Long-term Effects of Early Childhood Malaria Exposure on Education and Health: Evidence from Colonial Taiwan

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century, the Japanese colonial government initiated an island-wide malaria eradication campaign in Taiwan, resulting in not only a fast decline in malaria across time but also elimination of disparity across regions. Exploiting variations in malaria deaths *around birth* caused by the campaign, we estimate the causal effects of malaria exposure in early life on education and health of the elderly. To mitigate potential biases caused by measurement errors and omitted confounders, we employ climatic factors to instrument for malaria deaths. Our findings suggest that people who were exposed to a high malaria risk in the critical period around birth have lower life-time educational attainment and worse health outcomes at old age as reflected in worse cognitive function, a higher likelihood of cardiovascular and lung diseases and a higher mortality hazard. Our findings support the *fetal origins hypothesis*.

Keywords: Malaria; early childhood; education; health; Taiwan
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"*Living things are "plastic" in their early lives: their growth and development are molded by the environment.*"---David J. P. Barker (2000)

1. Introduction

The *fetal origins hypothesis* postulates that health shocks to the fetus *in utero* could permanently change her physiology and metabolism, and further shape her ability and health trajectory in adult life (Barker 1992, 1993, 1994, 1995, 2000). Empirically, epidemiologists have found that cardiovascular and lung diseases in adulthood are *associated* with intrauterine health conditions (Rasmussen 2001). Yet, to go beyond correlational studies, one needs either exogenous health shocks or other effective ways to address potential confounders (Almond and Currie 2011). This paper exploits variation in malaria deaths *around birth*—the birth year and the year before birth—resulted by a malaria eradication campaign in colonial Taiwan in the early twentieth century. To mitigate potential biases caused by measurement errors and omitted confounders, we use climatic factors to instrument for malaria deaths to estimate the causal effects of malaria exposure in early life on education and health of the elderly.

Malaria is an infectious disease caused by parasites called *Plasmodium* and mainly transmitted by female *Anopheles* mosquitoes.[1] It also can be vertically transmitted from an infected mother to her fetus (Manendez and Mayor 2007; Poespoprodjo et al. 2010). In fact, pregnant women and infants typically have low immunity and are particularly vulnerable to malaria infection. Once transmitted into the human body, the parasites would destroy red blood cells, leading to disruption of the supply of oxygen and

[1] There are four strains of *Plasmodium* that are known to infect humans: *P. falciparum*, *P. vivax*, *P. ovale*, and *P. malariae.* Further information is available at http://who.int/topics/malaria/en/.

mortality risk at the end stage of life, too. These findings support the *fetal origins hypothesis*.

Our paper adds to the growing literature in economics that treats the relationship between early-life health shocks and adult outcomes (Almond and Mazumder 2005; Almond 2006; Almond et al. 2007; Chen and Zhou 2007; Almond et al. 2009; Case and Paxson 2009; Meng and Qian 2009; Barreca 2010; Bleakley 2010; Case and Paxson 2010; Cutler et al. 2010; Kim et al. 2010; Lucas 2010). Yet, to the best of our knowledge, our paper is the first to document the detailed malaria effects on health outcomes in old age.

The rest of this paper is organized as follows. In the next section, we delineate the malaria eradication campaign in colonial Taiwan. Section 3 presents our empirical model and identification strategy. In Section 4, we describe the data, while section 5 reports the estimation results. Section 6 concludes.

