The Economic Burden of Malaria

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Abstract

Malaria and poverty are intimately connected. Controlling for factors such as tropical location, colonial history, and geographical isolation, countries with intensive malaria had income levels in 1995 only 33% of countries without malaria, whether or not the countries were in Africa.

The high levels of malaria in poor countries are not mainly a consequence of poverty. Malaria is very geographically specific. The ecological conditions that support the more efficient malaria mosquito vectors primarily determine the distribution and intensity of the disease. Intensive efforts to eliminate malaria in the most severely affected countries in the tropics have been largely ineffective. Countries that have eliminated malaria in the past half century have all been either subtropical or islands. These countries' economic growth in the five years after eliminating malaria has usually been substantially higher than growth in the neighboring countries.

Regressions using cross-country data for the 1965-90 period confirm the relationship between malaria and economic growth. Taking into account initial poverty, economic policy, tropical location, and life expectancy among other factors, countries with intensive malaria grew 1.3% less per person per year, and a 10% reduction in malaria was associated with 0.3% higher growth. Controlling for many other tropical diseases does not change the correlation of malaria with economic growth, and these diseases are not themselves significantly negatively correlated with economic growth. A second independent measure of malaria has a slightly higher correlation with economic growth in the 1980-1996 period.

The paper concludes with speculation about the mechanisms that could cause malaria to have such a large impact on the economy, such as foreign investment and economic networks within the country.

Keywords: malaria, economic cost of disease, economic growth, burden of disease, tropical disease

JEL Codes: I12, O11, O40

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Poverty and malaria

Malaria and poverty are intimately connected. As Nobel Laureate in Medicine T.H. Weller (1958: 497) noted, "It has long been recognized that a malarious community is an impoverished community." Weller could have said the same for malarious countries. Malaria is most intractable for countries in the poorest continent, Africa. The only parts of Africa free of malaria are the northern and southern extremes, which have the richest countries on the continent. India, the country with the greatest number of poor people in the world, has a serious malaria problem. Haiti has the worst malaria in the Western Hemisphere, and it is the poorest country in the hemisphere.

Malaria risk has always been very geographically specific, as shown in Figure 1. Widespread malaria is confined to the tropical and subtropical zone. Poverty is also geographically specific. As shown in Figure 2, poor countries predominate in the same regions as malaria. Almost all of the rich countries are outside the bounds of malaria risk.

A basic problem when studying the macroeconomic impact of malaria is the lack high quality data on malaria incidence or prevalence in the most severely affected countries. This study uses an index of malaria prevalence derived from historical maps of the geographical extent of high malaria risk shown in Figure 1 (digitized from Pampana and Russell, 1955, WHO 1966, and WHO 1997). Combined with detailed data on the world population distribution (Tobler and others, 1996), one can estimate the fraction of the population in high malaria risk areas in each country. Since most malaria mortality and severe morbidity is due to one of the four malaria species, the malignant *Plasmodium falciparum*, the index of malaria intensity used in this paper is the fraction of the population at risk of malaria multiplied by the fraction of malaria cases that are falciparum malaria (from WHO, 1990).[1] For the comparative statistics in this section, intensive malaria is defined as having a malaria index greater than 0.5.

Since we completed an earlier version of this paper, McCarthy and others (1999) have used recently released World Health Organization (WHO) data for malaria incidence data to estimate the impact of malaria on economic growth. The WHO data are typically least accurate in countries where a large proportion of the population is infected with malaria, and because of doubts about the comparability of the data across countries, we have not used the data in this study. McCarthy and others (1999) use these data with a methodology similar to ours, but a different time period, and they find somewhat smaller estimated effects of malaria than we find here.[2]

Take the 150 countries with populations over one million in 1995, which account for over 99 percent of the world's population. Forty-four of the 150 countries, or 29 percent, have intensive malaria. Thirty-five of these 44 countries are in Africa. The average purchasing-power parity gross domestic product (GDP) per capita in 1995 for the malarial countries was $1,526, compared to an average income of $8,268 in the countries without intensive malaria, more than five times higher.[3] Ranking the 150 countries by income per capita, all but three of the 44 countries with intensive malaria are in the bottom half of the ranking. The exceptions are Oman and Gabon, ranked 34th and 41st, which owe their wealth to oil, and the Philippines, which is barely in the top half with a rank of 74th out of 150. Of the 119 poorest countries, all but twelve have some incidence of malaria or are recovering from socialism. The richest 31 countries are entirely free of malaria.

Not only are malarial countries poor, but economic growth in malarial countries over the past quarter century has been dismal. Growth of income per capita from 1965 to 1990 for countries with intensive malaria has been 0.4% per year, while average growth for other countries has been 2.3%, over five times higher.[4] More than a third of the countries with intensive malaria (11 out of 29) had *negative* growth from 1965 to 1990.

The question is whether these dramatic correlations mean that malaria *causes* poverty and low growth. We will address this question in three ways. First, we consider the correlation of malaria with income levels after controlling

[1] A second index of malaria derived from completely different data is described and used below.
[2] According to the WHO (1999, p. 265) the data "permit only very limited comparison between countries or even between various periods for the same country." In other words, the data contain substantial measurement error which may explain the smaller estimated impact of malaria in McCarthy and others (1999) than we find.
[3] The 1995 PPP GDP data are from World Bank (1998), supplemented by CIA (1996, 1997) for countries without World Bank data.
[4] The data for GDP growth from 1965 to 1990 for 95 countries are from the Penn World Tables, Mark 5.6 (Summers and Heston, 1994).

for other factors that are likely to affect the world distribution of income, such as geography, history, and policy. Second, we discuss the determinants of malaria risk. Unlike other important diseases in poor countries caused by deficient living conditions, like diarrhea, tuberculosis, and schistosomiasis, malaria is not a direct consequence of poverty; its extent and severity are largely determined by the climate and ecology. Third, we explore the impact of malaria on subsequent economic growth. This provides the most direct evidence on the continuing importance of malaria as a cause of poverty.

Malaria and Income Levels

The coincidence of intensive malaria and low incomes could be due to many factors besides malaria itself. It could be a general effect of the tropics, caused by poor soils, low agricultural productivity, or tropical diseases other than malaria. It may capture geographical trade barriers, since many malarial countries are landlocked and far from the major centers of world trade. It could be an accident of history. Many malarial countries were colonies until recently, and the misfortunes of colonization may linger, keeping incomes low. Malaria could simply be a proxy for Africa, which may be poor for other reasons such as weak institutions, poor economic policies, or ethnic conflict.

There are strong geographical patterns to income levels around the world.[5] As shown in Regression 1 of Table 1, just four geographical variables account for almost half the variation in the log of GDP per capita income levels in 1995.[6] A country's accessibility to the coast, measured by the share of the population within 100 kilometers of the coast, is an important indicator of success in foreign trade and integration into the global economy, and hence related to high income levels. Another measure of accessibility, the minimum distance to the core world markets (New York, Rotterdam, and Tokyo), is inversely related to higher incomes. Thirdly, resource deposits, proxied by the log of hydrocarbon reserves per person, are higher in wealthier countries. Lastly, the tropics, measured by the percentage of a country's land area in the geographical tropics, is much poorer than the rest of the world. The "penalty" for being tropical was –0.68, signifying that tropical areas had only 51% (=exp(-0.68)) of the per capita income of non-tropical areas controlling for other factors.

