria itself restrains economic development, threatening a vicious circle. We explored these linkages using a cross-country data set on malaria, growth and other country characteristics. The study yielded two main results. First, while we confirmed prior research on the importance of climate as a determinant of malaria morbidity, we found that geography is not entirely destiny: controlling for climate, lower poverty ratios—enabling even poorer households to invest in antimalaria protection—are associated with lower malaria morbidity. Second, we found a robust negative baseline growth effect of –0.000064 for malaria morbidity per 100,000 population, reducing annual per capita growth by 0.25 percent for the most affected countries.

Appendix

The data set comprises three years: 1983, 1988. and 1993. In a few cases data are missing, the total number of observations on malaria morbidity is 280. Missing information on other variables drops the number of observations for the growth regressions reported in Table 7 to 187 (78 countries). In the following list, countries that are included in the growth regression are highlighted in bold.

Country List

Afghanistan	**Algeria**	**Angola**
Argentina	**Armenia**	**Azerbaijan**
Bangladesh	**Belize**	**Benin**
Bhutan	**Bolivia**	**Botswana**
Brazil	**Burkina Faso**	**Burundi**
Cambodia	**Cameroon**	**Cape Verde**
Central African Republic	**Chad**	**China**
Colombia	**Comoros**	**Congo**
Democratic Republic of Congo	**Costa Rica**	**Cote d'Ivoire**
Djibouti	**Dominican Republic**	**Ecuador**
Egypt	**El Salvador**	Equatorial Guinea
Eritrea	**Ethiopia**	French Guyana
Gabon	**The Gambia**	**Ghana**
Guatemala	**Guinea**	Guinea-Bissau
Guyana	Haiti	**Honduras**
India	**Indonesia**	**Iran**
Iraq	**Kenya**	**South Korea**
Lao	Liberia	**Madagascar**
Malawi	**Malaysia**	Maldives
Mali	**Mauritania**	**Mauritius**
Mexico	**Morocco**	Myanmar
Namibia	**Nepal**	**Nicaragua**
Niger	**Nigeria**	**Oman**
Pakistan	**Panama**	**Papua New Guinea**
Paraguay	**Peru**	**Philippines**
Rwanda	Sao Tome and Principe	**Saudi Arabia**
Senegal	Solomon Islands	Somalia
South Africa	**Sri Lanka**	**Sudan**
Suriname	**Swaziland**	**Syrian Arab Republic**
Tajikistan	**Tanzania**	**Thailand**
Togo	**Turkey**	Uganda
United Arab Emirates	Vanuatu	**Venezuela**
Vietnam	**Yemen**	**Zambia**
Zimbabwe		

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