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PARALYZED BY PANIC:
MEASURING THE EFFECT OF SCHOOL CLOSURES DURING THE 1916 POLIO PANDEMIC ON EDUCATIONAL ATTAINMENT

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ABSTRACT

We leverage the 1916 polio pandemic in the United States as a natural experiment to test whether short-term school closures result in reduced educational attainment as an adult. With over 23,000 cases of polio diagnosed in 1916, officials implemented quarantines and closed schools. Since the pandemic occurred during the start of the 1916 school year, children of working age may have elected not to return to school. Using state-level polio morbidity as a proxy for schooling disruptions, we find that children ages 14-17 during the pandemic had less educational attainment in 1940 compared to their slightly older peers.

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1 Introduction

People have enjoyed longer and healthier lives due to medical advances over the course of the 20th century. Diseases such as smallpox and polio appear to be relics of the past. Nevertheless, issues of microbial resistance to antibiotics, the resurgence of vaccine preventable diseases, and the emergence of highly drug resistant tuberculosis and malaria remind us of modern medicine's limitations. Pandemics and untreatable diseases may become more common as the world grows more integrated and connected. The outbreaks of SARS in 2003, H1N1 influenza in 2009, Ebola between 2013 and 2016, and the outbreak of Zika beginning in 2015 provide broad evidence of the costs of communicable disease.

In addition to the direct effects that communicable diseases have upon health outcomes, uncontrolled outbreaks of disease may also act as exogenous shocks to the economy as people attempt to mitigate their risk of exposure. Consumers stay home, tourists cancel trips, schools close, and governments halt trade, impose quarantines, or order the culling of livestock. Studies examining the impact of the 2003 SARS outbreak on the Chinese economy show that it resulted in temporary negative shocks to tourism, retail sales, and personal consumption, as well as a 0.5 percent reduction in GDP (Siu and Wong, 2004; Hanna and Huang, 2004). More recent studies of the impact of Ebola on the countries of Guinea, Liberia and Sierra Leone suggests that "aversion behavior" — the actions taken by people to avoid illness, and the actions taken by investors as they anticipate these behaviors — led to a loss of $1.6 billion in 2015, or about 12 percent of their combined GDP (Thomas et al., 2015).

In addition to impacting current health and economic activity, epidemics may have lifelong consequences for those infected who ultimately survive, and even for those who are not infected. Almond (2006) demonstrates that people who were *in utero* during the 1918 influenza pandemic had lower rates of educational attainment and income, and higher rates of disability compared to other cohorts.[1] It may also be the case that the disruption caused by epidemics affects individuals who do not get sick. For example, Parman (2013) examines the impact of the 1918 influenza pandemic on the siblings of those children born during the outbreak and finds that older siblings received an additional three months of education while younger siblings received slightly less education relative to children who did not have a sibling born during the pandemic. Educational attainment may also be disrupted during an epidemic as people seek to limit their risk of infection by going to public places, including schools. Public health officials may even close schools during epidemics. During the Ebola outbreak, five million children in Africa faced school closures (Sifferlin, 2014). Schools in Sierra Leone were closed for nine months, and schools in Guinea and Liberia were closed for six (Sifferlin, 2014; Paye-Layleh, 2015). In Nigeria, schools that were supposed to open in August remained closed until October (BBC News, 2014).

These short-term school closures may have long-run impacts on the educational attainment of affected children. Older children of legal working age may opt to drop out of school and join the workforce after a prolonged closure, thus acquiring a lower level of educational attainment than they might might have otherwise. Younger children who have their schooling disrupted even for short periods of time may suffer negative effects. For example, Marcotte and Hemelt (2008) find that unscheduled school closings due to weather negatively affect student performance on third grade state assessment exams. Middle-grade students may have lower rates of educational attainment if their learning is disrupted during key periods of development (Lloyd, 1978; Hernandez, 2011). Whether these effects

[1] Lee (2012) finds that even avoiding illness may lead to increased educational attainment; she finds that compulsory state vaccination laws had positive effects on educational outcomes.

persist into the long run is less clear. Card and Krueger (1992) find that men educated in states with higher-quality schools (measured by term length, student-teacher ratio, and teacher wage) earn higher economic returns from their schooling; however, Pischke (2007) uses data from a German school district that had a one-time shortening of the school year and finds that the short school year had no negative effect on earnings and employment later in life, although it did lead to more students repeating a grade and fewer students entering higher secondary school tracks.

