Am. J. Trop. Med. Hyg., 64(1, 2)S, 2001, pp. 85–96

THE ECONOMIC BURDEN OF MALARIA

JOHN LUKE GALLUP AND JEFFREY D. SACHS
Center for International Development, Harvard University, Cambridge, Massachusetts

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 of only 33% that 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 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 tropical countries 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 5 years after eliminating malaria has usually been substantially higher than growth in the neighboring countries. Cross-country regressions for the 1965–1990 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. We speculate 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.

POVERTY AND MALARIA

Malaria and poverty are intimately connected. As T. H. Weller, a Nobel laureate in medicine, noted, ''It has long been recognized that a malarious community is an impoverished community.''[1] 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 geographically specific, as shown in Figure 1. Intensive 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 intensive malaria.

A basic problem when studying the macroeconomic impact of malaria is the lack of 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 maps by Pampana and Russell[2] and the World Health Organization[3,4] [WHO]). Combined with detailed data on the world population distribution, one can estimate the fraction of the population in high malaria risk areas in each country.[5] Because most malaria mortality and severe morbidity is due to one of the 4 malaria species, the malignant *Plasmodium falciparum*, the index of malaria intensity used in this article is the fraction of the population at risk of malaria multiplied by the fraction of cases of malaria that are falciparum malaria (from WHO data[6]). (A second index of malaria derived from completely different data is described and used below.) For the comparative statistics in this section, severe malaria is defined as having a malaria index of > 0.5.

After the first draft of this article was completed, McCarthy and others (unpublished data) have estimated the impact of malaria on economic growth by use of recently released estimates of malaria morbidity from the WHO.[7] By use of a similar methodology to ours, but by use of a different data source and a different time period, they found somewhat smaller estimated effects of malaria than we find here. The smaller estimates could be due to measurement error in the WHO data because the data ''permit only very limited comparison between countries or even between various periods for the same country.''[7] Because the national reporting systems are systematically different between countries with high or low levels of malaria, this study does not use the WHO data on cases of malaria but instead uses the malaria index derived from malaria maps and falciparum prevalence data.

As an example, take the 150 countries with populations > 1 million in 1995, which account for $> 99\%$ of the world's population. Forty-four of the 150 countries, or 29%, 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 with an average income of $8,268 in the countries without severe malaria, > 5 times higher. (The 1995 purchasing-power parity GDP data are from the World Bank, supplemented by U.S. Central Intelligence Agency estimates for countries not reported in World Bank data.[8–10]) Ranking the 150 countries by income per capita, all but 3 of the 44 countries with severe 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 74 out of 150. Of the 119 poorest countries, all but 12 have some incidence of malaria or are recovering from socialism. The richest 31 countries are free of malaria as measured by our index.

Not only are malarial countries poor, but economic growth in malarial countries over the past quarter century has been

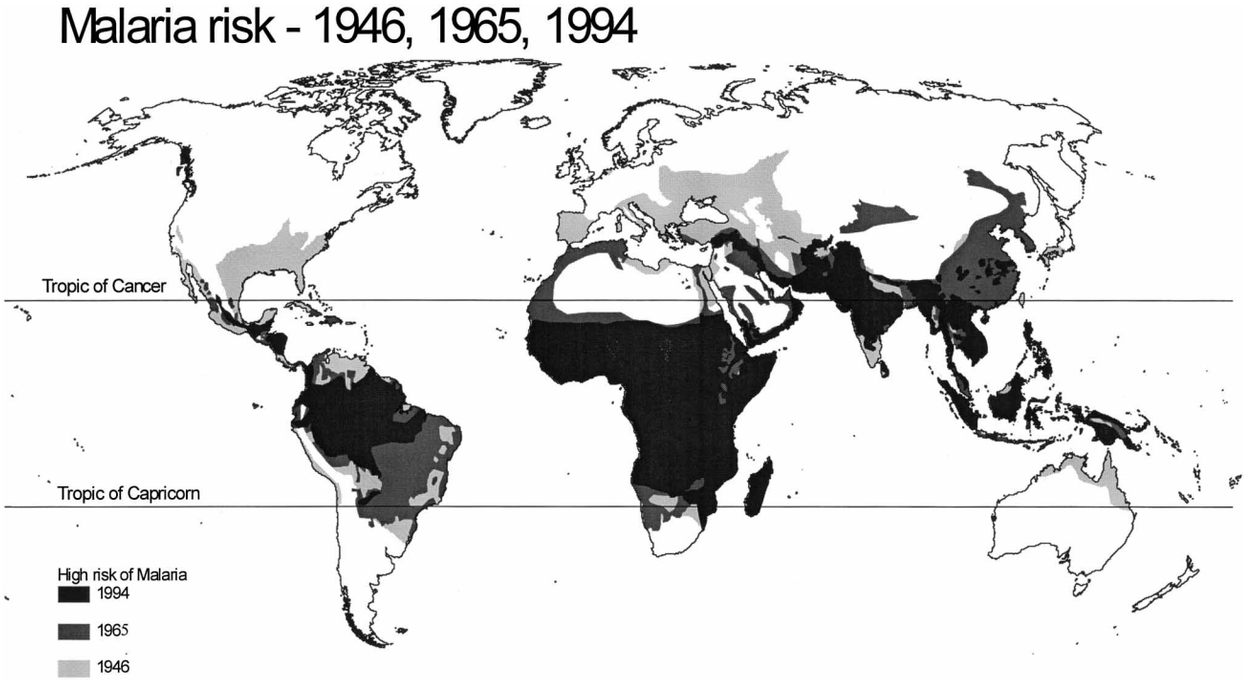

FIGURE 1. Malaria risk, 1946, 1965, 1944.

