Malaria Eradication in the Americas
A Retrospective Analysis of Childhood Exposure

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Introduction

- Public Health and Economic Outcomes
- Does disease cause underdevelopment in the tropics?
- Measure the effect of health environment!
  - Endogeneity
  - Targeted public-health interventions
  - This paper: efforts to combat malaria in the Americas
- Why childhood exposure?
- Childhood exposure to malaria suppresses income
Why Study This Particular Disease?

1. Symptoms of the Disease
2. Still Prevalent in Much of the Tropical Belt
3. Circumstances that lead to the Campaign
Two Key Antecedents to Eradication

1. Innovations to Knowledge
2. Innovations to Spending on Public Health

And the origins of both external to the affected regions.
Program for the Talk

Malaria
  Determinants
  Eradication Campaigns
    Southern U.S.
    Latin America

Data and Methodology
  Construction of the Data
  Research Design

Estimates
  Cohort-Specific Results
  Pre/Post Comparison

Discussion
  Interpretation
  Mechanisms
  Extrapolations

Summary

PS
Program for the Talk

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Geography or Human Influence?

Geography:

2. Stagnant water, “low” altitude.
3. Local prevalence of vectors.

But institutional factors matter too!

1. Provision of public health
2. Unintended consequences of development (positive and negative)
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PS
The U.S. Takes an Interest
“The First Mountain to be Removed”
This new knowledge was “repatriated” in the early 1920s.

Large declines in malaria mortality followed.
Mortality per 10K Population, Southern United States
Peculiar Origins of the Campaign in LatAm

Mothballs

DDT
Malaria Eradication in Latin America

1. Discovery of DDT
2. Application to WWII Effort
3. WHO Expands Program Worldwide
4. Colombia, Mexico, and Brazil implement programs in the 1950s
Spraying of DDT
Cases Notified per 1K Population, Colombia
Areas with Large Malaria Burdens Saw Large Declines in Morbidity
Malarious Areas Saw Larger Declines

US States, 1920–1932

Mexican States, 1950–1958

Colombian Departamentos, 1955–1969
Malaria Eradication

- Areas with Large Malaria Burdens Saw Large Declines in Morbidity.
- Are similar patterns evident for other outcomes?
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Underlying Microdata

- Census samples (www.ipums.org)
  - $y =$
    1. Literacy
    2. Education
    3. Income (Brasil and Mexico)
    4. Occupational/Sectorial Indices of Income
  - Ages: [15,55] (Restricted to [25,55] for income and education.)
  - Native Males (whites for US)
Construction of the Cohort-Level Data

- Start with the micro data.
- Average by area of birth and year of birth and census year. (3d panel)
- State of birth (United States, Brasil, Mexico)
- Municipio of birth (Colombia)
Aggregate Regressors

- **Controls**
  - Published aggregates from censuses prior to campaigns
  - Anuarios Estadisticos
  - Maps (Banco de la República, Colombia)
  - Random stuff

- **Malaria**
  - Malaria Ecology
  - Cases notified (Colombia)
  - Mortality (US, Colombia, Mexico)
  - Blood samples (Colombia; Brasil) (spotty)
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Part 1: The Effective Geography of Eradication

➤ Areas with large malaria burdens saw large declines in morbidity.

➤ Are similar patterns evident for other outcomes?

Part 2: Differential Exposure across Cohorts

➤ Childhood symptoms/infection worst

➤ Childhood as base of investments/development
Childhood Exposure to Eradication Campaign

-18
0

born after the campaign

childhood exposure to eradication campaign

year of birth relative to start of campaign
Childhood Exposure to Eradication Campaign

- Childhood exposure to eradication campaign
- Year of birth relative to start of campaign
- Already an adult when the campaign starts
- Born after the campaign
Childhood Exposure to Eradication Campaign

- Already an adult when the campaign starts
- Born after the campaign

Year of birth relative to start of campaign

Childhood exposure to eradication campaign
Childhood Exposure to Eradication Campaign

- already an adult when the campaign starts
- born after the campaign

childhood exposure to eradication campaign

year of birth relative to start of campaign
Childhood Exposure to Eradication Campaign

- already an adult when the campaign starts
- partially exposed
- born after the campaign

childhood exposure to eradication campaign

year of birth relative to start of campaign
Childhood Exposure to Eradication Campaign

The graph illustrates the exposure of individuals to a eradication campaign based on their year of birth relative to the start of the campaign. The x-axis represents the year of birth relative to the start of the campaign, with -18 indicating a person born 18 years before the campaign started and 0 indicating the start of the campaign. The y-axis denotes childhood exposure to the eradication campaign, ranging from 0 to 1. The dashed line indicates:

- People born after the campaign (right side of the graph).
- People partially exposed (middle section of the graph).
- People already an adult when the campaign starts (left side of the graph).

