Long-Term Impacts of Early-life Exposure to Malaria: Evidence from Taiwan in the 1950s

Ming-Jen Lin   Hsiu-Han Shih

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- In utero and postnatal health conditions have a lasting impact on an individual
  - early-life health conditions predetermine one's health capital later in life
  - health capital is an important determinant of economic capabilities throughout one's life
- Epidemiologists used to believe that the placenta was a perfect filter.
- Fetal origins hypothesis (Barker 1992) : certain chronic health conditions can be traced to the course of fetal development

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Medical Literature

- Experimental studies of nutritional programming using animal models

  - Poor early fetal conditions result in increased vascular resistance, hypertension (Langley-Evans, 2001), and increase the risk of schizophrenia. (Brown et al., 2004)

- Famine episodes

  - Limited long-term mortality effects were found for survivors in utero during the Finnish famine (Kannisto et al., 1997).
  - For cohorts in utero during the Dutch famine, there were effects for coronary heart disease morbidity (Roseboom et al., 2000; Bleker et al., 2005), and adult antisocial personality disorders (Neugebauer et al., 1999).

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Economic Literature

- Almond (2006): compared with those born just before or after the 1918 influenza pandemic, cohorts in utero during the peak of the influenza exhibited large negative long-term consequences.

- Chen and Zhou (2007): cohorts exposed to China's Great Famine around the time of their birth were shorter in adulthood

- Black et al. (2007) and Oreopoulos et al. (2006) use twin differences to control for observable and unobservable family-level factors: better in utero health conditions (birth weight) positively influence long-term health, educational attainment, and labor market outcomes

This research

- Estimate long-term impacts of early-life exposure to malaria.

  - Malaria in pregnant women can result in anemia and interruption of in utero nutritional transmission, which can affect subsequent cognitive, physical, and neurosensory development
  - Childhood sufferers of severe malaria can have lifelong cognitive difficulties and increased susceptibility to other illnesses

- Problems: Omitted factors (genetic or socioeconomic conditions), and measurement-error bias

  - Regions with high levels of malaria transmission are often poorer.

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This research

- Estimate the effects of malaria by utilizing the malaria eradication campaign in Taiwan in the 1950s as a quasi-experiment

    - Use the difference-in-difference identification strategy
    - Match data for adults from the 1992 – 2012 Taiwan Social Change Survey to data for the malaria intensity in their birth place and birth year in the1950s

- When comparing cohorts born after eradication with those born before eradication in the same region, men born in regions with larger decreases in malaria intensity had larger increases in the educational attainment and family income in adulthood.

- No significant benefit from the eradication for women.

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Literature of Malaria: IV strategy

- Barreca (2010): use variation in "malaria ideal" temperatures to instrument for malaria exposure at the time of birth in the U.S.

  - Cohorts exposed to malaria in their year of birth have significantly lower levels of educational attainment and higher rates of poverty as adults.

- Chang et al. (2013): employ climatic factors such as rainfall and relative humidity to instrument for malaria deaths in Taiwan during Japanese colonization.

  - People who were exposed to a high malaria risk in the critical period around birth have lower educational attainment and worse health outcomes at old age.

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Literature of Malaria: DID strategy

- Lucas (2010): use malaria eradication campaigns in Paraguay and Sri Lanka as quasi-experiments

  - By the combination of pre-existing geographic variation in malarial intensity and cohort exposure based on the timing of the national anti-malaria campaigns
  - Negative and significant effect of the malaria rate on educational attainment

- Bleakley (2010): employ the malaria-eradication campaigns in the United States, Brazil, Colombia, and Mexico

  - Relative to non-malarious areas, cohorts born after eradication had higher income as adults than the preceding generation in malarious areas

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Background of Malaria

- Malaria is caused by a parasite called Plasmodium, which is transmitted via the bites of infected female Anopheles mosquitoes.

- In the human body, the parasites multiply in the liver, and then infect red blood cells.

- The WHO has undertaken malaria eradication campaigns in many countries and succeeded since the late 1940s, typically using DDT spraying.

  - By reducing contact between humans and mosquitoes, eradication campaigns reduce the probability that the disease is transmitted from mosquito to human, or vice versa.

