Economic Effects of Childhood Exposure To Tropical Disease

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To what extent do tropical diseases contribute to the poverty characteristic of tropical countries? Estimates of the impact of health on income are difficult to obtain because health is a normal good—countries with higher income will buy more of it—and third factors such as remoteness and bad government might impede both productivity and public health. In the Abuja Declaration of 2005, African heads of states claim that malaria has depressed income growth in Subsaharan Africa since the 1960s, so much so that GDP in the region today is 40% lower because of malaria. Estimates of this magnitude have been mocked at cocktail parties and clambakes. But how ridiculous is this number?

In my own work, I attempt to deal with the circular causality between health and income by studying large-scale, targeted interventions in public health, which, I argue, can be sources of plausibly exogenous variation in tropical health. I focus on measuring the effect of early-life exposure to malaria and hookworm on income in adulthood, for several reasons. First, the parasites that cause these diseases afflict several billion people today. Second, children are more susceptible to these diseases than adults. Third, although partial immunity is conferred by age, the damage from childhood exposure may be hard to undo: Most of a person's human-capital and physiological development happens early in life.

Malaria and hookworm were widespread even in subtropical regions in the 20th century, and were in many cases the focus of 'big push' campaigns for eradication. One area I study is the Southern United States, where these diseases were so prevalent that historians blame them for giving rise to the widespread stereotype of the 'lazy Southerner.' Similar stereotypes exist in the tropical countries of Latin America, another region that I consider. I analyze malaria-eradication campaigns in the United States (circa 1920) and Latin America (circa 1955), as well as a campaign to eradicate hookworm in the Southern U.S. (circa 1910).

Examining these episodes has a few useful features. First, sufficient time has passed that we can evaluate the long-term consequences of these eradication campaigns. Second, these countries have (a) nonmalarial areas that can serve as a comparison group, and (b) census microdata available that cover the relevant sets of cohorts. Third, these campaigns began because of critical advances in health technology and spending that originated outside the affected regions, which reduces concerns about reverse causality.

I. Malaria

Just before the turn of the 20th century, Ronald Ross discovered that malaria was transmitted via certain mosquitoes. The US Government, faced with the daunting task of building the Panama canal, used this knowledge to develop a workable package for malaria control. These techniques were then successfully applied to the malarious regions of the South starting around 1920.

In tropical Latin America, serious campaigns against malaria were made possible by a remarkably powerful insecticide: dichloro-dipenyl-trichloro-ethane, or DDT. This chemical was rediscovered in 1939, and used (secretly) in the Allied war effort. The World Health Organization (WHO) proposed a worldwide campaign to eradicate malaria, and the US government provided substantial aid to countries that took up this task. The nations of Latin America started DDT-based anti-malaria campaigns in the 1950s, and the region (including the three countries I study) saw large declines in malaria prevalence in short periods of time (for example, a 90% drop within a few years in Colombia).

I examine the malaria-control campaigns in

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the Southern U.S. (circa 1920) and Brazil, Colombia, and Mexico (circa 1955) in Bleakley, 2006b. In each case, growing up during or after the eradication campaign implies less exposure to malaria. I use census microdata to construct cohort-level panels (by birth-year×birthplace), which allows me to follow the cross-cohort evolution of income in both malarious and non-malarious areas. The basic finding of this research is that cohorts born after eradication campaigns had higher income (and literacy) as adults than the preceding generation. This is true both in absolute terms and when measured relative to comparable cohorts in low-malaria areas. Further, the timing of things supports the childhood-exposure hypothesis: the observed changes coincide with childhood exposure to the campaigns rather than with pre-existing trends across cohorts.

These results point to a large, negative effect of early-life exposure to malaria on lifetime income. First, results from the US: in the states with the highest levels of malaria, cohorts born after the anti-malaria campaign earned 15% more than the previous generation, relative to the benchmark of cohorts in malaria-free states. Second, Latin America: cross-cohort changes in income are about 27–35% higher in areas with more malaria before the DDT campaign. Next, I use the estimated decline in malaria with the campaigns to normalize these reduced-form effects into a number whose units are income per probability of being infected with malaria at a point in time during childhood.[1] In the US, the most malarious areas had infection rates around 1/3, while the comparable number for Brazil, Colombia, and Mexico is approximately 2/3. This implies effects on income per probability infection of about 45–50% in the various countries studied. (This calculation is like Indirect Least Squares, or ILS.) Another way of interpreting this number is that, for each year of childhood infected with malaria, adult income drops by $\sim 2.5\%$. Relatedly, I use county-level cross sections to show that school attendance and literacy rose differentially fast among school-aged children in the most malarious areas of the South, coinciding with the malaria control efforts of the 1920s rather than pre-existing trends (Bleakley, 2003).