The graph shows how exposure changes as one moves from before the campaign start to after the campaign start.
Childhood Exposure to Eradication Campaign

- already an adult when the campaign starts
- partially exposed
- born after the campaign

versus
exposure
at age 15?

versus
intrauterine
exposure?

year of birth relative to start of campaign
Childhood Exposure to Eradication Campaign

- already an adult when the campaign starts
- partially exposed
- born after the campaign

childhood exposure to eradication campaign

year of birth relative to start of campaign

0

-18
When did the changes happen?

Cohort-by-cohort Estimates:

\[ y_{it} = \alpha_t + \beta_t M_i + X_i \Gamma_t + \epsilon_{it} \]

where \( t \) is year of birth and \( i \) is area of birth.

Plot the \( \beta \).

1. Do we observe a shift?
2. When does it happen?
3. Does it coincide with childhood exposure?
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Childhood Exposure to Eradication Campaign

- already an adult when the campaign starts
- partially exposed
- born after the campaign

*year of birth relative to start of campaign*

*childhood exposure to eradication campaign*
Basic Specification, Occupational Income Score

Basic Specification, Duncan Score

Additional controls, Occupational Income Score

Additional controls, Duncan Score
Malaria mortality / total mortality, 1890.
Region dummies
Average unskilled wages, 1899 (Lebergott)
Adult literacy rate (1910)
Fraction of population living in urban areas (1910),
unemployment rate (1930)
1902-32 logarithmic changes in school term length, pupil/teacher ratios.
fertility rates (1910)
fraction of deaths in 1890 caused by
- scarlet fever
- measles
- whooping cough
- diphtheria/croup
- typhoid fever
- diarrheal diseases
- pneumonia

Infant-mortality rate (1899)

1899-1932 change in infant mortality rates

doctors per capita (1898)

state public health spending per capita (1898)

WWI recruits found “defective” at draft physical

WWI recruits infected with hookworm
Brazil: Variables

- Malaria ecology (Mellinger et al. 2005)
- Region dummies
- Population Density
- Infant mortality
- Log of Electricity Consumption
- Fraction of pop economically active
- Share of labor force in...
  - Agriculture
  - Extractive Industries
  - Manufacturing
  - Transportation
  - Services
Brazil, Basic Specification

- Year: 1900 to 1980
- Data Points: Scatter plot showing changes over time
Brazil, Additional Controls
Colombia: Variables

- Malaria ecology (Poveda et al. 2000)
- Region dummies
- “La Violencia” before 1955, 1955 and after
- High Concentration “Minifundista”
- Coffee-growing Region
- Coal Mining Region
- Expansion of Ranching, 1960+
- Infrastructure/Market Access
- Share of labor force in manufacturing
- General level of development ("Nivel de Vida")
Mexico

- Malaria mortality per 1000 population, 1949-1953
- Region dummies
- Population Density
- Infant mortality
- Log of Electricity Consumption
- Fraction of pop economically active
- Share of labor force in...
  - Agriculture
  - Extractive Industries
  - Manufacturing
  - Transportation
  - Services
- Household income GINIs
Horserace:

\[ \hat{\beta}_k = \alpha \text{ Exp}_k + \sum_{i=1}^{n} \gamma_n k^n + \Phi(L)\hat{\beta}_k + \eta_k + \text{constant} + \epsilon_{ts} \]
<table>
<thead>
<tr>
<th>Specification:</th>
<th>Outcome:</th>
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<tbody>
<tr>
<td>Basic</td>
<td>Occupational Income Score</td>
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<tr>
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<td>0.124 ***</td>
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**Panel A: United States**

**Panel B: Brazil**

**Panel C: Colombia**
Degree of Polynomial-Trend Control: 0 1 0 1 2 0 2 2
Degree of Autoregressive Process: 0 0 1 1 0 2 2