2. Malaria Eradication in Colonial Taiwan

In the early stage of the Japanese ruling period (1895-1945), malaria was not only rampant but also deadly in Taiwan.[2] Between 1906 and 1909, for example, more than 10,000 residents died of malaria each year, while the population was only about 3 million (Department of Health, Taiwan 1991). To fight against malaria, the Japanese colonial

[2] It is worth noting that malaria was not the only infectious disease in the colonial period. Others include plague, dysentery, cholera etc. However, malaria was the most prevalent and deadliest one. For example, in 1902, malaria caused 13,444 deaths, while plague only caused 1,853 deaths, dysentery 754 and cholera 613 (*Yearly Statistics Book of the Office of the Governor-general in Taiwan* 1903). Besides, plague had been under control by 1910 and was eradicated in 1917, while dysentery and cholera never became island-wide endemic (Tetsuzou 2007).

government initiated an island-wide eradication campaign in 1911, which lasted until the eruption of World War II (Ting 2008; Ku 2010; Liu 2010).[3]

An island-wide monitoring system was first established. All malaria cases had to be reported to local physicians by the police and the local self-policing system.[4] So-called "anti-malaria districts" were gradually set up throughout the whole island.[5] Residents within the districts were required to provide blood smears to test for malaria and, if found to carry malaria parasites, they were forced to take quinine for 18 consecutive days under the supervision of a policeman. In 1919, the campaign expanded to areas beyond the districts and emphasized more on vector-control measures such as cleaning up the environment, while blood tests and quinine prophylaxis continued.[6]

At the beginning, malaria distribution varied considerably from north to south. Figure 1 portrays the five regions in colonial Taiwan in 1920, with darker areas characterized by higher malaria death rates.[7] As illustrated, malaria was generally more serious in the south than in the north. Yet, the trends of malaria death rates in Figure 2 clearly exhibit the effect of the eradication campaign.[8]

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[3] The Governor-general, head1n Finor

deaths per 1,000 people in the early 1910s to less than 1 in the late 1920s, remaining under control through the 1930s.[9]

The declining trend prior to 1910 seems to suggest that malaria was also correlated with other transitional factors such as economic growth and infrastructure development. However, the sudden rise in the early 1910s, especially in the *Taichung* and *Nankao* region, strongly suggests that such transitional factors do not explain the fast decline in malaria and the elimination of regional disparity afterwards. In our estimation below, we do control for the transitional factors by including region and cohort dummies and their interaction terms to allow for heterogeneous regional effect across cohorts. We argue that the variation left after controlling for the transitional factors can be mostly attributed to the eradication campaign. A disadvantage of this strat

- *y* is an individual outcome variable in adulthood;
- is regional malaria exposure risk;
- is a region fixed effect;
- is a grouped birth-cohort fixed effect;
-

must infer the exposure risk from observed malaria death rates, which are the best information available to us.[12] To make our empirical model operational, we assume that malaria death rates are proportional to the exposure risk and therefore we can use malaria deaths per 1,000 individuals at the regional level as a proxy for the malaria exposure risk. More explicitly, we assume that the stochastic relationship between malaria death rates and the malaria exposure risk with a potential measurement error is as follows.

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where *Malaria* is malaria deaths per 1,000 individuals; is a proportionality coefficient; is an unobserved measurement error; other notations are the same as before. Following the classical errors-in-variables assumption, we assume and are uncorrelated. Plug (2) into (1) and after some arrangements we can get an operational model as follows.

,

where .

The parameter

In addition to simple observation errors, measurement errors could arise for two reasons. First, malaria death rates may deviate away from proportionality to exposure risk due to unobserved factors. For example, three parasite strains were found among malaria patients in colonial Taiwan: *P. falciparum*, *P. vivax* and *P. malariae* (Sawa 1931; Morishita 1976). Of these, only *P. falciparum* would typically cause mortality, but all three strains could cause morbidity. The parasites composition could vary geographically and over time. Second, measurement errors could arise from mis-identification of birth place for a subset of our sample, as indicated in the data section.

Omitted Confounders

There also exists some omitted family characteristics that may lead to a biased estimate of . For example, it is possible that a better-off family has more means to protect their children from malaria and also invest more in their human and health capital. Parents' education may well play a similar role. In our empirical model, we control for father's education and occupation, but we do not have family wealth or income.