[1]Note that this probability is in effect the fraction of childhood spent infected with malaria, *not* the probability of ever being infected during childhood.

II. Hookworm

Earlier work (Bleakley, 2007a) considered long-term effects of childhood exposure to hookworm disease. Hookworm, a parasite that infects humans, is like malaria in that it has a large burden of childhood morbidity (including anemia), but with considerably less mortality. The children of the Southern United States had hookworm infection rates of 30-40%, and areas of the sandy coastal plain had close to 100% childhood infection rates.

Control of hookworm in the Southern US also depended crucially on innovations to medical knowledge and spending, the origins of which were external to the afflicted region. The transmission mechanism for hookworm was discovered somewhat accidentally in Europe in the 1890s. At that time, hookworm infection in the American South was not even recognized as a problem. A decade later, Charles Wardell Stiles, a European-educated doctor from New York state, observed that a variety of health problems among Southerners could be attributed to hookworm disease, although his hypothesis did not achieve broad acceptance.

John D. Rockefeller, being the Bill Gates of his day, donated a considerable sum of money to a campaign to 'deworm' the South in the 1910s. The Rockefeller Sanitary Commission (RSC) surveyed infection rates in eleven Southern states, and found that an average of forty percent of school children suffered from hookworm. The RSC sponsored treatment dispensaries throughout the region. Follow-up studies of infection rates indicate that the campaign brought about a substantial and immediate reduction in hookworm disease.

Results of the anti-hookworm campaign were remarkable. Testimonials came in from across the region, such as this one from a teacher from the Tidewater region of Virginia who reported that, after deworming,

> children who were listless and dull are now active and alert; children who could not study a year ago are not only

> studying now, but are finding joy in learning.

or this report from a school in Louisiana:

> In short, we have here in our schoolrooms today about 120 bright, rosy-faced children, whereas had you not been sent here to treat them we would have had that many pale-faced, stupid children.

Moving beyond anecdotes, I use census data to systematically examine the impact of hookworm eradication on children. Similar to the malaria study cited above, areas that were hookworm free served as a comparison group. (Such areas did not benefit directly from the health improvements, but would have been exposed to many of the other shocks that prevailed at the time.) Children growing up in areas that benefited from the anti-hookworm campaign saw large increases in income, relative to earlier cohorts.

Further, the pattern of across-cohort changes coincided with childhood exposure to the campaign rather than to pre-existing trends. This can be seen in Figure I, where, for each year-of-birth cohort, I relate pre-eradication hookworm infection in one's state of birth to adult income. (Data and precise methods for these results are described in the original paper.) The dashed line measures the approximate number of years of potential childhood exposure to the hookworm-eradication activities in the South. For cohorts born after the campaign, the 'pre' hookworm variable is unrelated to adult income. In contrast, this variable is strongly predictive of lower income in the earlier cohorts, who already had turned adults by the time the RSC rolled through. And for those born between 1890–1910, who spent a portion of their childhood potentially exposed to the RSC campaign, their coefficients interpolate between the older and newer cohorts. The reduced-form effect that I estimate is that, in areas that were most wormy prior to the campaign, cross-cohort income growth was about 12–15% faster than areas that in areas never infected. Persistent childhood hookworm infection depressed adult income by 43% percent, or around 2.2% per year infected. (This is the ILS calculation for hookworm.) I also examined the changes over time

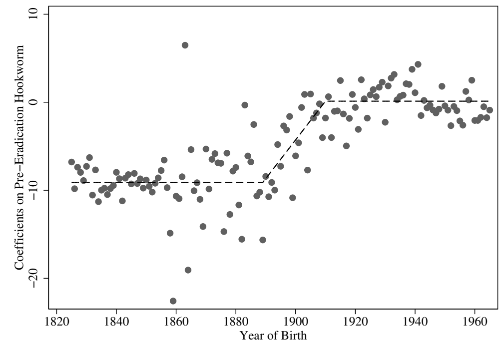

FIGURE 1: IN AREAS WITH MORE PRE-ERADICATION HOOKWORM, ADULT INCOME INCREASED AMONG COHORTS WITH MORE CHILDHOOD EXPOSURE TO THE CAMPAIGN

across counties and found that school attendance and child literacy rose sharply in potentially dewormed areas.