### Specification: Outcome:

#### Panel A: United States

<table>
<thead>
<tr>
<th>Specification</th>
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<th>Coefficient 1</th>
<th>Coefficient 2</th>
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<td>0.154 ***</td>
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#### Panel B: Brazil

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#### Panel D: Mexico

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<td>(0.311)</td>
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Literacy and Years of Schooling

- Standard model: $MB = MC$ of schooling
- Childhood malaria depresses both.
- Predictions ambiguous about inputs.
- To first order, outputs $\uparrow$. 
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Pre/Post Comparison

- Compare Cohorts: Exposed versus Unexposed
  1. Born before 1940 (US 1895)
  2. Born after 1955 (US 1920)

- Compare Areas: Malarious versus Nonmalarious Areas

- Difference in Difference (regression adjusted)
Similar results to above.

Effect not concentrated in a few outliers.

Similar results for various subsets of controls.

IV for measurement error: magnitude $\uparrow$

Similar results: movers and nonmovers

Similar results in US for mother’s BPL
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Estimates
  Cohort-Specific Results
  Pre/Post Comparison

Discussion
  Interpretation
  Mechanisms
  Extrapolations

Summary

PS
Interpretation: Reduced-form Income Differences

Compare most malarious to least malarious areas.

- United States (occscore): 0.13
- United States (Duncan): 0.16
- Brazil (total): 0.37
- Brazil (earned): 0.26
- Mexico (earned): 0.24
- Colombia (indscore): 0.10
Approximating the Magnitude of the Decline in Malaria

Type of Endemicity

1. None 0%
2. Hypoendemic 0-10%
3. Mesoendemic 10-50%
4. Hyperendemic 50-75%
5. Holoendemic 75-100%

Pre-eradication malaria...

- in the US ranged from “none” to “meso”  $\Delta m \approx 0.3$
- in BCM ranged from “none” to “hyper”  $\Delta m \approx 0.6$
Effect per probability of childhood infection?

Normalize the reduced-form differences with the estimated decline in malaria

- US: $\frac{\Delta y}{\Delta m} = \frac{.145}{.3} \approx .47$
- Brazil: $\frac{\Delta y}{\Delta m} = \frac{.37}{.625} \approx .59$
- Mexico: $\frac{\Delta y}{\Delta m} = \frac{.26}{.625} \approx .41$
- Colombia: $\frac{\Delta y}{\Delta m} = \frac{.07}{.625} \approx .11$ (adjusted: 0.39)
Program for the Talk

Malaria
  Determinants
  Eradication Campaigns
    Southern U.S.
    Latin America

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Accounting for magnitude of the result

- Education: quantity, +/- 25%; return, +/- 100%

- Labor-market experience:
  hours ↓; returns ↑, explains ≈ 20% of effect?

- Other vector-borne diseases: numbers too small.
  Colombia 1963: 22 cases of yellow fever, 21,245 cases of malaria

- Mortality selection: implausible. 30% × 30% = 9%.

- *falciparum versus vivax*

- The timing of childhood exposure

- Spillovers
Childhood Exposure to Eradication Campaign

- already an adult when the campaign starts
- partially exposed
- born after the campaign

versus exposure at age 15?

versus intrauterine exposure?

year of birth relative to start of campaign
Regional comparisons

Between North and South (US):
- 1900 gap in log(GDP) was 0.75
- 10–20% infection; effect of 0.6 on income
- ⇒ 8–17% of the gap

Between US and LatAm:
- 1950 gap in log(GDP) was 1.5–2
- 30–40% infection; effect of 0.6 on income
- → 10–16% of the gap
Comparison with macro estimates

▶ Me: $\partial \log Y / \partial \text{Prob(infection)} \approx -0.6$

▶ Sachs & co.: $\partial \log Y / \partial \text{Prob(infection)} \approx -2.15$

▶ About 25% of the macro estimate.

▶ But note about *falciparum*
▶ Large drop in malaria, circa 1920 in the US South and circa 1950 in LatAm
▶ Quasiexogenous in that it results from external factors
▶ Nonmalarious areas serve as a comparison group
▶ Faster cross-cohort growth in literacy and income in malaria-prone areas; Mixed evidence for education
▶ Coincident with childhood exposure to the program
Open questions

- General equilibrium effects
- Interaction effects
- Vivax versus Falciparum
- Related evidence on parasitic disease
Before 1910, forty percent of children in the South were infected with hookworm.