Instrumental Variables

We adopt the instrumental variable method to mitigate the potential bias caused by above concerns. We employ climatic factors, e.g. rainfall, rainy days, relative humidity, and wind speed, in the colonial period that we argue are presumably uncorrelated with the measu

Watershed versus Wiggle Effect

From the perspective of policy makers, it would be interesting and important to learn the full benefit of the eradication campaign by utilizing the full variation in malaria during the colonial period. For example, if malaria deaths per 1,000 people drop from 4 (before the campaign) to 0 (after the campaign), an ideal estimate of the full benefit of the eradication would be the difference in a later-life outcome between people who were born into the high-risk environment (where malaria death rates are four per thousand) and those who were born into the low- risk environment (where malaria death rates are virtually zero), provided that all else were equal. We use Bleakley's term to dub this the *watershed effect*.[16] However, we do not attempt to estimate the watershed effect, because colonial Taiwan experienced transitions in social and economic aspects during the period of malaria eradication, such as infrastructure, public health system, which were likely correlated with malaria reduction. We do control for these transitional factors as previously described, but as a result, we are left with residual variations in malaria that remain after holding constaeiu(l)-2(a)4(r)3(i)-(i)-2(t)-2(i(s)-1(a)4)-2(n s)-1(oc)4(l)-12(a)4(t)-2(e)4(d w)2(i)-

4. Data

We collect historical data on malaria deaths, population, climate, education and economic variables from various *Yearly Statistics Books of the Office of the Governor-general in Taiwan* published by the colonial government.[17] Because malaria death information is only available for the period 1901-1941, we restrict our study period accordingly. Two key malaria variables are defined as follows. MALARIA1 is the malaria deaths per 1,000 people in the year of birth, and MALARIA2 is the average malaria deaths per 1,000 people in the year of birth and the year before birth. Both are measured at the regional level. For climatic factors, we collect annual rainfall, annual rainy days, relative humidity, and wind speed. Unfortunately, climate data for the *Hsinchu* region was not available until the late 1930s. Therefore, we have to exclude this region in our IV estimation. Yet, we later show that OLS results are similar whether this region is included or not. For more details about historical data, see Data Appendix.

Individual Level Data

The individual level data come from a longitudinal survey—*Survey of Health and Living Status of the Middle-aged and the Elderly in Taiwan*. This survey was initiated in 1989 using a representative sample of the elderly aged 60 and older. In 1996, it drew another sample representing the middle-aged population between 55 and 66. We combine these t diseases, and death records.[18] Another advantage of our individual-level data is that we have exact birth place information for two thirds of our sample. For the remaining one third, we use current residence as the measure of birth place. We believe current residence is a reasonable proxy for birth place based on robustness checks, which we show later.[19]

Sample Characteristics

Table 1 summarizes the sample characteristics by region. All outcomes are evaluated in 1996, except for mortality. We observe death records during 1989-2007. Note that cognitive measures and self-reported chronic conditions are only available for a subsample of those alive and interviewed in 1996, while we know other information for the entire sample. On average, these individuals were of age 70 and had slightly more than three years of schooling, which are two years longer than their father had. By this age, a substantial proportion of them had reported that they had cardiovascular or lung diseases. By the end of 2007, slightly more than half of them had died.

5. Estimation Results

We present OLS and 2SLS estimates of equation (3). The OLS estimates are executed with and without the *Hsinchu* region to establish evidence of the robustness of our 2SLS to exclusion of this region because of lack of data on the critical IV's.

OLS Estimates of Malaria Effects

[18] Lung diseases include pneumonia, bronchitis, asthma and emphysema.
[19] We know both the birth place and current residence for the elderly people born between 1901 and 1929 (66% of the sample), while we only know their current residence for those born between 1930 and 1941 (34% of the sample).

birth place or current residence, suggesting that the use of current residence for the one third should be less of a concern.

In principle, children under age 5 are all at high risk of malaria infection. Yet, Figure 5 illustrates that infections in the birth year and the year before birth are generally more serious than other ages. We repeat the regressions using malaria death rates measured in different years relative to the birth year (year “0”) from the year before birth (year “-1”) up to five years after birth (year “5”). The OLS estimates are plotted in Figure 5. As shown, the malaria effects are generally the highest before and at birth and then gradually die out as the child builds up her immunity.