III. In The Aggregate

Malaria and hookworm affected large fractions of the population, and improving the health of so many should change equilibrium prices. Nevertheless, the analysis above, like most of the micro-empirical literature on health effects, assumed prices were fixed. This assumption could bias the across-cohort estimates in either direction, if wages of untreated cohorts were affected by the presence of healthier workers. On the one hand, adding more effective labor to the economy should depress factor ratios, and thus reduce wages of the incumbent cohorts. On the other hand, adding workers with more human capital might equally raise wages for the incumbent, less skilled cohorts by changing the return to skill or via human-capital externalities.

In another study (Bleakley 2007b), I consider the aggregate impact when these healthier cohorts entered the labor market. The goal is to estimate both the direct effect of reduced childhood disease exposure *plus* any other associated changes in prices. Because these questions hinge on the entrance of cohorts treated by the eradication campaigns, the central explanatory variable in the analysis is the fraction of the population treated, which I model as each area's pre-eradication disease burdens interacted with the labor force's average childhood exposure to the respective campaign. I then relate the time path of this interaction to state per-capita income across the years 1880–2000.

The main finding is that average income rises appreciably as cohorts with greater childhood exposure to the eradication efforts enter the working-age population. The estimates concord with the previous, cohort-based results in that they are of similar magnitude; if anything, the estimates from aggregate data are a bit larger. Moreover, these increases in income coincide roughly with the time path of treated cohort's presence in the labor force, and are not sensitive to controlling for pre-existing state-specific trends or the inclusion of variety of control variables. I then return to the census data and estimate reduced-form spillovers (from treated to untreated cohorts) that are around one fifth of the direct effect on treated cohorts, which I interpret in a simple model with human-capital externalities and imperfect substitutability across skill types.

The total burden of hookworm and malaria was large enough to account for one third of the income difference that existed at the time between the wealthier North and the impoverished South. The magnitudes of the estimates suggest that eradication of both disease increased aggregate income in the region by around 25%. Yes, the "New South" in part stems from having healthier Southerners.

IV. Extrapolations

The evidence from historical campaigns against malaria and hookworm brings us back to the Abuja declaration. The Abuja document states that income in Africa would be 37% higher today, but for the influence of malaria since 1960. How does this number compare with the estimates above, if we were to extrapolate from the Americas to Africa? I attempt this exercise, *cum grano salis*, in Table 1, which reports results for three areas: the Southern US, Northern Brazil, and the non-arid, tropical countries of Africa. Panel A contains estimated childhood infection rates for malaria and hookworm. The malaria numbers are based of expert judgment of pre-control endemicity (see Bleakley 2006b for more on this), while the hookworm numbers are from infection surveys (Bleakley, 2007a, for the US South, and Nilanthi de Silva *et alia*, 2003). In Panel B, I report the estimated changes in adult income that come from reducing the point-in-time probability of childhood infection from one to zero, which are the cross-cohort estimates in Sections I and II from Bleakley (2006b,2007a). The blanks cells in this panel indicate that I do not have direct estimates of this number in the indicated region, thus the need for extrapolation.

Finally, Panel C contains the estimated gain in income from eradication, which is computed by simply multiplying together the respective numbers from Panels A and B. Income in the Southern US would be 15% higher, consistent with what we saw in Sections I and III. The pre-1960 malaria numbers for the remaining areas map on to the Abuja statement: think of this exercise as saying what would have happened if malaria had been eradicated in the 1950s in the tropical regions. Northern Brazil would have seen a 35% gain, and the wet tropics of Africa, being somewhat more malarious than Brazil, would have seen an increase in income of approximately 40%. The latter number is not far off from the Abuja claim, despite being estimated with completely different samples and methodologies. For what it is worth, however, the estimates here are well short of those from a cross section of countries, as in Sachs (2003), who reports estimates that are approximately quadruple mine. (See Bleakley, 2006b, pp.25-6.) The childhood infection rates from hookworm in the tropical areas, however, are more recent estimates, so the exercise here is prospective: how much would income rise in northern Brazil and wet/tropical Africa is hookworm were eradicated today? The numbers in this case are also substantial: 11% and 24% gains in the respective regions. Note that, because the mechanism considered here is childhood exposure, these gains would take 50+ years to be realized as the healthier cohorts filled out the working-age population.[2]