The next three regressions in Table 1 add the malaria index to the geographical correlates of income per capita in two different years, 1950 and 1995.[7] The malaria index has a strong negative association with income levels after controlling for the other four geographical factors. Malaria's coefficient increases slightly from 1950 to 1995, suggesting that if anything, malaria has become more important for explaining income levels over time. The association of income with malaria dominates the association with the tropics, which loses statistical significance in the regressions. The coefficient on malaria of -1.22 in 1995 implies that malarial countries have a per capita income only 30% as high as non-malarial countries.

Regression 4 of Table 1 includes indicators for former colonies, and socialist countries in the post-World War II era. These new explanatory variables are strongly associated with lower income levels, but taking them into account does not substantially alter the correlation of malaria with low incomes. Regression 5 adds a measure of economic policy, trade openness in the 1965 to 1990 period, and an index of the quality of government institutions. Malaria's association is still unaffected, but the socialist and colony variables lose their significance. If malaria is excluded from this regression, income levels are significantly lower in countries that have been colonized, which suggests that the economic weakness of countries with malaria might have been a factor in their colonial subjugation.

The final regression in Table 1 excludes the sub-Saharan African countries. Malaria has just as strong association with poverty outside of Africa as for the whole world. Malaria is clearly distinguishable from other problems faced by Africa.

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[5] See Gallup and Sachs (1998) for a wider investigation of the role of geography in economic development, and more detailed explanation of the variables used in this section.
[6] Regression analysis is explained in any econometrics textbook, such as Greene (1997).
[7] The data for PPP GDP per capita in 1950 in Table 1 are from Maddison, 1995. The PPP GDP per capita data for 1995 are as in footnote 2.

Geography, history, and policy all have clear correlations with income levels, but taking them into account does not alter the pattern of lower incomes in malarial countries. The association of malaria with poverty seems to be more than just a mask for other plausible causes of low income.

Cause or Effect?

Malaria is prevalent in the poorest countries. Could this be a consequence, rather than a cause, of poverty? Many other serious diseases predominantly found in poor countries clearly *are* a direct consequence of poverty, caused by inadequate sewage treatment, unsafe drinking water, poor hygiene, or substandard housing. Malaria, though, does not follow this pattern – it's severity, and the difficulty in controlling it, are determined mainly by climate and ecology. Personal behavior, such as use of screens and bednets, and the general level of development, especially urbanization, also affect malaria prevalence, but they are not the main determinants.

Certain countries with very high incomes still face serious malaria problems due to their geographical location. Oman, with an income per capita of almost $10,000, has intensive malaria throughout the country except in remote areas of high altitude and desert. United Arab Emirates, next door with one of the highest income levels in the world, also has been unable to eliminate malaria.

Successful elimination of malaria through vector control requires a well-run organization and financial resources. However, the determining factor in where malaria has been eliminated in the post-war era has not been institutional or financial. It has been the susceptibility of malaria and the vector to control. Figure 1 shows that since 1946 malaria has only been eliminated in nontropical regions and certain islands where it foothold is much weaker. Coluzzi (1999) writes "Above all, it should be stressed that malaria eradication [in temperate areas in the late nine-teen forties and early 1950s] was [only] achieved within more or less marginal ecoepidemiological zones, particularly for *P. faliparum*" due to seaonality of malaria transmission, low nighttime outdoor temperatures, and less efficient malaria vectors in temperate regions.

The large differences in the difficulty of controlling malaria in various climatic zones is supported by Table 7. Those regions with the worst malaria in 1965 had the least reduction in malaria in the following three decades. Countries with a predominantly humid tropical climate actually saw an increase in the malaria index. Although the absolute reduction in the malaria index in temperate countries was lower than in other climatic zones, that is because the malaria level is bounded by zero – malaria as measured by the malaria index was completely eliminated in temperate countries.

Some of the most effective control efforts historically in the worst affected areas have used very few material resources other than labor, so they are not constrained by poverty *per se*. The elimination of breeding sites for malarial mosquitoes in parts of Panama by Gorgas at the time the canal was built (McCullough, 1977), the control of the outbreak of *Anopheles gambiae* mosqitoes in northeastern Brazil in the 1930s (Soper and Wilson, 1943), and the malaria-free enclaves around some African mines (Watson, 1953) show what is possible with a combination of complete monitoring of all open water sources inside and outside households, drainage of wetlands, and a military precision in all operations. Unfortunately, such control efforts have never been sustained in more than small areas or for more than short periods of time.[8]

In addition to differences in malaria intensity due to climate, the world distribution of *Anopheles* mosquitoes, the malaria vectors, have a major impact on malaria prevalence and severity. Vectorial capacity is a measure of the efficiency with which mosquitoes carry malaria from one human to another, an estimate of the number of secondary cases of malaria generated by one primary case. The vectorial capacity of different species of *Anopheles* varies by

[8] The major efforts devoted to malaria control in the building of the Panama canal and at African mines demonstrates the economic impact of malaria on workers. Malaria mortality was a major factor in the French failure to complete the canal (at least 20,000 people lost in nine years), and the American efforts were not effective until malaria and yellow fever were brought under control (McCullough, 1977). Some tropical African mines created a *cordon sanitaire* around their operations where African workers could not regularly leave or enter. The large investments in monitoring, drainage and housing could only have been justified by higher worker productivity in the malaria-free mines.

orders of magnitude. By far the most efficient vector, *Anopheles gambiae,* is exclusively found in sub-Saharan Africa.

Vectorial capacity has a major impact on the feasibility of controlling or eradicating malaria in a region. Consequently, malaria eradication through vector control has been orders of magnitude more difficult in sub-Saharan Africa. According to a recent expert committee report: "The epidemiology of malaria is driven by the dynamics of the mosquito vectors. Thus, 90% of the world's malaria is in Africa because it is home to the three most effective vectors." (NIH, 1997, p.12) Not only do the mosquito species determine the intensity of transmission, but they also affect the mix of malaria between the malignant *P. falciparum*, and the less serious *P. vivax, P. malariae*, and *P. ovale*. Africa is also the only major region of the world where falciparum malaria predominates.

Malaria control in sub-Saharan Africa has been a non-starter. There has been no successful malaria control of large regions outside of the temperate southern tip, the controlled environment of some mining camps, and a few islands. In response to the failure of WHO vector control projects in Cameroon, Nigeria, and elsewhere in Africa in the 1960s, the WHO sponsored an intensive malaria control and research project in the district of Garki, Nigeria (Molineaux and Gramiccia, 1980). No resources, manpower, or institutional support were spared. Over the course of seven years, WHO and the Nigerian government spent more than $6 million to try to eliminate malaria in 164 villages and compare the changes to control villages. Insecticide spraying of every hut at least every 10 weeks during the course of the study had an average coverage of 99%. A third of the villages were also given mass drug administration as a prophylaxis against malaria.