- Malaria still occurs in 99 countries (most of which are in Africa) and more than 3 billion people are at risk of malaria.

- Children under 5 years old and pregnant women are most severely affected.
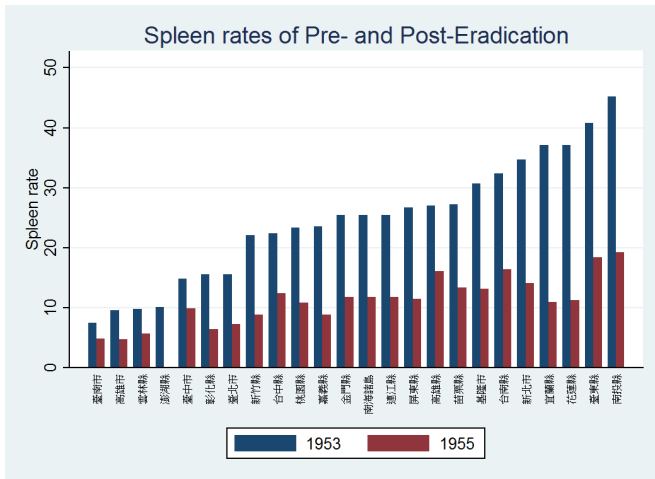
Malaria in Taiwan

- In Taiwan, malaria accounted for most part of the overall disease burden during the early 20th century. The death rate was about 0.3%.

- The Japanese colonial government adopted the Koch's method to control malaria from 1911.

- Malaria still affected people severely (especially for children) in the late 1940s.

- The ROC government continued antimalarial efforts with the support of WHO and other international agencies.

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Eradication

- Taiwan implemented a malaria eradication campaign with technical support of the WHO in the 1950s.
  - 1946-1951: Preparation for the malaria eradication campaign
  - 1952-1955: DDT spraying began experimentally in 1952
  - 1953-1955: DDT spraying was extended to highly malarious regions
  - 1954-1955: DDT spraying was extended to moderate and Less malarious regions
- Malaria declined rapidly following the commencement of the eradication.

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Spleen rate in 1953 and 1955

Spleen rates of Pre- and Post-Eradication

- The spleen rate (commonly used to measure malaria prevalence) largely decreased for each county after the eradication campaign.

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Empirical Strategy

Difference-in-differences specification:

$$y_{irc} = \alpha + \beta(\textit{malaria}_r \times \textit{era}_c) + \gamma X_{irc} + \delta_r + \lambda_c + \varepsilon_{irc}.$$

- y_{irc} : Outcomes of individual i in region r of cohort c
- $\textit{malaria}_r$: the malaria intensity in region r (county or township level)
- $\textit{era}_c$: dummy for a post-eradication cohort, $\textit{era}_c = 1$ for birth year $\geq$ 1953
- Under the hypothesis that malaria has negative effects:
  - β should be positive if cohorts born after eradication in regions with higher malaria intensity have better outcomes than those born before eradication in the same region.

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Data: Malaria Intensity

- Health Statistics Yearbook: Define malaria intensity using malaria spleen rates in county-level
  - Use the difference in malaria spleen rate between 1953 and 1955: $malaria_r = SpleenDif_r$
- Malaria Eradication in Taiwan (1991): Define malaria intensity using level of malaria spleen rates in township-level
  - Define $malaria_{high,r} = 1$ if level of malaria spleen rates $\geq 50\%$
  - Use the difference in $malaria_{high,r}$ between 1953 and 1955: $malaria_r = Malaria_{high}Dif_r$

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Data: Adult Outcome

- Taiwan Social Change Survey: 1992 – 2012
- Outcomes: Education level, personal income, family income
- Controls : Birth year, birth place, parents' level of education and ethnicity, and terms of survey
- Limit the sample to those born in 1950 – 1955
  - The compulsory education was extended from 6 to 9 years in 1968.
  - Cohorts born after 1956 might be affected by the policy.
- The post-eradication cohort: birth year $\geq$ 1953

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Summary Statistics: Education