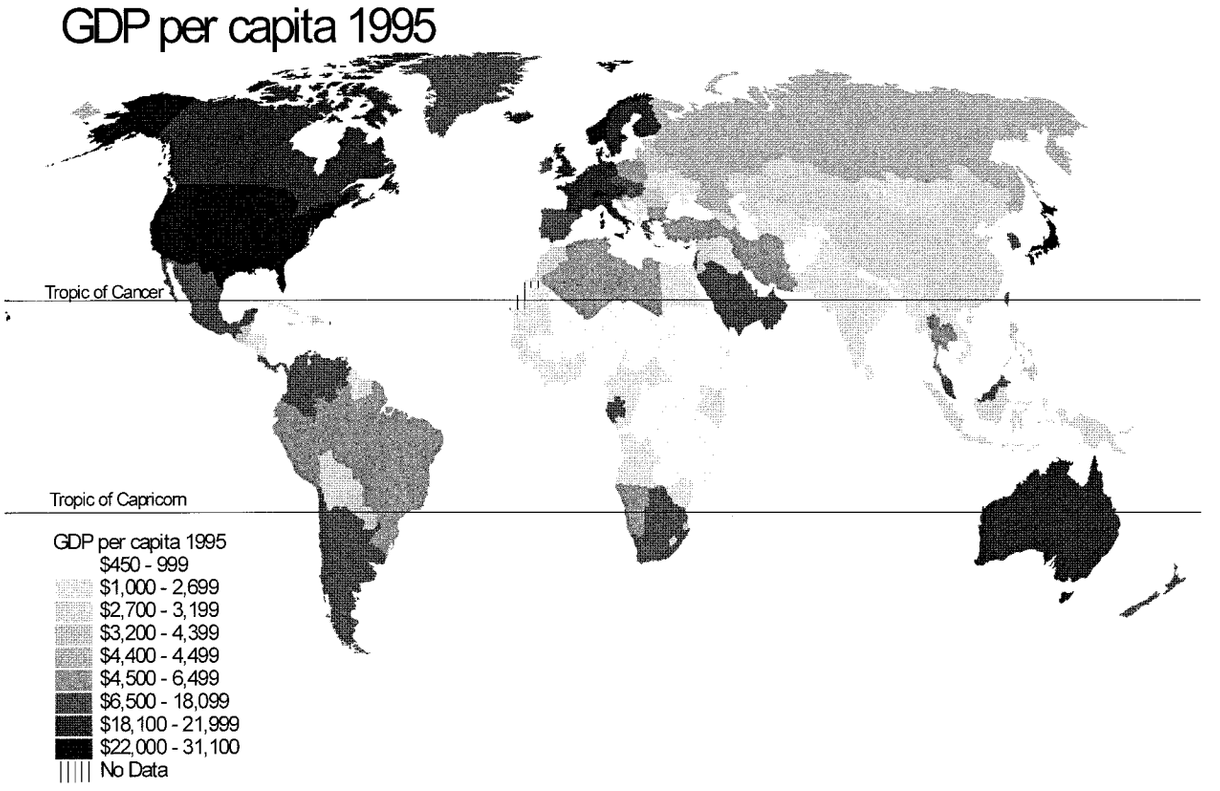

FIGURE 2. Gross domestic product (GDP) per capita, 1995.

TABLE 1
Level of gross domestic product (GDP) per capita

	Regression model					
	1	2	3	4	5	6
	Log GDP per capita†					
Variable	1995	1950	1995	1995	1995	1995 (non-Africa)
Population within 100 km 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^2	0.47	0.59	0.62	0.62	0.88	0.88

† Robust *t*-statistics are in parentheses.
* Significant at 5% level.
** Significant at 1% level.

dismal. Growth of income per capita 1965–1990 for countries with severe malaria has been 0.4% per year, whereas average growth for other countries has been 2.3%, > 5 times higher. (The data for GDP growth 1965–1990 for 95 countries are from the Penn World Tables.[11]) More than a third of the countries with severe malaria (11 out of 29) had *negative* growth 1965–1990.

The question is whether these dramatic correlations mean that malaria *causes* poverty and low growth. We will address this question in 3 ways. First, we consider the correlation of malaria with income levels after controlling 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, such as diarrhea, tuberculosis, and schistosomiasis, malaria is not primarily a consequence of poverty; its extent and severity are largely determined by climate and ecology. Third, we explore the impact of malaria on subsequent economic growth. This provides the most direct evidence of the continuing importance of malaria as a cause of poverty.