The intensity of malaria transmission in Garki was "very high indeed". During the wet season, a person in this district would be bitten on average 174 times *per night* by the *Anopheles gambiae* s.l.malaria vector and 94 times per night by the *Anopheles funestus* vector.[9] The vectorial capacity, or the transmission rate of malaria between persons through the vectors, reached 2000 times the critical value required to maintain endemic malaria, with a range of between 18 and 145 malaria-transmitting bites per person per year in the eight villages studied (Molineaux and Gramiccia, 1980, p. 107). In lay terms, everyone was constantly reinfected with malaria.

The vector control efforts reduced the man-biting rate of mosquitoes in the Garki villages by 90% from their pre-study level, but despite this huge reduction in mosquito density, there was no significant change in the parasite rate among the villagers. The control efforts were defeated by the vectorial capacity of the mosquitoes, which vastly exceed what was required to maintain transmission of malaria. The conclusions of the study show that the failure to control malaria in similar environments was not the consequence of poverty or lack of institutional capacity. This was summed up in a conference paper summarizing the Garki study: "The malaria control measures employed in the Garki Project failed to have a significant overall impact on malaria transmission, suggesting that these measures are unlikely to be of long-term use in the African dry savannah belt." This failure occurred despite the fact that "at all times during this study, it was known that the strategies employed were much too detailed and expensive for long-term use in the study area." (Loutan and others, 1981, p.15).

At least two biological factors explain the exceptional severity of malaria in Africa. The most efficient mosquito vector and the most serious malaria strain both most likely came from Africa. The vector *Anopheles gambiae* s.s. coevolved with humans in the Afrotropical rain forest. The development of African agriculture in forest clearings resulted in the vector's most important characteristic for malaria transmission: it almost exclusively bites humans (Coluzzi, 1999). The explosive potential of the *Anopheles gambiae* vector for transmitting malaria in similar climates elsewhere was shown by the introduction of the mosquito into Brazil in the late 1920s, which was luckily brought under control soon enough to eliminate it (Soper and Wilson, 1943). The most pathogenic human malaria species, *P. falciparum,* most likely originated in Africa, probably in the past 5000-10000 years with the onset of agriculture (Coluzzi, 1999).

With no proven method of controlling malaria in sub-Saharan Africa and other areas of intense transmission, it is difficult to argue that poverty effectively causes malaria, or determines the success of control efforts. A recent NIH

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[9] Such high biting rate estimates are not unusual. Robert and others (1991) estimates that a person in the Kou Valley in Burkina Faso sleeping without mosquito protection (as most do) receives 158 bites by Anopheles gambiae per night, with total mosquito bites of 35,000 per year.

(1997) report notes the intractable nature of malaria Africa: “The availability of anti-malaria measures, when correctly integrated and applied without financial constraints, can probably cope successfully with the malaria problem everwhere in the Tropics *except in the Afrotropical region*.” (emphasis added)

A different sort of evidence that malaria is a cause of poverty comes from evolution. In areas with the most severe malaria today, sub-Saharan Africa and parts of the Middle East and India, many ethnic groups have developed a partial genetic defense against the ravages of malaria: sickle cell trait. In some parts of Africa, this red blood cell abnormality is carried by 25-30% of the population (Weatherall, 1984). The value of sickle cell’s protection against malaria must be great because it comes at a very high cost: all children (in developing countries) who inherit the trait from both mother and father die before the age of childbearing. The Garki project confirmed this cruel equilibrium (Molineaux and Gramiccia, 1980, p.229). Sickle cell trait in Garki adults was much higher than in children due to selective survival. The burden of malaria on human wellbeing must have been high indeed for such a mutation to be beneficial.[10] Milder congenital blood diseases, such as thalassemia in parts of southern Europe and Asia, confer some protection against malaria in regions where malaria is correspondingly less severe. These blood diseases highlight the importance of the burden of falciparum malaria relative to other forms since they protect primarily against *P. falciparum* infections (Luzzato, 1984).[11]

The geographical specificity of malaria, the wide biological variation in the capacity of mosquito vectors, the inability to control malaria in Africa under experimental conditions, and the persistence of fatal blood diseases as a defense all point to a causation from malaria to poverty, not vice versa. Large-scale vector control projects require resources, but if they were clearly feasible, the resources would probably be forthcoming from the international community. Much of the effective malaria control (in subtropical areas) has in fact come from low-technology drainage and larvaciding,[12] which could be carried out independently by a poor tropical country if the technique offered a viable prospect of malaria control.

Anecdotes from countries that have eliminated malaria

A small number of the countries that had intensive malaria earlier this century eliminated the disease. Many other changes were simultaneously occurring in the economies of these countries before and after eradication, but in almost all cases for which we have data, the countries experienced an acceleration of growth immediately following eradication, and faster growth than neighboring countries.

Malaria eradication in southern Europe has been a clear success story in the fight against malaria. Major control efforts in Greece, Italy, and Spain were started in the 1930s and completed in the late 1940s. Greece up to that time had been the most malarial country in Europe, in peak years totalling a quarter of the total population (Kamarck, 1976, p. 12). Jones (1909) argues that the spread of *faliparum* malaria through most of Greece in the first millenium AD was the main factor in the decline of ancient Greek civilization. Greece was the site of major malaria epidemics in the nineteenth and early twentieth century, and the famed plain of Marathon became virtually uninhabited due to malaria despite very fertile soils. The use of DDT starting in 1946 had spectacular results (having a major influence on the subsequent WHO world eradication campaign), with malaria falling from 1-2 million cases per year in the early 1930s to only 5,000 in 1951 (Bruce-Chwatt and de Zulueta, 1980). Although complete eradication would take another twenty years, partly due to vector resistance to DDT, from an economic point of view malaria was under control.

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[10] Sickle cell trait also shows the role of climate in determining the relative burden of disease in different regions of the world. “The distribution of sickle cell trait in tropical Africa corresponds almost exactly to the areas of tropical rain forest” (Carlson, 1984, p.29).

[11] Many ethnic groups in Africa also have complete protection from *P. vivax* malaria due to a blood characteristic called the Duffy factor, which makes *vivax* malaria rare in Africa. Although this suggests that *vivax* malaria is also burdensome, it does not demonstrate that the human burden is large because the Duffy factor causes no mortality in people who carry it. Africans could easily maintain the Duffy factor in the face of evolutionary selection even with a low disease burden from *vivax* malaria.

[12] See Kriton and Spielman (1989) on the major role of these simple technologies in many of the successful eradication efforts.

The longstanding problem of malaria in Italy contributed to the major role of Italians in early malaria research. Just before the control campaign, Italy had over 300,000 cases of malaria per year with about 20,000 deaths (Haworth, 1988). The Pontine Marshes south of Rome were rendered uninhabitable by the disease. *P. falciparum* was eliminated by the end of the 1940s, with *P. vivax* and *P. malariae* disappearing more slowly.