First Stage Estimates

Before we proceed with our 2SLS estimation, we first examine the correlation between the climatic factors and malaria death rates. More specifically, we regress malaria death rates on annual rainfall, rainy days, relative humidity and wind speed as well as all other exogenous variables in equation (3). The first stage results reported in Table 4 show that these factors are highly correlated with malaria death rates. Specifically, they suggest that malaria death rates are positively correlated with rainy days, relative humidity and wind speed, which are conducive for breeding and spreading of mosquitoes. The results also suggest a negative relationship between total rainfall and malaria death rates, which seems surprising. Yet, in Taiwan, most mosquitoes lay eggs on still water in a shallow pond or container. Conditional on other factors, too much rainfall brought by storms or typhoons actually could flush away the eggs or larvae and thus interrupt the transmission of malaria.

2SLS Estimates of Malaria Effects

Again, due to lack of climate data for the Hsinchu region, we only include the other four regions in our 2SLS estimations. The 2SLS results in Table 5 are thus comparable to Panel B in Table 2. In general, 2SLS results are 2~3 times larger than OLS results, which is ichn(s)-1issh ish2(lt5(e) 6(s)a)6t5(e)lieecawhn(s)4(awe4(Or5(ln(s) t2(ia)6tt)-126)21(S)-8(

This paper exploits variation in malaria deaths around birth caused by a malaria eradication campaign in colonial Taiwan in the early twentieth century to estimate the malaria effect on education and health outcomes in later life. To make a causal inference,

References

Almond, D. (2006). "Is the 1918 Influenza pandemic over? Long

Bleakley, H. (2010). “Malaria eradication in the Americas: a retrospective analysis of childhood exposure.” *American Economic Journal: Applied Economics*, 2: 1-45.

Case, A., and C. Paxson (2009). “Early life health and cognitive function in old age.” *The American Economic Review: Papers and Proceedings*, 99 (2): 104-109.

Case, A., and C. Paxson (2010). “The long reach of childhood health and circumstatnce: evidence from the Whitehall II Study.” *NBER working paper* 15640.

Chen, Y., and L. Zhou (2007). “The long-term health and economic consequences of the 1959–1961 famine in China.” *Journal of Health Economics*, 26 (4): 659-681.

Cutler, D., W. Fung, M. Kremer, M. Singhal and T. Vogl. (2010). “Early-life malaria exposure and adult outcomes: evidence from malaria eradication in India.” *American Economic Journal: Applied Economics*, 2: 72-94.

Department of Health, the Executive Yuan, Republic of China. (1991). *Malaria eradication in Taiwan*. Taipei, Taiwan.

Holding, P., and R. Snow (2001). “Impact of plasmodium falciparum malaria on performance and learning: review of the evidence.” *American Journal of Tropical Medicine and Hygiene*, 64: 68-75.

Kim, S., Q. Deng, F. Belton and S. Li (2010). “The lasting impact of mother’s feutrition on their offspring: evidence from th e China Great Leap Forward famine.”

Ku, Y. (2009). “Anti-malaria policy and its consequences in colonial Taiwan.” In *Disease, Colonialism, and the State*, edited by K. Yip. Hong Kong: Hong Kong University Press.

Liu, S. (2009). “The theory and practice of malariology in colonial Taiwan.” In *Disease, Colonialism, and the State*, edited by K. Yip. Hong Kong: Hong Kong University Press.

Lucas, A. (2010). “Malaria eradication and educational attainment: evidence from Paraguay and Sri Lanca.” *American Economic Journal: Applied Economics*, 2: 46-71.

Meng, X., and N. Qian (2009). “The long term consequences of famine on survivors: evidence from a unique natural experiment using China's great famine.” *NBER Working paper* 14917.