Sample	Spleen_Dif > mean	Overall	Male	Female
Panel A	1950-1952			
Above high school		0.526	0.613	0.436
		(0.499)	(0.487)	(0.496)
Above junior school		0.384	0.456	0.310
		(0.487)	(0.498)	(0.463)
Observations		2,644	1,347	1,297
Panel B	1953-1955			
Above high school		0.606	0.702	0.511
		(0.489)	(0.458)	(0.500)
Above junior school		0.458	0.546	0.371
		(0.498)	(0.498)	(0.483)
Observations		2,829	1,405	1,424

- *SpleenDif* > *mean*(13.02%): highly malarious regions
- Men had higher educational attainment than women.
- Cohorts born after eradication had higher educational attainment than those born before eradication.

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Summary Statistics: Education

Sample	Spleen_Dif < mean	Overall	Male	Female
Panel A	1950-1952			
Above high school		0.559	0.646	0.473
		(0.497)	(0.479)	(0.499)
Above junior school		0.438	0.513	0.363
		(0.496)	(0.500)	(0.481)
Observations		2,300	1,146	1,154
Panel B	1953-1955			
Above high school		0.619	0.718	0.521
		(0.486)	(0.450)	(0.500)
Above junior school		0.499	0.576	0.425
		(0.500)	(0.494)	(0.494)
Observations		2,483	1,228	1,255

- *SpleenDif < mean*: lowly malarious regions
- Lowly malarious regions had smaller increases in educational attainment than highly malarious region when comparing cohorts born after eradication with those born before eradication.

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Results: Education

Sample	Overall	Male	Female
Panel A Independent variable: SpleenDif × Era			
Education level			
Above high school	0.0015	0.0022	0.0009
	[0.001]	[0.001]	[0.001]
Above junior school	0.0026*	0.0026*	0.0030
	[0.001]	[0.001]	[0.002]
Observations	10,180	5,083	5,097
Panel B Independent variable: $\text{Malaria}_{high}\text{Dif}$ × Era			
Education level			
Above high school	0.0123	0.0332	-0.0199
	[0.020]	[0.028]	[0.028]
Above junior school	0.0231	0.0437*	-0.0121
	[0.025]	[0.026]	[0.036]
Observations	10,053	5,024	5,029

- For male, those born in regions with larger decrease in malaria intensity had larger increases in the probability of junior high school completion.

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Results: Income

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	ln(personal_income_Deflated)		ln(family_income_Deflated)			
Panel A Independent variable: SpleenDif × Era						
Overall	0.0014	0.0016	0.0045*	0.0032	0.0037*	0.0033*
	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]
Observations	6,763	6,763	7,411	7,411	7,411	7,411
Male	0.0036	0.0046	0.0042	0.0031	0.0049*	0.0042
	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]	[0.003]
Observations	3,933	3,933	3,741	3,741	3,741	3,741
Female	-0.0034	-0.0043	0.0042	0.0028	0.0021	0.0021
	[0.004]	[0.004]	[0.003]	[0.003]	[0.003]	[0.003]
Observations	2,830	2,830	3,670	3,670	3,670	3,670
Education level	✗	✓	✗	✗	✓	✓
Education level of spouse		✗		✗	✗	✓

- *SpleenDif × Era*: Regions with larger decrease in malaria intensity had larger increases in family income.

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Results: Income

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	ln(personal_income_Deflated)		ln(family_income_Deflated)			

Panel B Independent variable: $\text{Malaria}_{high}\text{Dif} \times \text{Era}$

	(1)	(2)	(3)	(4)	(5)	(6)
Overall	0.0234	0.0360	-0.0129	-0.0074	-0.0100	-0.0020
	[0.049]	[0.044]	[0.041]	[0.041]	[0.039]	[0.039]
Observations	6,685	6,685	7,320	7,320	7,320	7,320
Male	0.0313	0.0443	-0.0158	-0.0020	0.0016	0.0145
	[0.055]	[0.054]	[0.052]	[0.056]	[0.053]	[0.054]
Observations	3,888	3,888	3,695	3,695	3,695	3,695
Female	-0.0194	-0.0024	-0.0033	0.0024	0.0027	0.0064
	[0.073]	[0.063]	[0.063]	[0.063]	[0.064]	[0.064]
Observations	2,797	2,797	3,625	3,625	3,625	3,625
Education level	✗	✓	✗	✗	✓	✓
Education level of spouse			✗	✓	✗	✓