MALARIA AND INCOME LEVELS

The coincidence of severe 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; 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 terrible 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. (See Gallup and others[12] for a wider investigation of the role of geography in economic development and for a more detailed explanation of the variables used in this section.) As shown in Regression 1 of Table 1, just 4 geographical variables account for almost half the variation in the log of GDP per-capita income levels in 1995. A country's accessibility to the coast, measured by the share of the population within 100 km of the coast, is an important indicator of success in foreign trade and integration into the global economy and hence is 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. Third, resource deposits, proxied by the log of hydrocarbon reserves per person, are higher in wealthier countries though the effect is very small. Last, 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 nontropical areas, controlling for other factors.

The next 3 regressions in Table 1 add the malaria index to the geographical correlates of income per capita in 2 different years, 1950 and 1995. (The data for purchasing-power parity GDP per capita in 1950 in Table 1 are from Maddison.[13] The purchasing-power parity GDP per-capita data for 1995 are those used above.) The malaria index has a strong negative association with income levels after controlling for

the other 4 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 nonmalarial countries.

Regression 4 includes indicators for former colonies and for 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 1965–1990 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 an association with poverty outside of Africa as for the whole world. Malaria is clearly distinguishable from other problems faced by Africa.

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; its severity, and the difficulty in controlling it, are determined mainly by climate and ecology. Personal behavior, such as use of screens and bed nets, and the general level of development, especially urbanization, also affect malaria prevalence, but they are not the main determinants.

Certain countries with high incomes still face serious malaria problems because of their geographical location. Oman, with an income per capita of almost $10,000, has severe 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, has also been unable to eliminate malaria.

Successful elimination of malaria through vector control requires a well-run organization and financial resources. The determining factor in where malaria has been eliminated in the postwar era has not been institutional or financial, however. 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[14] writes, ''Above all, it should be stressed that malaria eradication [in temperate areas in the late 1940s and early 1950s] was [only] achieved within more or less marginal ecoepidemiological zones, particularly for *P. falciparum*'' because of seasonality of malaria transmission, low nighttime outdoor temperatures, and less efficient malaria vectors in temperate regions.

TABLE 2
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

* Countries are classified by their predominant ecozone from the following groupings: temperate (temperate, boreal, and polar ecozones), desert (tropical and subtropical deserts), subtropical (nondesert subtropical), and tropical (nondesert tropical).[12] The index and average reduction are unweighted averages over countries.

The large differences in the difficulty of controlling malaria in various climatic zones is supported by information provided in Table 2. Those regions with the worst malaria in 1965 had the least reduction in malaria in the next 3 decades. Countries with a predominantly humid tropical climate actually saw a small 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 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, the control of the outbreak of *Anopheles gambiae* mosquitoes in northeastern Brazil in the 1930s, and the malaria-free enclaves around some African mines 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.[15–17] Unfortunately, such control efforts have never been sustained in more than small areas or for more than short periods of time.

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 were lost in 9 years), and the American efforts were not effective until malaria and yellow fever were brought under control.[15] 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.

In addition to differences in malaria intensity due to climate, the world distribution of *Anopheles* mosquitoes—the malaria vector—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 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.''[18] 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 severe *Plasmodium vivax, Plasmodium malariae,* and *Plasmodium ovale.* Africa is also the only major region of the world where falciparum malaria predominates.

Malaria control in sub-Saharan Africa has been a nonstarter. 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.[19] No resources, manpower, or institutional support were spared. Over the course of 7 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.''[19] 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. Such high biting rate estimates are not unusual. Robert and others[20] estimate 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. The vectorial capacity, or the transmission rate of malaria between people through the vectors, reached 2,000 times the critical value required to maintain endemic malaria, with a range of 18–145 malaria-transmitting bites per person per year in the 8 villages studied.[20] In lay terms, everyone was constantly reinfected with malaria.

The vector control efforts reduced the human-biting rate of mosquitoes in the Garki villages by 90% from their prestudy 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. According to 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, unpublished data).

At least 2 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.[14] The explosive potential of the *Anopheles gambiae* vector for transmitting malaria in similar climates elsewhere was shown by the accidental introduction of the mosquito into Brazil in the late 1920s, which was luckily brought under control soon enough to eliminate it.[16] The most pathogenic human malaria species, *P. falciparum,* most likely originated in Africa, probably in the past 5,000–10,000 years with the onset of agriculture.[14]

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 U.S. National Institutes of Health report[18] 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 everywhere 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.[21] The value of sickle cell's protection against malaria must be great because it comes at a high cost: all children in developing countries who inherit the trait from both mother and father die before they reach childbearing age. The Garki project confirmed this cruel equilibrium.[19] Sickle-cell trait in Garki adults was much higher than in children because of selective survival. The burden of malaria on human well-being must have been high indeed for such a mutation to be beneficial. 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.''[22]

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 because they protect primarily against falciparum infections.[23] (Many ethnic groups in Africa also have complete

TABLE 3
Gross domestic product (GDP) per-capita growth before and after malaria eradication in southern European countries (late 1940s)

Country	GDP growth		Difference with western Europe	
	1913–1938	1950–1955	1913–1938	1950–1955
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

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.)