Tetsuzou, S., (2007). “The opening of sanitary policies in early Japanese Taiwan—from the public health physician reports.” *Journal of Taiwan Normal University*, 37: 143-180. (In Chinese)

Ting, K. (2008). “The public hygiene of the area of Yunlin County during the Japanese ruling period of Taiwan.” *Journal of Living Sciences*, 11: 195-243. (In Chinese)

Yearly Statistics Books of the Office of the Governor-General in Taiwan from 1895 to1945. Online archive: http://tcsd.lib.ntu.edu.tw/main_browse.php.

WHO (2010). Health Topics on Malaria

Data Appendix:

Administrative Division Changes

During 1901-1941, administrative divisions were redrawn in 1909 and 1920. Before 1920, divisions were called *Ting*; after 1920, some were called *Zhou* (prefecture) and others were still called *Ting*. In general, a *Zhou* is about the size of 3-4 *Tings*. During 1901-1908, there were 19 *Tings* on the main island of Taiwan.[21] During 1909-1919, there were 11 *Tings*. After 1920, there were five *Zhous* in the west and two *Tings* in the east. In this paper, we use the division after 1920 as basis. We group two *Zhous* in the south and two *Tings* in the east to minimize the inconsistency caused by the division changes. Therefore, we have 5 regions in the end. There are still three townships belonging to different prefectures according to our definition in different periods. For individuals born to these three townships, we include three dummy variables into all regressions to pick up the effect caused by the administrative division inconsistency.

Malaria Death Rate

We count the yearly malaria deaths for the 5 prefectures and then divide them by corresponding population (in thousands). Note that the malaria [illegible] for the *Taichung* region, Tainan station (22°59'N,120°12'E) for the *Nankao* region and Taidong station (22° 45'N, 121°08'E) for the *Huadong* region.

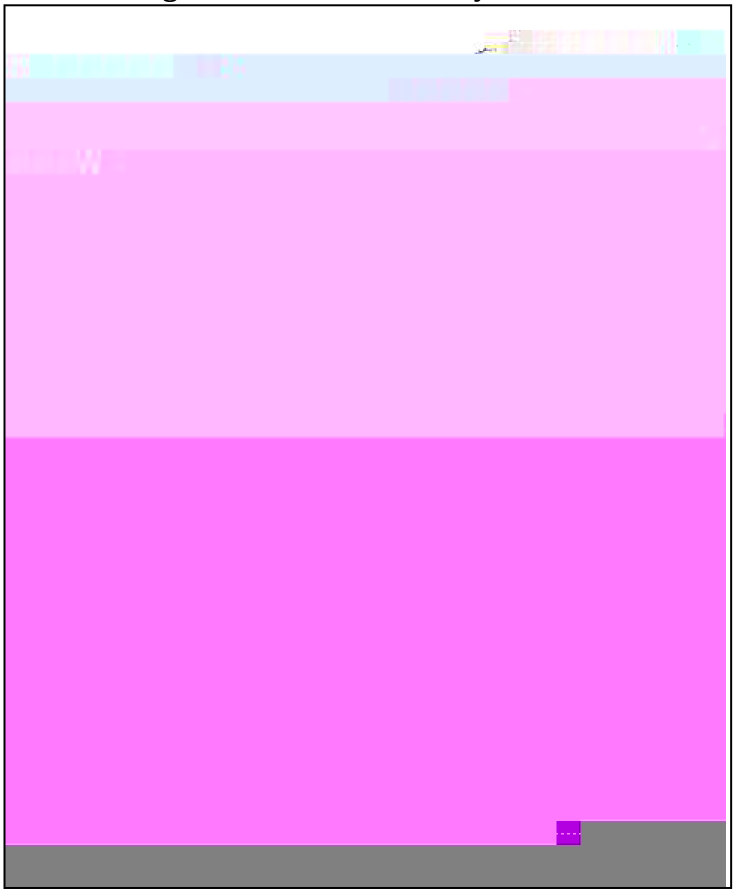
Agricultural Production

Taiwan was an agrarian economy during the colonial period. The two most important agricultural products then were rice and sugar cane. While sugar cane was most popular in the south, rice was widespread in the whole island. We thus calculate the per capita value of rice and sugar cane production in each prefecture to measure the local economic status. We use the prices of rice and sugar cane in 1929. This variable is included in all regressions as a control for time-varying local economic status.