Spain reported 400,000 cases of malaria with 1700 deaths in 1943 (Haworth, 1988), but had effectively controlled the disease by the end of the 1940s.

The period immediately before effective control of malaria was wartime and the post-war reconstruction. Due to the anomalies of the period and the lack of data, we compare growth in the post-control years of 1950-1955 to growth in the period 1913-1938 in Table 2.[13] In all three countries, economic growth in the post-control period was much higher than in the prewar period, and higher than growth in rest of Western Europe 1950-1955. In the prewar period, Greece and Italy also grew somewhat faster than Western Europe, but the increment in growth over the European average was also higher in the post-control period than the prewar period.

Portugal was another southern European country with intensive malaria (over 100,000 cases per year in the 1940s – Haworth, 1988) that controlled malaria later than Greece, Italy and Spain. As shown in Table 3, growth accelerated after eradication in 1958 compared to the period before eradication, and once again the increment of growth over the average in the rest of Western Europe increased after eradication.

There are, unfortunately, few success stories for malaria eradication in developing countries, but the islands of Taiwan and Jamaica are among the few. Tables 4 and 5 show that growth accelerated in the two countries after eradication, in 1961 for Taiwan and 1958 in Jamaica. In both cases, growth also increased by more than growth in their respective regions.

The U. S. South was still very malarious before World War II. 135,000 cases of malaria with 4000 deaths were reported in 1935 (Haworth, 1988). After large-scale drainage projects by the W.P.A. in the 1930s were followed by insecticide spraying after the war, malaria was brought under control by the end of the 1940s. In the decade of the 1950s, the South had its most dramatic catch-up with the rest of the country, going from 60% of the income per capita of the rest of the U.S. in 1950 to 68% in 1960 (calculated from Barro and Sala-i-Martin, 1991).

An exception to prove the rule is Mauritius. A small island off the coast of East Africa, Mauritius was first exposed to malaria in 1865 with castrophic results. In one year, 1867, between an eighth (Verdrager and others, 1964) and a quarter (Ross, 1910, quoted in Soper and Wilson, 1943) of the total population died in the malaria epidemic. Malaria was finally eliminated in 1963. Economic growthi n a small, closed, sugar-producing economy continued to be *negative* until 1973 when Mauritius opened its economy, built export processing zones, and took off economically. Countries do not become prosperous by controlling malaria alone, but the dramatic success of Mauritius in become a manufacturing exporter since 1973 was certainly made easier by eliminating malaria.

Malaria control within regions of some other countries has had dramatic impacts on agricultural output and settlement patterns. "Until malaria was wiped out [in Corsica], no one farmed [on the eastern plain]. Today this plain accounts for 60 percent of Corsica's agricultural production." (Kamarck, p. 12) The southern plains of Nepal, the Terai, were virtually uninhabited until the early 1950s because of malaria. It is now the richest and most agriculturally productive part of the country (Kamarck, p. 12).

These country examples of growth after the control of malaria are merely suggestive. In every country examined economic growth was higher immediately after the eradication of malaria, but there were surely many other factors that influenced the economy at the same time. In several of the countries (Greece, Spain, and Jamaica), the rapid development of the tourism industry was only possible because of malaria eradication. Few tourists thought of basking on shores of the Aegean when Greece was the most malarial country in Europe.

[13] GDP data for the 1913-1938 period are from Maddison, 1995. All other country GDP data in this section are from Summers and Heston, 1994.

Malaria and economic growth

We have shown that most malarial countries are poor, and certain countries that managed to completely eliminate malaria in recent times have had more rapid economic growth than their neighbors. But can we find any general, statistically convincing evidence that initial malaria prevalence and reductions in malaria affect economic growth? Would a reduction in malaria significantly improve the economic prospects of poor countries?

The most direct way to assess the causal effect of malaria on country economic performance is to look at the relationship between economic growth, initial malaria levels and change in malaria over same period. Above we saw that countries with intensive malaria in 1965 have had much lower economic growth in the subsequent 25 years, but this did not take into account the initial poverty of countries, nor did it consider the role of human capital levels (overall health and education), government policies, or geographical variables. After the role of human capital, policy, and geography are taken into account, it is generally found that poorer countries grow faster than richer countries (Barro and Sala-i-Martin, 1995), so if malaria were really just a proxy for poverty, one would expect malarial countries also to grow faster.[14]

Table 6 presents a cross-country empirical growth estimation in the style of Barro (1991). Growth in GDP per capita over the 1965 to 1990 period is related to initial income levels, initial human capital stock, policy variables, and geographical variables. Human capital stock is measured by secondary education and life expectancy at birth. Policy is measured by trade openness over the period and an index of the quality of public institutions. The geographical variables include an indicator for the geographical tropics and the fraction of the population within 100 kilometers of the coast.[15] To these well-researched predictors of economic growth we add the malaria index in 1965 in Regression 1 of Table 6.[16] Countries with intensive malaria in 1965 had much lower economic growth, amounting to 1.3% lower growth per year, *even after other factors like initial income level, overall life expectancy and tropical location are taken into account*.

Reductions in malaria over the 1965-1990 period, in addition to malaria levels in 1965, are associated with much higher economic growth, as shown in Regression 2 of Table 6. This corresponds to a 0.3% rise in annual economic growth for a 10% reduction in the malaria index. Over the twenty-five year period the average reduction in the malaria index was 7% among countries that had malaria in 1965. By extrapolation far outside the observed sample variation, a country with its whole territory affected by 100% *P. falciparum* malaria is predicted to raise permanently its annual growth by 3.2% if it completely eliminates malaria! Unfortunately, no country came near to accomplishing this. Of the fourteen countries in the sample with a malaria index above 0.9 in 1965, only one reduced it significantly: the malaria index in Zimbabwe fell by one-third.

Economic growth itself might be a cause of the observed malaria reductions if economic growth made greater resources available for malaria control, or other factors such as a high institutional capacity could be responsible for both economic growth and successful malaria control. In this case the estimates of the effect of malaria reduction on economic growth would be biased. To control for the possible endogeneity of malaria reduction, Regression 3 of Table 6 uses instrumental variables (see, for example, Greene, 1997, pp. 288-295). The instruments are the prevalence of 53 different *Anopheles* mosqito vectors in each country in 1952.[17] The different *Anopheles* mosqitoes vary widely in their efficacy in transmitting human malaria, so that the distribution of *Anopheles* vectors is strongly correlated with malaria intensity and its change (the first-stage instrumental variables regression of the change in the malaria index on *Anopheles* vectors, which is not shown, has an R^2 of 0.51). There is no reason to think that the distribution of malaria mosquito vectors is a cause of economic growth apart from the direct influence of malaria,

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[14] In fact, over the 1965 to 1990 period, poor countries on average grew slower than rich countries, but poor countries also had lower initial human capital, followed less successful economic policies, and were disadvantaged geographically.

[15] Gallup and Sachs (1999) give a more detailed description of these variables.