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 larviciding, which could be carried out independently by a poor tropical country if the technique offered a viable prospect of malaria control. Kriton and Spielman[24] describe the major role of these simple technologies in many of the successful eradication efforts.

ANECDOTES FROM COUNTRIES THAT HAVE ELIMINATED MALARIA

A small number of the countries that had severe malaria in the Twentieth 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 of malaria, 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, a quarter of the total population was infected.[25] Jones[26] argues that the spread of falciparum malaria through most of Greece in the first millennium was the main factor in the decline of ancient Greek civilization. Greece was the site of major malaria epidemics in the 19th and early 20th century, and the famed plain of Marathon became virtually uninhabited due to malaria, despite fertile soil. The use of DDT (dichlorodiphenyltrichloroethane) starting in 1946 had spectacular results (which in turn had 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 cases in 1951.[27] Although complete eradication would take another 20 years, partly because of vector resistance to DDT, from an economic point of view, malaria was under control.

TABLE 4
Gross domestic product per-capita growth before and after malaria eradication in Portugal (1958)

Country	1953–1958	1958–1963	Change
Portugal	3.0	5.3	+2.3
Western Europe	1.9	3.8	+1.9
Difference	+1.1	+1.5	+0.4

The long-standing problem of malaria in Italy contributed to the major role of Italians in early malaria research. Just before the control campaign, Italy had > 300,000 cases of malaria per year, with ~20,000 deaths.[28] The Pontine Marshes south of Rome were rendered uninhabitable by the disease. *Plasmodium 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 1,700 deaths in 1943, but it had effectively controlled the disease by the end of the 1940s.[28]

The period immediately before effective control of malaria was wartime and the postwar reconstruction. Because of the anomalies of the period and the lack of data, we compare growth in the postcontrol years of 1950–1955 to growth in the period 1913–1938 in Table 3. (GDP data for the 1913–1938 period are from Maddison.[13] All other country GDP data in this section are from Summers and Heston.[11]) In all 3 countries, economic growth in the postcontrol period was much higher than in the prewar period and higher than growth in rest of western Europe in 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 postcontrol period than the prewar period.

Portugal was another southern European country with severe malaria (over 100,000 cases per year in the 1940s) that controlled malaria later than Greece, Italy, and Spain.[28] As shown in Table 4, growth accelerated after eradication in 1958 compared with 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 5 and 6 show that growth accelerated in the 2 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.

TABLE 5
Gross domestic per-capita growth before and after malaria eradication in Taiwan (1961)

Country	1956–1961	1961–1966	Change
Taiwan	2.8	5.8	+3.0
East Asia	3.4	5.5	+2.1
Difference	−0.6	+0.3	+0.9

TABLE 6
Gross domestic product per-capita growth before and after malaria eradication in Jamaica (1961)

Country	1956–1961	1961–1966	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

The South of the United States was still malarious before World War II; 135,000 cases of malaria with 4,000 deaths were reported in 1935.[28] After large-scale drainage projects by the Works Progress Administration (WPA) 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 United States in 1950 to 68% in 1960 (calculated from Barro and Sala-i-Martin[29]).

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 catastrophic results. In a single year, 1867, between an eighth and a quarter of the total population died in the malaria epidemic.[30,31] Malaria was finally eliminated in 1963. Economic growth in 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.''[25] 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.[25]

These country examples of growth after the control of malaria are merely suggestive. In almost every country we 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.

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 the same period. Above, we saw that countries with severe 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, 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, so if malaria were really just a proxy for poverty, one would expect malarial countries also to grow faster.[32] (In fact, over the 1965–1990 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.)

Table 7 presents a cross-country empirical growth estimation in the style of Barro.[33] Growth in GDP per capita over the 1965–1990 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 km of the coast. (Gallup and others[12] give a more detailed description of these variables.) To these well-researched predictors of economic growth, we add the malaria index in 1965 in Regression 1.

The malaria index for 1965 (Figure 3) is constructed similarly to the malaria index 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 due to *P. falciparum*.[3,5,6] This assumes that the relative share of *P. falciparum* cases did not change substantially from 1965 to 1990. The change in the malaria index over the 1965–1994 period was constructed with a similar malaria index for 1994 (Figure 4).[4–6]

Countries with severe malaria in 1965 had much lower economic growth, amounting to 1.3% lower growth per year, *even after other factors such as initial income level, overall health, 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 in Table 7. This corresponds to a 0.3% rise in annual economic growth for a 10% reduction in the malaria index. Over the 25-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 permanently raise its annual growth by 2.6% if it completely eliminates malaria! Unfortunately, no country came near to accomplishing this. Of the 14 countries in the sample with a malaria index > 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 greater resources were made available for malaria control, or if a high institutional capacity were

TABLE 7
Growth of gross domestic product (GDP)

Variable	Regression model†					
	1 1965–1990	2 1965–1990	3 1965–1990 (IV)	4 1965–1990 (non-Africa)	5 1965–1990	6 1980–1995
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 100 km 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, first principle component					0.1	
					(1.51)	
Initial World Health Organization advisory malaria index						−1.6
						(2.8)**
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^2	0.77	0.80	0.80	0.76	0.77	0.71

† Robust *t*-statistics are in parentheses.
* Significant at 5% level.
** Significant at 1% level.