Primary Schools

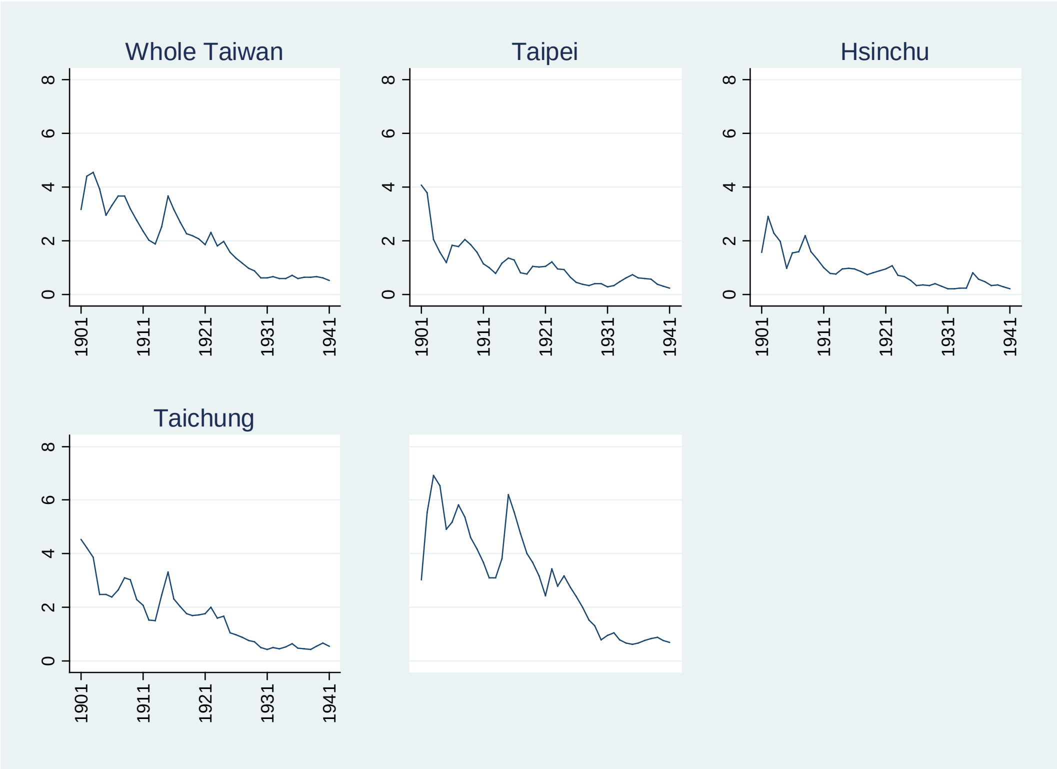
To control for local education resources, we use the number of primary schools per 100,000 people and this variable is also included in every regression. Primary schools were the most available education resource to native Taiwanese in the colonial period.