But almost nobody knew about it!
Rockefeller Campaign: Dispensaries

BUREAU OF EDUCATION

COUNTY DISPENSARY FOR FREE TREATMENT HOOKWORM DISEASE.

BULLETIN, 1914, NO. 20 PLATE 6
Rockefeller Campaign: Education

R. TYPICAL DISPENSARY SCENE, ALABAMA
There was substantial heterogeneity across areas, largely due to soil type.

(red = more infection. green = less. blue = no data)
Highly Infected Areas Saw Greater Declines in Hookworm
Highly Infected Areas Saw Greater Increases in School Attendance
The Shift in School Attendance Coincided with the Rockefeller Anti-Hookworm Campaign
Areas with High Pre-Eradication Hookworm Saw Faster Cross-Cohort Growth in Income.
The Shift in Income Coincided with Childhood Exposure to Hookworm (the dashed line)
General equilibrium effects

- Do healthy workers displace unhealthy workers?
- Healthy workers raise the productivity of those around them?

Aggregate: \[ \text{direct + spillovers} \]

Coefficients on Pre-Eradication Hookworm for each Year of Birth
Average Childhood Exposure to Eradication Efforts

- **Malaria**
- **Hookworm**

Census Year

- 1850
- 1900
- 1950
- 2000
Specification: Spillovers

- Estimate model with period-specific coefficients on regressors.
- Absorb all cohort effects ($\text{YOB} \times \text{birthplace}$).
- Report the beta’s on pre-campaign hookworm and malaria by census year.

Independent regressors:

1. Basic: region dummies, Lebergott’s measure of 1909 unskilled wages, and both diseases.
2. Full: basic, plus the following: child mortality, 1890; infant mortality, 1935; fraction urban, 1900; fraction of adults literate, 1910; doctors per capita, 1898; fraction black, 1910; male unemployment rate, 1930; fertility rate, 1880.
Hookworm, Raw Coefficients

Malaria, Raw Coefficients

Hookworm, Detrended Coefficients

Malaria, Detrended Coefficients
Data and Specification: Aggregate

Data:
- Real personal income per capita
- By state (plus the then territories, except Okla. 1880)

Specification:
- For each period, a cross-sectional regression.
- Report the beta’s on pre-campaign hookworm and malaria.
- Independent, time-invariant regressors:
  1. Basic: region dummies, Lebergott’s measure of 1909 unskilled wages, and both diseases.
  2. Full: basic, plus the following: child mortality, 1890; infant mortality, 1935; fraction urban, 1900; fraction of adults literate, 1910; doctors per capita, 1898; fraction black, 1910; male unemployment rate, 1930; fertility rate, 1880.
  3. Mitchener-McLean: basic, plus the following: fraction employed in mining, 1880; fraction enslaved, 1860; dummy of access to ocean or great lakes; Dummies for colonial origin (French, Spanish, Dutch); Average number of cooling degree days.
Spillover effects, Brazilian States
Aggregate effects, Brazilian States
Does a disease-specific intervention have more or less effect if health along other dimensions is poor?

Two logical possibilities:

1. \( \frac{\partial^2 Y}{\partial h_1 \partial h_2} > 0 \). Co-morbidities reinforce each other.
2. \( \frac{\partial^2 Y}{\partial h_1 \partial h_2} < 0 \). Once you’re sick, you’re sick.
For each year of birth $k$:

$$Y_{jk} = \beta_k M_j + \alpha_k H_j + \theta_k H_j \times M_j + \phi_k M_j \times IMR_j + \delta_k + X_j \Gamma_k + \nu_{jk}$$
Estimated Interactions

- Hookworm
- Malaria
- Malaria x Hookworm
- Malaria x Infant Mortality Rate

Graphs showing the interaction between Hookworm and Malaria over the years 1820 to 1960.
Falciparum versus Vivax

- Mostly *vivax* in the Americas
- Data on the mix of infections in Colombia circa 1955.
- Weak evidence that it’s *vivax* that generates results above.
Open questions

- General equilibrium effects
- Interaction effects
- Vivax versus Falciparum
- Related evidence on parasitic disease
Malaria Eradication in the Americas
A Retrospective Analysis of Childhood Exposure

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