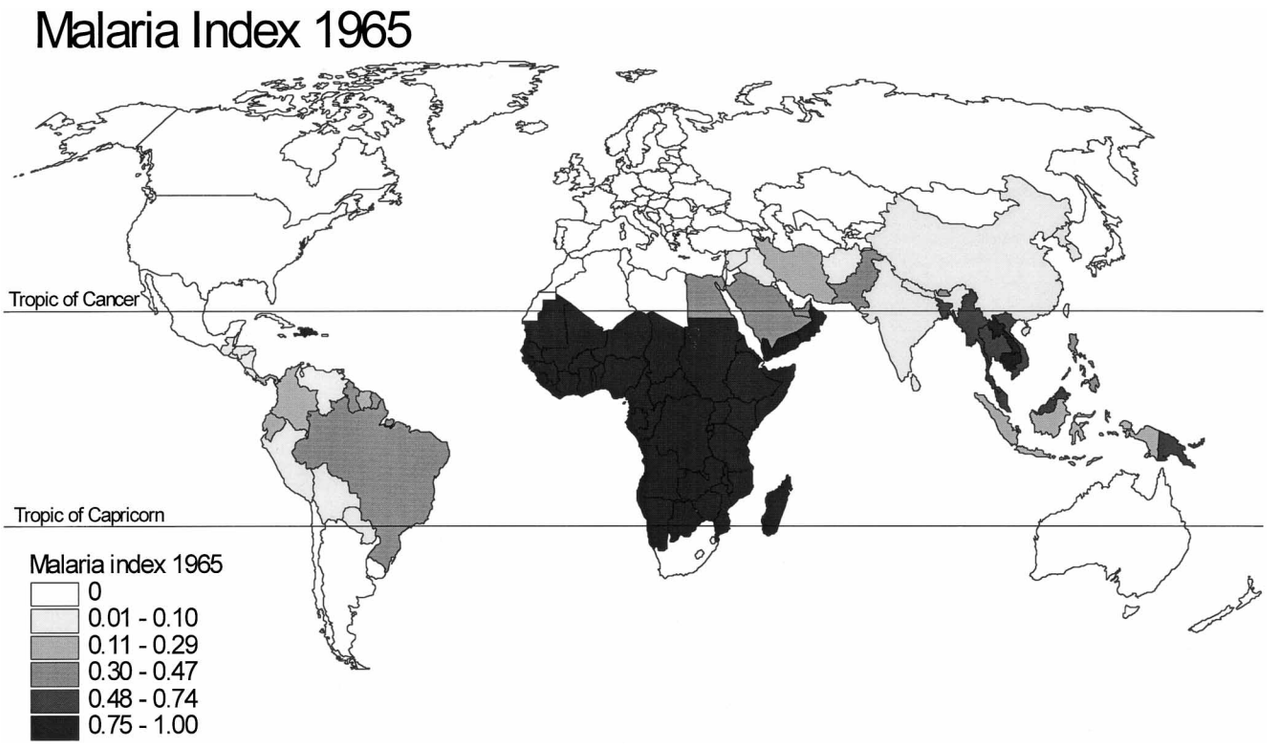

FIGURE 3. Malaria index, 1965.