Figure 1. Malaria severity in 1920



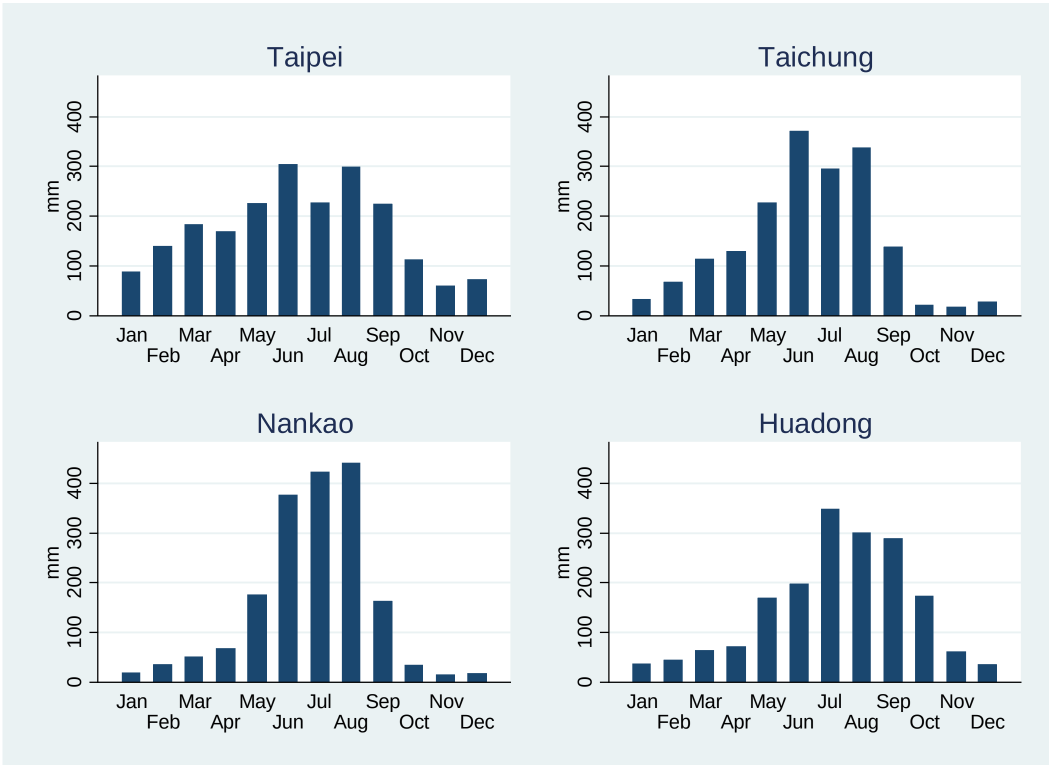
Note: darker areas are characterized with higher malaria mortality.

Figure 2. Trend of malaria death rate by region



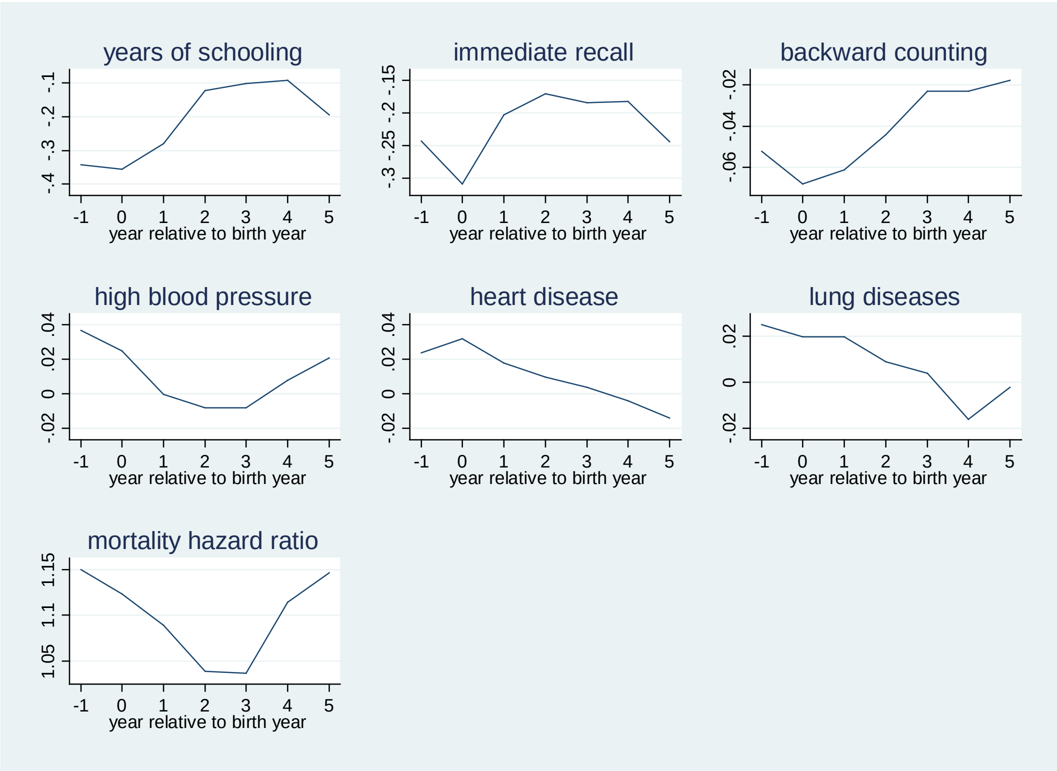
Note: malaria death rate is defined as malaria deaths per 1,000 people.