[2]These numbers are not adjusted for general equilibrium effects. On the one hand, land dilution could shade these extrapolations down a few percent (Ashraf, Lester, and Weil (2009) and Bleakley (2009), if the economy is land dependent. On the

TABLE 1: ESTIMATES AND EXTRAPOLATIONS

	US South	Northern Brazil	Tropical, Non-Arid Africa
Panel A: Childhood Infection Rate (Year)			
Malaria	0.33 (1900)	0.67 (1950)	0.80 (1950)
Hookworm	0.40 (1910)	0.25 (2000)	0.55 (2000)
Panel B: Δ Income per P(Infection)			
Malaria	0.47	0.52	—
Hookworm	0.43	—	—
Panel C: Gains from Eradication = $A \times B$			
Malaria	0.15	0.35	0.40
Hookworm	0.17	0.11	0.24

Perhaps these estimates do not generalize to other contexts, as was my prior belief. But my results cast some doubt on this view. When normalized by the approximate decline in malaria in each episode, the estimated effects on adult income of childhood exposure to malaria are quite similar in the four countries studied. The similarity of these estimates stand in contrast with the substantial differences in income and institutions across these countries.[3]

But are hookworm and malaria unusual diseases? No, in the sense that over two billion people worldwide are infected with these and related parasites. Yes, in the sense that these parasites cause a relatively high burden of morbidity, especially among children. These features make for a sharp contrast with diseases that have high case-fatality rates and/or short-lived bouts of morbidity, such as smallpox. Whatever effects eradicating smallpox had, they probably worked through changes in mortality rates, and the consequences were therefore very different from the effects of malaria and hookworm eradication.

I do not argue (nor do I believe) that the eradication of any conceivable disease would necessarily have such large effects as those seen for hookworm and malaria. Using economic theory and good empirical design to unpackage health seems key for understanding the relationship between health and development. Some of the leading macro studies[4] treat health primarily as mortality, while my work treats improvements in childhood morbidity. The former are likely to skew towards Malthusian effects, while the latter tilt to depressing critical stages of physical and mental development.

The analysis above proceeds under the assumption that control of these diseases is the feasible, which is by no means guaranteed. Consider the case of hookworm eradication in the American South. Deworming treatments are short-term solutions, and follow-up efforts by private and governmental actors played a key role in consolidating the gains from the RSC. Harder to measure, but of considerable importance, the hookworm problem had entered into the public consciousness. An interesting episode for comparison comes from Puerto Rico. Around the same time as the RSC, a commission from the U.S. Army sponsored an anti-hookworm campaign throughout that Caribbean island. While large gains against hookworm were realized immediately after the campaign, the colonial government provided little follow-up, and these gains had mostly disappeared a decade later. [5] Improving tropical health is a long,

other hand, direct estimates from aggregate income data in the Southern US (Section III and Bleakley, 2007b) suggests that we should adjust these numbers upwards by a few percent.

[3] A remaining issue regarding the extrapolation is that malaria in Africa is more likely to be of the *falciparum* variety, while *vivax* was thought to be more prevalent in the Americas. The former strain is more lethal, and is also more concentrated among children under 5 years of age. I attempt to separately identify the effects of malaria by strain in Colombia in Bleakley (2006b), but estimates are imprecisely determined. Understanding differences in the response to different strains of the malaria remains an important topic for future research.

[4] See, for example, work by Daron Acemoglu and Simon Johnson (2007) and by Quamrul Ashraf, Ashley Lester, and David Weil (2009). See also my comments on the latter: Bleakley (2009).

[5] Similar issues arise with malaria. The US achieved eradication of malaria in the South and in the Panama Canal Zone. But eradication from much of rural, tropical world has proved elusive. A widely

hard slog, and interventionists should be ready for as much.

V. Conclusions

In recent work, I consider the impact of tropical-disease eradication campaigns in the Americas, particularly via the effect of being infected early in life. I find that two tropical diseases—malaria and hookworm—explain a non-trivial amount of the income difference between temperate and tropical areas. Indeed, childhood exposure to these diseases depresses adult income by amounts that are similar in magnitude to numbers in the famous Abuja declaration, but fall well short of estimates from a cross-section of countries. By my calculation, while eradicating tropical disease is not a 'magic bullet' that fixes everything, there are potentially large benefits of public-health interventions in developing countries where these diseases are still endemic today.

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