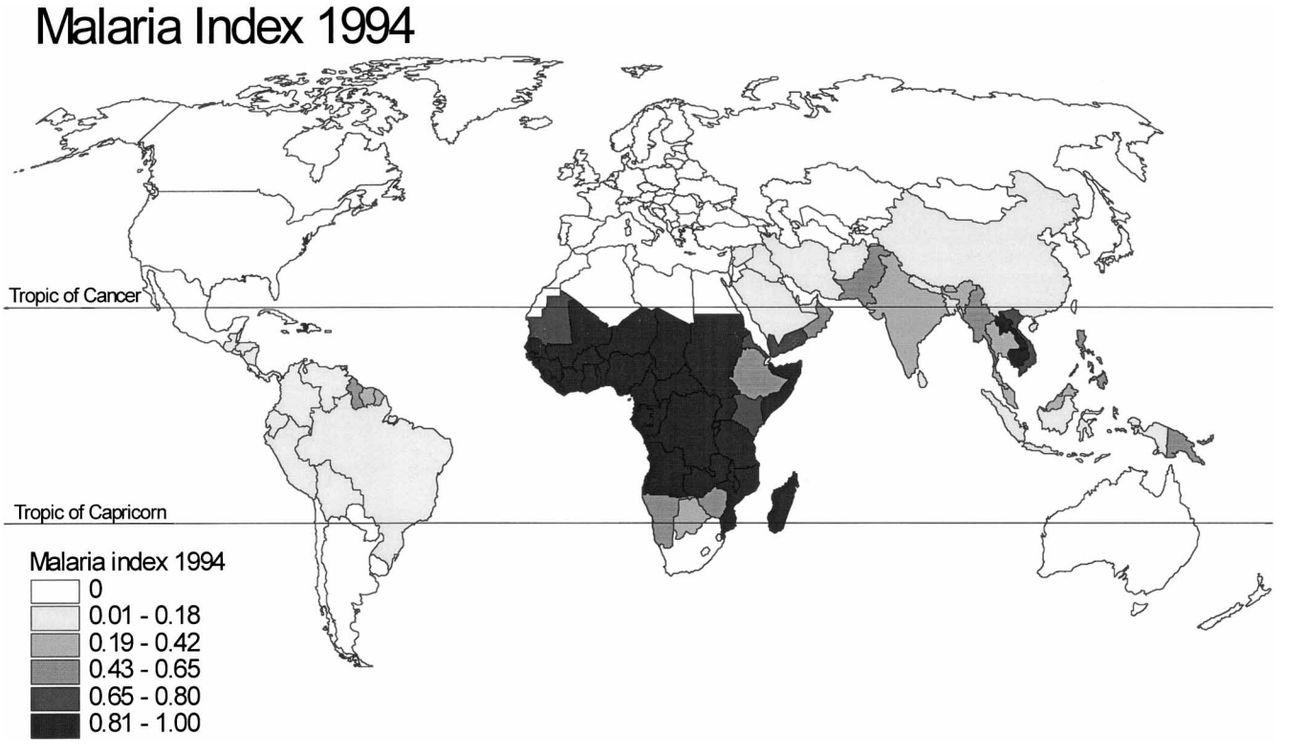

FIGURE 4. Malaria index, 1994.

responsible both for 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 in Table 7 uses instrumental variables. The instruments are the prevalence of 53 different *Anopheles* mosquito vectors in each country in 1952. (The *Anopheles* data were digitized from an American Geographical Society map[34] and used to calculate the percentage of land area in each country affected by each *Anopheles* species.) The different *Anopheles* mosquitoes 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 regression of the change in the malaria index on *Anopheles* vectors 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, 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 test finds no significant difference the ordinary least-squares and instrumental variables estimates, rejecting the endogeneity of the change in malaria.

Regression 4 in Table 7 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 severe 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 severe malaria, acquired immunodeficiency syndrome (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 only 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 (sleeping sickness). We have identified detailed maps of the geographical extent of all these diseases except for trypanosomiasis from the 1950s, as well as data for 10 other, less important tropical diseases providing measures of the extent of 20 different tropical diseases.[35–37] The other diseases are dengue fever, yellow fever, helminthiases (*Paragonimus westermani, Fasciolopsis buski, Opisthorchis felineus, Diphyllobothrium latum,* and *Clonorchis sinensis*), and leishmaniases (oriental sore, kala azar, and American). The schistosomiasis data are broken down into *Schistosoma haematobium* and *Schistosoma mansoni,* and the filariasis data into loa loa, *Wucheria bancrofti, Wucheria malayi, Acanthocheilonema perstans,* and *Mansonella ozzardi,* giving a total of 20 nonmalaria tropical disease variables. The land area affected by the disease is weighted by detailed population distribution data (in 1994[5]) to provide an estimate of the fraction of the population at risk of each disease. Because the disease data precede the period of economic growth under

study, they show the impact of initial disease on later economic performance, thus avoiding problems of reverse causation.

The large number of diseases makes 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 20 diseases as an additional regressor separately to the regression specification in Regression 1 of Table 7. The estimated impact of malaria was remarkably stable across these 20 regressions, with a point estimate range of just −0.7 to −1.3, and statistically significant at the 10% level in 17 of 20 regressions (data not shown). Rather surprisingly, none of the other tropical diseases had a significant negative correlation with economic growth, even at the 10% 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 7, the first principal component of the tropical diseases has an insignificant positive correlation with subsequent economic growth, and malaria has the same significantly negative correlation with economic growth as in Regression 1. Controlling for a range of other tropical diseases does not substantially affect the correlation of initial malaria with subsequent growth.

The malaria index—although 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 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 country-specific health advice for travelers.[38] The earliest descriptions of malaria in these advisories date from 1980, and the index is set equal to 1 for countries in which malaria affects the whole country or the whole country except for major cities, and the index is set at 0 otherwise. The WHO advisory malaria indicator for 1980 is correlated with economic growth across countries for 1980–1995 by use of World Bank purchasing-power parity GDP per capita.[8] Barro and Lee[39] provide data for secondary schooling of those aged 15 and over in 1980, and the United Nations[40] provides data for the life expectancy at birth, supplemented with government yearbook estimates for Taiwan. The other covariates come from regressions covering the 1965–1990 period.