Figure 3. Monthly Rainfall in the Colonial Period



Note: Monthly rainfalls are averages over 1897-1945 for *Taipei*, *Taichung*, *Nankao* and 1901-1945 for *Huadong*.

Figure 5. OLS Estimates of Malaria Effect in Different Years Relative to Birth



Note: all 5 prefectures are used; malaria death rates are measured in different years relative to birth year, which is year “0”; “-1” means the year before birth; “1” means the year after birth.

Table 1. Sample Characteristics by Region

Region	(1) All	(2) Taipei	(3) Hsinchu	(4) Taichung	(5) Nankao	(6) Huadong
Age	70.16	69.20	70.79	70.58	70.13	68.65
Female (%)	51.15	53.33	49.42	51.89	50.18	54.47 [illegible]
Minnan people (%)	77.77	95.13	34.50	88.23	85.40	31.71
Father's years of schooling	1.10	1.34	1.13	1.08	1.02	0.77
Father was farmer (%)	61.38	45.64	69.39	65.85	61.21	

Table 2. OLS Estimates of Malaria Effect on Education and Health												
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	years of schooling		immediate recall		backward counting		high blood pressure		heart disease		lung diseases	
	Panel A: All 5 regions											
MALARIA1	-0.355		-0.309		-0.068		0.025		0.032		0.020	
	(0.183)		(0.138)		(0.026)		(0.020)		(0.013)		(0.015)	
MALARIA2		-0.442		-0.345		-0.075		0.039		0.035		0.030
		(0.211)										

Table 3. OLS Estimates Using a Subsample with Both Known Birth Place and Current Residence

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	years of schooling		immediate recall		backward counting		high blood pressure		heart disease		lung diseases	
	Panel A: Malaria death rate defined by birth place											
MALARIA1	-0.264		-0.261		-0.054		0.027		0.033		0.012	
	(0.135)		(0.103)		(0.014)		(0.024)		(0.010)		(0.018)	
MALARIA2		-0.363		-0.310		-0.065		0.038		0.031		0.021
		(0.176)		(0.138)		(0.018)		(0.025)		(0.009)		(0.014)
Observations	3022	3013	1815	1814	1815	1814	2024	2019	2024	2019	2024	2019
R-squared	0.35	0.35	0.10	0.10	0.09	0.09	0.03	0.03	0.02	0.02	0.02	0.03
	Panel B: Malaria death rate defined by current residence											
MALARIA1	-0.235		-0.216		-0.038		0.010		0.029		-0.001	
	(0.061)		(0.033)		(0.016)		(0.011)		(0.012)		(0.008)	
MALARIA2		-0.271		-0.212		-0.041		0.018		0.027		0.005
		(0.064)		(0.031)								

Table 4.

Table 5. 2SLS Estimates of Malaria Effect on Education and Health

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	years of schooling		immediate recall		backward counting		high blood pressure		d heart d			

Table 6. Cox Model Estimates of Malaria Effect on Mortality Hazard

	(1)	(2)	(3)	(4)	(5)	(6)
			Panel A: Coefiiad			