[16] The malaria index for 1965 is constructed similarly to the malaria index for 1994, described above. It is the product of the fraction of the population living in areas with high malaria risk in 1965 times the fraction of malaria cases in 1990 that are *P. falciparum.* This assumes that the *relative* share of *P. falciparum* cases did not change substantially from 1965 to 1990. The malaria data for 1965 were digitized from a WHO (1966) map.

[17] The *Anopheles* data were digitized from American Geographical Society (1952) and used to calculate the percent land area in each country affected by each *Anopheles* species.

making vector prevalence an ideal instrument for malaria change. After correcting for the possible endogeneity of malaria reduction, the estimated effect on economic growth is essentially unchanged, so it is unlikely that the changes in malaria prevalence are a consequence of economic growth. A Hausman (1978) test finds no significant difference the ordinary least squares and instrumental variables estimates, rejecting the endogeneity of the change in malaria.

Regression 4 restricts the sample to non-sub-Saharan African countries. The size of the estimates for malaria are substantially the same. The change of malaria has a statistically significant coefficient, but the estimate for initial malaria loses statistical significance. Even without including the sub-Saharan African countries with the most intensive malaria, a reduction in malaria corresponds to much higher economic growth.

Malaria could be a proxy for a range of tropical diseases that are not adequately controlled for by life expectancy. One disease that is starting to have major economic impacts in many of the same countries with intensive malaria, AIDS, is not relevant for the time period under study here. By 1990, the end of the period of economic growth studied, the burden of AIDS was still sufficiently small to cause very minor economic impacts. Other major diseases prevalent in the tropics that may be correlated with malaria are hookworm, onchocerciasis, schistosomiasis, filariasis, dengue fever, and trypanosomiasis. We have indentified detailed maps of the geographical extent of all these diseases except for trypanosomiasis from the 1950s, as well as data for ten other less important tropical diseases providing measures of the extent of twenty different tropical diseases.[18] The land area affected by the disease is weighted by detailed population distribution data to provide an estimate of the fraction of the population at risk of each disease. Since the data preceed the period of economic growth under study, they show the impact of initial disease on subsequent economic performance avoiding problems of reverse causation.

The large number of diseases make it impractical to include them all as independent correlates in the economic growth regression due the limited sample of countries. To assess whether the other diseases were responsible for the correlation of initial malaria with economic growth, we included each of the twenty diseases as an additional regressor separately to the regression specification in Regression 1 of Table 6. The estimated impact of malaria was remarkably stable across these twenty regressions with a point estimate range of just –0.7 to –1.3, and statistically significant at the ten percent level in 17 of 20 regressions (not shown – available from the authors upon request). Rather surprisingly, *none* of the other tropical diseases had a significant negative correlation with economic growth even at the 10 percent level, after controlling for malaria in these regressions. A second way to combine the other disease information is to estimate its principal components and include a linear combination of the other disease variables in the growth regression. As shown in Regression 5 of Table 6, the first principal component of the tropical diseases has a insignificant positive correlation with subsequent economic growth, and malaria has the same significantly negative correlation with economic growth as in Regression 1 of Table 6. Controlling for a range of other tropical diseases does not substantially affect the correlation of initial malaria with subsequent growth.

The malaria index, though it is the best measure of malaria burden we could construct, is admittedly crude. We have also developed an alternative measure of malaria intensity, which although it is also crude, is derived from completely different data sources, and covers a different time period. The alternative malaria indicator used qualitative assessments of the severity of malaria from the WHO's (1981) country-specific health advice for travelers. The earliest descriptions of malaria in these advisories date from 1980, and the index is set equal to one for countries in which malaria affects the whole country or the whole country except for major cities, and zero otherwise. Using data on economic growth from 1980 to 1995 and corresponding data on covariates in Regression 6 of Table 6, the "WHO Advisory" malaria indicator for 1980 shows a significant negative correlation of initial malaria with subsequent growth.[19] Countries with malaria throughout the country except for major cities had 1.6%

[18] The other diseases are dengue fever, yellow fever, helminthiases (*Paragoniumus westermani*, *Fasciolopsis buski*, *Opisthorchis elineus*, *Diphyllobothrium sp*., and *Clonorchis sinensis*), and leischmaniases (oriental sore, kala azar, and various American forms of the disease). The schistosomiasis data are broken down into *Schistosoma haematobium* and *S. mansoni*, and the filariasis data into *Loa loa*, *Wuchereria Bancrofti*, *W. malayii*, *Acanthocheilonema perstans*, and *Mansonella ozzardi*, giving a total of 20 non-malaria tropical disease variables.
[19] The data sources for the variables in Regression 6 of Table 6 that have not already been documented are the World Bank (1998) for purchasing power parity GDP per capita 1980-1995, Barro and Lee (1993) for initial secondary schooling for those aged fifteen and over, initial life expectancy at birth from United Nations (1996) supplemented with government yearbook estimates for Taiwan.

lower growth in GDP per capita in the 1980-95 period. Using malaria data from a completely independent source and assessing a different (though overlapping) time period from the other growth regressions, malaria still has a very large and statistically significant correlation with economic growth.

A recent study of the macroeconomic impact of malaria (McCarthy and others, 1999) uses still different data sources for measuring malaria, and a different period of economic growth (1983-1998), and different independent control variables. The study finds a robust correlation between malaria and growth using WHO morbidity data, but of a somewhat smaller magnitude than we find here: just over one quarter of a percent per year of economic growth for about a quarter of the sample.

The growth regression results show that countries with intensive malaria in 1965 had dramatically lower economic growth in the subsequent twenty-five years, after controlling for other factors that likely influenced growth, like initial poverty, economic policy, initial health and education levels, and tropical location. Countries that managed to reduce malaria over the period had much higher economic growth. These problems affected sub-Saharan Africa most severely because malaria levels are highest there, but the same relationship with economic growth holds in the non-African world. Using an independent malaria measure over a different time period shows a similar correlation of malaria and economic growth.

Could malaria have such a large impact on economic growth?

We have presented several kinds of evidence suggesting that malaria has large economic effects. What are the channels through which malaria could be a major drag on the economy?

The traditional medical view of malaria at its most severe, in holoendemic areas, is that malaria contributes significantly to child mortality and can cause acute disease in pregnant women, but it does not have large effects on the fitness of other mature adults due to their partial immunity acquired through constant reinfection. McGregor (1988, p. 754) states this clearly: "in adult life...a host-parasite balance resembling commensualism is achieved. Despite sustained infectious challenge, adults constitute an economically viable work-force capable of coping with the strenuous physical activities that are required to maintain essential food supplies in subsistence agricultural communities." Though this view may be shared by many in the medical field, it has rarely been the subject of careful research. One wonders if the medical focus on mortality and acute disease obscures a general debilitation that could be caused by malaria. At least one article reports that long-term asymptomatic malaria may be the cause of chronic pains and lassitude among Europeans in East Africa (Wilks and others, 1965).