In Regression 6 of Table 7, the malaria indicator for 1980 shows a significant negative correlation of initial malaria with subsequent growth. Countries with malaria throughout the country except for major cities had 1.6% lower growth in GDP per capita in the 1980–1995 period. By using malaria data from a completely independent source, and by assessing a different (though overlapping) time period from the other growth regressions, malaria was found to still have a large and statistically significant correlation with economic growth.

A recent study of the macroeconomic impact of malaria (McCarthy and others, unpublished data) uses still different data sources for measuring malaria, a different period of economic growth (1983–1998), and different independent control variables. The study finds a robust correlation between malaria and growth by use of WHO morbidity data, but a correlation of a 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. As discussed above, the smaller correlation may be due to high measurement error in the WHO malaria data.

The growth regression results show that countries with severe malaria in 1965 had dramatically lower economic growth in the next 25 years, after controlling for other factors that likely influenced growth, such as initial poverty, economic policy, initial health and education levels, and tropical location. Countries that managed to reduce malaria over the time 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. Use of 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 because of their partial immunity acquired through constant reinfection. McGregor[41] states this clearly: ''in adult life . . . a host-parasite balance resembling commensalism is achieved. Despite sustained infectious challenge, adults constitute an economically viable workforce 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.[42]

Formidable methodological and measurement problems confront any assessment of the impact of malaria on individual people and on households in areas with 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 burden because of 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 individuals with disease 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 and 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, and Malaney, unpublished data). Some recent studies have found larger measurable impacts of malaria at the household level (Cropper and others, unpublished data).[43] However, the difficulty in measuring who actually suffers 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 lifelong 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, however, because their impact is virtually unstudied. Anemia due to iron deficiency per se has been shown to affect the cognitive skills of children as well as their cognitive abilities in later life.[44,45]

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, however, malnutrition probably confers some protection against malaria. McGregor,[41] in his survey of the topic, finds that ''the balance of available evidence indicates that malnutrition in humans is more commonly antagonistic to malaria.''

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. The better educated and the ambitious who move to the largely malaria-free cities lose their natural protection because of lack of exposure. They may be reluctant to maintain contact with the countryside for fear of infection. Communities in unstable malarial areas may make people from stable malarial areas unwelcome. In general, the transmission of ideas, techniques, and development of transportation systems may all be stunted by malaria.

CONCLUSIONS

The location and severity of malaria are mostly determined by climate and ecology, not poverty per se. Areas with severe 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 afterward. The estimated impact of malaria on economic growth, by use of 2 different measures of malaria, is large, but the mechanisms behind the impact are unclear.

Authors' addresses: John Luke Gallup and Jeffrey D. Sachs, Center for International Development, Harvard University, 79 JFK Street, Cambridge, MA 02138.

Reprint requests: John Luke Gallup, Center for International Development, Harvard University, 79 JFK Street, Cambridge, MA 02138 (e-mail: john_gallup@harvard.edu).

REFERENCES

1. Weller TH, 1958. Tropical medicine. *Encyclopedia Britannica.* Chicago: William Bennet, 495–497.
2. Pampana EJ, Russell PF, 1955. *Malaria: A World Problem.* Geneva: World Health Organization.
3. World Health Organization, 1966. Malaria eradication in 1965. *WHO Chron 20*: 286–300.
4. World Health Organization, 1997. World malaria situation in 1994, part I. *Wkly Epidemiol Rec 72*: 269–274.
5. Tobler W, Deichmann U, Gottsegen J, Maloy K, 1995. *The Global Demography Project.* National Center for Geographic Information and Analysis. Technical Report TR-95-6.
6. World Health Organization, 1992. World malaria situation in 1990, part II. *Wkly Epidemiol Rec 67:* 169–174.
7. World Health Organization, 1999. Malaria, 1982–1997. *Wkly Epidemiol Rec 74*: 265–270.
8. World Bank, 1998. *World Development Indicators 1998 CD-ROM.* Washington, DC: International Bank for Reconstruction and Development.
9. U.S. Central Intelligence Agency, 1996. *The World Factbook.* Washington, DC: Central Intelligence Agency.
10. U.S. Central Intelligence Agency, 1997. The world factbook. Available at: http://www.odci.gov/cia/publications/factbook/index.html. Accessed August 15, 1999.
11. Summers R, Heston A, 1994. The Penn World Tables, Mark 5.6. Available at: http://pwt.econ.upenn.edu/. Accessed January 23, 2001.
12. Gallup JL, Sachs JD, Mellinger AD, 1999. Geography and economic development. Pleskovic B, Stiglitz JE, eds. *World Bank Annual Conference on Development Economics 1998.* Washington, DC: World Bank, 127–178.
13. Maddison A, 1995. *Monitoring the World Economy, 1820–1992.* Paris: OECD.
14. Coluzzi M, 1999. The clay feet of the malaria giant and its African roots: hypotheses and inferences about origin, spread and control of *Plasmodium falciparum. Parassitologia 41*: 277–283.
15. McCullough D, 1977. *The Path Between the Seas: The Creation of the Panama Canal, 1870–1914.* New York: Simon and Schuster.
16. Soper FL, Wilson DB, 1943. *Anopheles gambiae in Brazil, 1930 to 1940.* New York: Rockefeller Foundation.
17. Watson M, 1953. *African Highway: The Battle for Health in Central Africa.* London: Murray.
18. National Institutes of Health, 1997. Final report, International Conference on Malaria in Africa: challenges and opportunities for cooperation (January 6–9, 1997, Dakar, Senegal). Available at: http://www.niaid.nih.gov/dmid/malaria/malafr/default.htm. Accessed August 15, 1999.
19. Molineaux L, Gramiccia G, 1980. *The Garki Project: Research on the Epidemiology and Control of Malaria in the Sudan Savanna of West Africa.* Geneva: World Health Organization.
20. Robert V, Ouedraogo V, Carnevale P, 1991. La transmission du paludisme humain dans un village au centre de la Rizière de la vallée du Kou, Burkina Faso. Robert V, Chippaux J-P, Diomandé L, and others, eds. *Le Paludisme en Afrique de l'Ouest: Etudes Entomologiques et Epidémiologiques en Zone Rizicole et en Milieu Urbain.* Paris: Editions de ORSTOM, 5–15.
21. Weatherall DJ, 1984. Common genetic disorders in the tropics.