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Results of Education: Interaction for Each Birth Year

Sample	Overall	Male	Female
Panel A Outcome: *Above junior high school*			
Year1953 × Spleen_Dif	0.0028	0.0032	0.0033
	[0.002]	[0.003]	[0.004]
Year1954 × Spleen_Dif	0.0027*	0.0010	0.0042*
	[0.002]	[0.001]	[0.002]
Year1955 × Spleen_Dif	0.0023	0.0039**	0.0013
	[0.002]	[0.002]	[0.002]
Panel B Outcome: *Above high school*			
Year1953 × Spleen_Dif	0.0012	0.0024	0.0006
	[0.001]	[0.002]	[0.002]
Year1954 × Spleen_Dif	0.0016	0.0014	0.0013
	[0.002]	[0.002]	[0.002]
Year1955 × Spleen_Dif	0.0019	0.0031	0.0009
Observations	10,180	5,083	5,097

- Replace $\beta(malaria_r \times era_c)$ with a separate interaction term for each birth year after the eradication.

- Eradication campaign has a positive and significant effect on the probability of junior high school completion for men born in 1955, and a positive effect for women born in 1954.

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Results of Education: Exposure to Malaria

Sample	Overall	Male	Female	Overall	Male	Female
Panel A Outcome: *Above junior high school*						
spleenDif × Malaria_Exposure	-0.0029	-0.0025	-0.0047	-0.0222**	-0.0269*	-0.0182
	[0.004]	[0.003]	[0.006]	[0.011]	[0.015]	[0.013]
spleenDif × Malaria_Exposure^2				0.0359*	0.0450*	0.0254
				[0.017]	[0.026]	[0.023]
Panel B Outcome: *Above high school*						
spleenDif × Malaria_Exposure	-0.0007	-0.0026	0.0007	-0.0185**	-0.0240	-0.0115
	[0.003]	[0.003]	[0.004]	[0.009]	[0.015]	[0.010]
spleenDif × Malaria_Exposure^2				0.0330*	0.0395	0.0229
				[0.018]	[0.027]	[0.022]
Square term of exposure	✗	✗	✗	✓	✓	✓
Observations	10,180	5,083	5,097	10,180	5,083	5,097

- Define malaria "exposure" of cohort c as the percentage of years prior to age 5 that are spent in the pre-eradication period.
- Replace $\beta(malaria_r \times era_c)$ with $\beta(malaria_r \times exposure_c)$
- Exposure to malaria exhibited a negative effect on educational attainment for men, and the effect is diminishing.

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Results of Education: Fake Intervention

Sample	Overall	Male	Female
Panel A Outcome: *Above junior high school*			
Era1943 × Spleen_Dif (Sample: 1940-1945)	-0.0016 [0.002]	-0.0038 [0.003]	0.0011 [0.004]
Observations	5,016	2,563	2,453
Era1963 × Spleen_Dif (Sample: 1960-1965)	-0.0001 [0.001]	-0.0011 [0.001]	0.0005 [0.001]
Observations	10,655	5,177	5,478
Panel B Outcome: *Above high school*			
Era1943 × Spleen_Dif (Sample: 1940-1945)	-0.0006 [0.002]	0.0013 [0.003]	-0.0021 [0.001]
Observations	5,016	2,563	2,453
Era1963 × Spleen_Dif (Sample: 1960-1965)	-0.0011 [0.001]	-0.0002 [0.001]	-0.0023 [0.002]
Observations	10,655	5,177	5,478

- With a fake intervention 10 years earlier in 1943 or 10 years later in 1963
- No significant effect on educational attainment

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- When comparing cohorts born after eradication with those born before eradication in the same region, men born in regions with larger decreases in malaria intensity had larger increases in the educational attainment and family income in adulthood.

- There was no significant benefit from the eradication for women.

- There were negative and significant effects of early-life malaria exposure on adult outcomes in Taiwan.