Formidable methodological and measurement problems confront any assessment of the impact of malaria on individuals and households in areas of stable malaria. There is not even a clear method for diagnosing which individuals suffer from malaria. Virtually the whole population carries malaria parasites, and the density of parasites is not a reliable measure of disease due to a variable immune response, which is still poorly understood. Fever symptoms are not specific to malaria. If everyone is infected with malaria, there is no comparison group for measuring the impact of malaria on diseased individuals relative to the healthy population.

If a clear measure of disease burden were available, one still faces the problem of assessing the cost of illness in extended rural households, accounting for the compensating behavior of other household members. It is hard to evaluate the cost of lost opportunities of household members who help out a person with malaria. Most attempts to directly measure the lost work due to malaria (which ignore these problems) find small impacts (Chima and Mills, 1998; Malaney, 2000). Some recent studies have found larger measurable impacts of malaria at the household level (Cropper and others, 1999, Audibert and others, forthcoming). A recent study of the impact of parental illness on child health in Tanzania found that children with fathers or especially mothers who were ill with malaria had worse health, whereas parental AIDS was not significantly related to child health (Dayton, 1999). However the difficulty in measuring how much individuals actually suffer from malaria in an environment where most people carry malaria parasites, and the myriad problems of measuring household response to debilitation make all the microeconomic estimates incomplete.

Malaria has life-long effects on cognitive development and education levels through the impact of chronic malaria-induced anemia and time lost or wasted in the classroom due to illness. The importance of these effects is speculative, though, since their impact is virtually unstudied. Iron-deficiency anemia *per se* has been shown to affect the cognitive skills of children as well as their cognitive abilities in later life (Pollit and others, 1989, and Lozoff and others, 1991).[20]

In short, the impact of malaria on the productivity of individuals in areas of stable malaria cannot be assessed with the current state of research. Whether or not individuals are significantly debilitated by malaria, there are several other channels through which malaria could have large impacts on the economy. The first is the impact of malaria on foreign direct investment and tourism. Malaria, unlike diseases resulting from poverty, does not discriminate between rich and poor victims. As long as malaria protection is imperfect and cumbersome, well-to-do foreign investors and tourists may stay away from malarial countries. A second channel through which malaria may affect the economy is limitation on internal movement.[21] The better educated and the ambitious who move to the largely malaria-free cities lose their natural protection due to lack of exposure. They may be reluctant to maintain contact with the countryside for fear of infection. Communities in unstable malaria areas may make people from stable malaria areas unwelcome. In general, the transmission of ideas, techniques, and development of transportation systems may all be stunted by malaria.

Conclusion

The location and severity of malaria are mostly determined by climate and ecology, not poverty per se. Areas with intensive malaria are almost all poor and continue to have low economic growth. The geographically favored regions that have been able to reduce malaria have grown substantially faster afterwards. The estimated impact of malaria on economic growth, using two different measures of malaria, is very large, but the mechanisms behind the impact are not clear.

[20] It might be thought that malaria has a large impact in poor countries because of its interaction with malnutrition. Malaria, along with other childhood infectious diseases, has been found to exacerbate malnutrition. Surprisingly, though, malnutrition probably confers some protection against malaria. McGregor (1988, p. 763), in his survey, finds that “the balance of available evidence indicates that malnutrition in humans is more commonly antagonistic to malaria.”

[21] We thank Andrew Spielman for suggesting this effect of malaria.

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Table 1. Level of GDP per capita

	(1)	(2)	(3)	(4)	(5)	(6)
	Log GDP per capita					
	1995	1950	1995	1995	1995	1995 (non-Africa)
Population within 100km of coast (%)	1.26	0.80	0.57	0.65	0.33	0.40
	(6.31)**	(5.19)**	(2.74)**	(3.40)**	(2.23)*	(2.76)**
log Distance to major markets	-0.35	-0.12	-0.33			
	(3.79)**	(1.37)	(4.03)**			
log Hydrocarbons per person	0.01	0.01	0.01	0.01	0.00	0.00
	(2.28)*	(2.56)*	(1.86)	(2.13)*	(1.36)	(1.27)
Tropical land area (%)	-0.68	-0.14	-0.23	-0.59	-0.09	-0.10
	(3.97)**	(0.89)	(1.01)	(3.04)**	(0.59)	(0.83)
Falciparum malaria index		-1.17	-1.22	-1.16	-1.16	-1.10
		(6.28)**	(5.67)**	(4.73)**	(6.41)**	(4.34)**
Socialist				-0.80	-0.10	-0.05
				(5.20)**	(0.66)	(0.30)
Colony				-0.14	-0.05	-0.12
				(2.18)*	(0.89)	(2.24)*
Trade openness (0-1)					0.50	0.43
					(2.99)**	(2.98)**
Quality of public institutions (0-10)					0.22	0.23
					(6.85)**	(7.82)**
Constant	10.50	8.54	10.91	8.75	7.15	7.15
	(14.10)**	(13.54)**	(17.36)**	(46.40)**	(29.27)**	(32.30)**
Observations	149	127	127	149	97	66
R-squared	0.47	0.59	0.62	0.62	0.88	0.88

Robust t-statistics in parentheses
* significant at 5% level; ** significant at 1% level

Table 2. GDP per capita growth before and after malaria eradication in southern European countries (late 1940s)

	GDP p.c. growth		Difference w/W. Europe	
	1913-38	1950-55	1913-38	1950-55
Greece	2.1	3.6	1.1	1.3
Italy	1.0	5.3	0.1	3.0
Spain	-0.4	6.2	-1.4	4.0
Western Europe	0.9	2.3	0.0	0.0

Table 3. GDP per capita growth before and after malaria eradication in Portugal (1958)

	1953-58	1958-63	Change
Portugal	3.0	5.3	+2.3
Western Europe	1.9	3.8	+1.9
Difference	+1.1	+1.5	+0.4

Table 4. GDP per capita growth before and after malaria eradication in Taiwan (1961)

	1956-61	1961-66	Change
Taiwan	2.8	5.8	+3.0
East Asia	3.4	5.5	+2.1
Difference	-0.6	+0.3	+0.9

Table 5. GDP per capita growth before and after malaria eradication in Jamaica (1961)

	1956-61	1961-66	Change
Jamaica	3.4	4.1	+0.7
Central America and Caribbean	2.6	3.1	+0.5
Difference	+0.8	+1.0	+0.2