Warren KS, Mahmoud AAF, eds. *Tropical and Geographical Medicine.* New York: McGraw-Hill, 88–102.
22. Carlson DG, 1984. *African Fever: A Study of British Science, Technology, and Politics in West Africa, 1787–1864.* Canton, MA: Science History Publications.
23. Luzzato L, 1984. Genetic factors modifying tropical disorders. Warren KS, Mahmoud AAF, eds. *Tropical and Geographical Medicine.* New York: McGraw-Hill, 77–87.
24. Kriton U, Spielman A, 1989. Suppression of transmission of malaria through source reduction: antianopheline measures applied in Israel, the United States, and Italy. *Rev Infect Dis 11*: 391–406.
25. Kamarck AM, 1976. *The Tropics and Economic Development: A Provocative Inquiry into the Poverty of Nations.* Washington, DC: World Bank.
26. Jones WHS, 1909. *Malaria and Greek History.* Manchester: Manchester University Press.
27. Bruce-Chwatt LJ, de Zulueta J, 1980. *The Rise and Fall of Malaria in Europe: A Historico-Epidemiological Study.* Oxford: Oxford University Press.
28. Haworth J, 1988. The global distribution of malaria and the present control effort. Wernsdorfer WH, McGregor I, eds. *Malaria: Principles and Practice of Malariology.* Edinburgh: Churchill Livingstone, 1379–1419.
29. Barro RJ, Sala-i-Martin X, 1991. Convergence across states and regions. *Brookings Papers Econ Activity 1*: 107–182.
30. Verdrager J, Mamet R, Roche S, Klein JP, 1964. *La Campagne d'Éradication du Paludisme à l'Ile Maurice.* Port Louis, Ile Maurice: Imprimery Officiel.
31. Ross R, 1910. *The Prevention of Malaria.* New York: E. P. Dutton.
32. Barro RJ, Sala-i-Martin X, 1995. *Economic Growth.* New York: McGraw Hill.
33. Barro RJ, 1991. Economic growth in a cross-section of countries. *Q J Econ 106*: 407–443.
34. American Geographical Society, 1951. Distribution of malaria vectors. *Geogr Rev 41:* map.
35. American Geographical Society, 1952. Distribution of helminthiases. *Geogr Rev 42:* map.
36. American Geographical Society, 1952. Distribution of dengue and yellow fever. *Geogr Rev 42:* map.
37. American Geographical Society, 1954. World distribution of leishmaniases. New York: American Geographical Society, map.
38. World Health Organization, 1981. *Vaccination Certificate Requirements For International Travel and Health Advice to Travellers.* Geneva: World Health Organization.
39. Barro RJ, Lee J-W, 1993. International comparisons of educational attainment. *J Monet Econ 32*: 363–394.
40. United Nations, 1996. *World Population Prospects 1950–2050 (The 1996 Revision).* New York: United Nations. Computer diskettes.
41. McGregor IA, 1988. Malaria and nutrition. Wernsdorfer WH, McGregor IA, eds. *Malaria: Principles and Practice of Malariology.* Edinburgh: Churchill Livingstone, 753–767.
42. Wilks NE, Turner PP, Somers K, Markandya OP, 1965. Chronic ill-health from unrecognized malaria. *East Afr Med J 42*: 580–583.
43. Audibert M, Mathonnat J, Nzeyimana I, Henry M-C, in press. Rôle du Capital Humain dans l'Efficience Technique des Producteurs de Coton du Nord de la Côte-d'Ivoire. *Rev Econ Dev.*
44. Lozoff B, Jimenez E, Wolf A, 1991. Long-term developmental outcome of infants with iron deficiency. *N Engl J Med 325*: 687–695.
45. Pollit E, Hathirat P, Kotchabharkdi N, Missel L, Valyasevi A, 1989. Iron deficiency and educational achievements in Thailand. *Am J Clin Nutr 50*: 687–696.