Table 6. Growth of GDP

	(1) 1965-90	(2) 1965-90	(3) 1965-90 (IV)	(4) 1965-90 (non-Africa)	(5) 1965-90	(6) 1980-95
Log initial GDP per capita	-2.6	-2.6	-2.4	-2.5	-2.3	-3.6
	(8.07)**	(7.90)**	(7.54)**	(6.36)**	(8.04)**	(7.95)**
Log initial secondary schooling	0.1	0.1	0.1	0.1	0.1	-0.2
	(1.04)	(0.90)	(0.60)	(0.62)	(0.77)	(0.62)
Log initial life expectancy	4.4	3.1	3.0	3.8	4.6	9.6
	(4.46)**	(3.41)**	(3.51)**	(2.34)*	(4.19)**	(3.44)**
Trade openness (0-1)	1.8	1.7	1.6	1.7	1.7	3.0
	(4.91)**	(4.91)**	(4.51)**	(4.14)**	(4.55)**	(5.10)**
Quality of public institutions (0-10)	0.4	0.4	0.3	0.4	0.3	0.6
	(3.29)**	(3.79)**	(3.32)**	(2.95)**	(2.78)**	(4.03)**
Tropical land area (%)	-0.6	-0.6	-1.0	-0.6	-1.0	-0.6
	(1.30)	(1.31)	(2.55)*	(1.28)	(2.50)*	(1.22)
Population within 100km of coast (%)	0.9	0.7	0.7	0.6	0.8	0.9
	(2.85)**	(2.64)*	(2.41)*	(1.66)	(2.36)*	(1.80)
Initial falciparum malaria index	-1.3	-2.1	-1.8	-1.8	-1.3	
	(2.24)*	(3.77)**	(3.12)**	(1.77)	(1.98)*	
Change of falciparum malaria index		-2.6	-2.5	-2.2		
		(4.07)**	(3.48)**	(2.24)*		
Tropical disease, 1st principle component					0.1 (1.51)	
Initial "WHO Advisory" malaria index						-1.6 (2.18)*
Constant	1.3	6.1	5.7	3.7	-0.9	-14.8
	(0.36)	(1.68)	(1.58)	(0.63)	(0.21)	(1.42)
Observations	75	75	73	60	73	78
R-squared	0.77	0.80	0.80	0.76	0.77	0.71

Robust t-statistics in parentheses
* significant at 5% level; ** significant at 1% level

Table 7. Level and Changes in Malarial Prevalence between 1965 and 1994 by Climate Zone

Predominant Climate	Malaria Index 1965 (0-100)	Average Change 1965-1994
Temperate (N=57)	0.2	-0.2
Desert (N=23)	27.8	-8.8
Subtropical (N=42)	61.7	-5.0
Tropical (N=21)	64.9	0.5

Note: Countries are classified by their predominant ecozone from the following groupings: Temperate (temperate, boreal and polar ecozones), Desert (tropical and subtropical deserts), Subtropical (non-desert subtropical), and Tropical (non-desert tropical). The index and average reduction are unweighted averages over countries. See Gallup and Sachs (1999) for the sources of climate zone data.

Figure 1.
Malaria risk - 1946, 1965, 1994

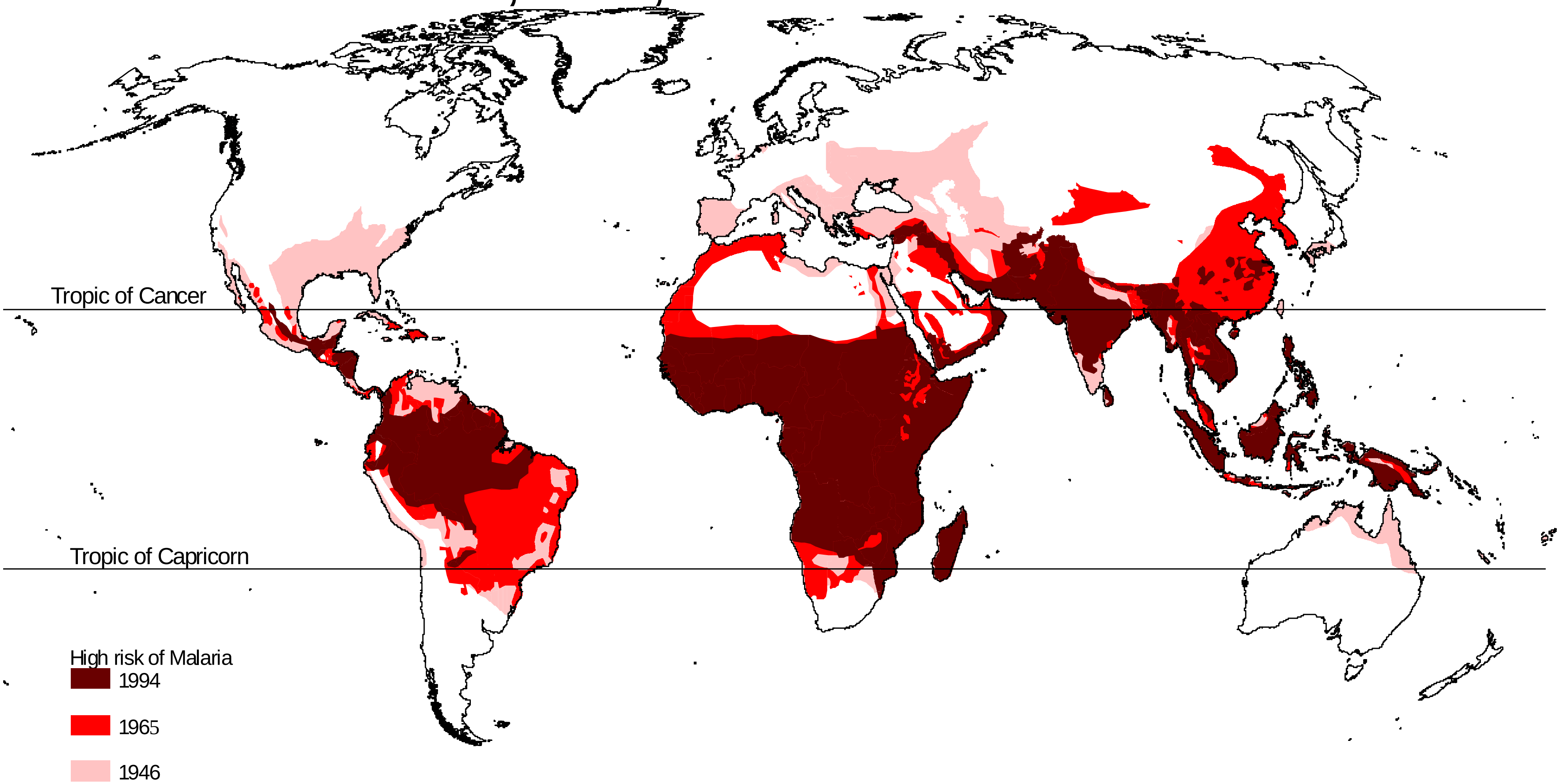

Figure 2.
GDP per capita 1995

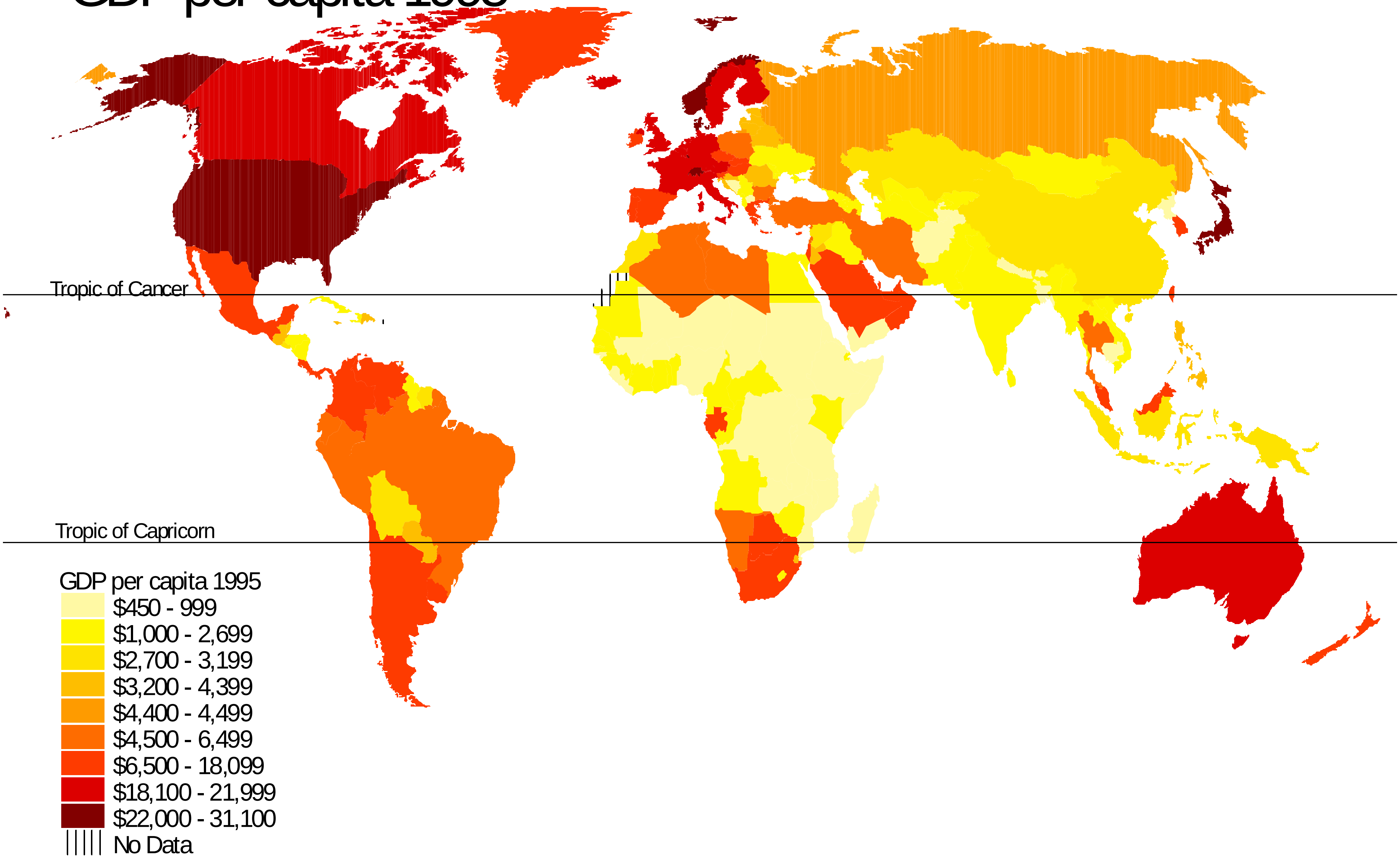

Figure 3.

Malaria Index 1965

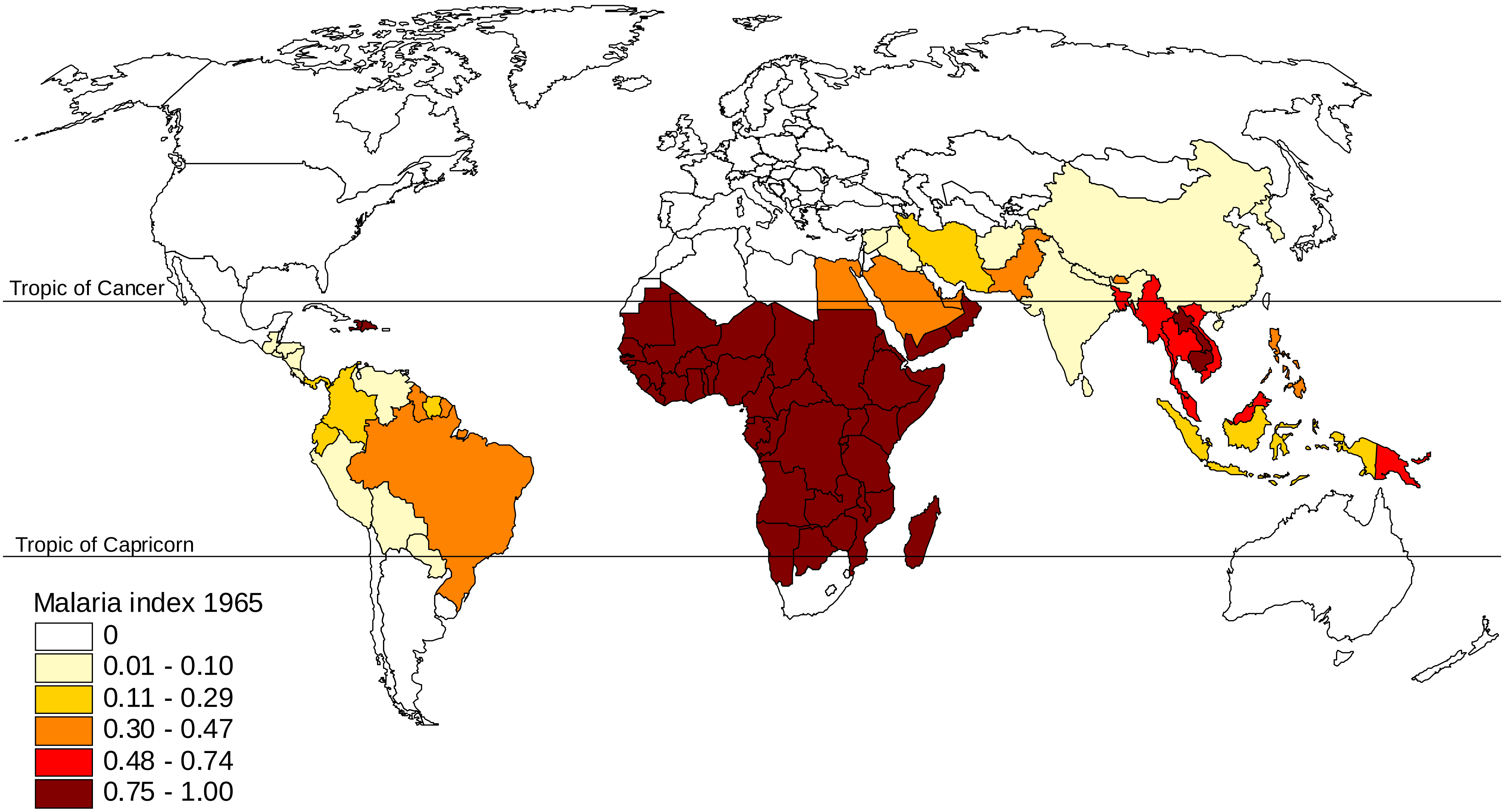

Figure 4.

Malaria Index 1994