In this paper, we provide insight into the impact of epidemics on education by examining the effect of the 1916 polio epidemic on educational attainment reported by adults in the 1940 census. Prior to 1916, most of the U.S. population had limited experience with polio. Minor and relatively isolated outbreaks occurred previously in the United States, with Vermont enduring a notably large outbreak in 1914. Between 1909 and 1915, the rate of reported polio cases had not risen above 7.9 per 100,000 population (Paul, 1971). In contrast, the 1916 outbreak affected more than three times the number of people as previous outbreaks, with 28.5 cases reported per 100,000 people (Paul, 1971; Nathanson and Kew, 2010). The 1916 epidemic struck in late June and continued into November.[2]

While New York City and New Jersey were the first to experience outbreaks and experienced the greatest rates of infection, 27 other states reported large scale outbreaks of the disease as the virus migrated west and south, as shown in Figure 1. Over the course of the outbreak, there were over 5,000 deaths and 23,000 more documented infections, numbers that eclipsed those of previous epidemics (Lavinder et al., 1918; Trevelyan et al., 2005). Departments of public health and politicians faced an acute crisis. As the disease spread,

[2]The 1916 epidemic may also have been underreported compared to later epidemics; prior to 1945, only cases with paralytic symptoms were reported (Nathanson and Kew, 2010). Moreover, Trevelyan et al. (2005) suggest that the 1916 epidemic was more intense than subsequent outbreaks since it had the highest rates of notification per capita of any U.S. polio epidemic.

officials became increasing desperate. Many states restricted the movement of people, enforced broad quarantines, and shut down schools at the start of the academic year. These school closures may have led some students to drop out of school and join the labor force, and may have lessened the number of days in the school year for others.

We hypothesize that children who were of legal working age (above age 13 in most states) would be more likely to leave school than other children, since they faced a higher opportunity cost of remaining in school. It is true that our measured effect combines this indirect effect of polio lessening educational attainment through school closures with the direct effect of polio, which may have lessened educational attainment for infected children. In this case, our results are an upper bound for the plausible effects of school closures on educational attainment. While we cannot ascertain the magnitude of the indirect effect, we believe it to be greater than the direct effect since nearly 90 percent of children infected by polio before 1919 were under the age of 10 (Nathanson and Kew, 2010).

Since we do not have data on school closures, we use within state-of-birth variation in polio morbidity rates to measure the effect of the pandemic on adult educational attainment reported by individuals in the 1940 census.[3] Our results suggest that individuals living in areas harder hit by polio in 1916 experienced decreases in educational attainment, depending on their age during the outbreak. We find that an increase of one standard deviation more cases per 10,000 population resulted in about 0.07 fewer years of schooling for children between the ages of 14 and 17, relative to the reference cohort of people aged 19-21. Children who were already ages 17 or 18, or who were between 10 and 14 were not affected. Given that returns to schooling may be greater now than in 1916, we offer these

[3]The U.S. Federal Government did collect information on schooling at the state level, but information is missing for the 1916/1917 school year. This is because the government transitioned from reporting the information on an annual basis to a biannual basis this exact year. As such they did not collect they did not collect data for the 1916/1917 school year.

estimates as an upper bound of what might happen to educational attainment currently if pandemics lead to school closures.

2 The Pathology of Polio and the 1916 Epidemic

Polio is caused by the poliovirus, an enterovirus transmitted via the fecal-oral route. Evidence on Egyptian stele (depicting an adult with a withered leg and crutch) dating from 1580-1350 BC suggests that polio has existed for thousands of years (Nathanson and Kew, 2010). Although the existence of polio dates to antiquity, it was not until the late 19th century that epidemics began occurring in the United States and Europe. The most plausible explanation for this pattern is that prior to the late 19th and early 20th centuries, most people were probably exposed to polio during infancy, when infants had circulating maternal antibodies that made the infection much less severe. Over the next 100 years, improved public sanitation delayed exposure to the virus, thus increasing both the age of primary infection as well as the severity of the illness, since maternal antibodies were no longer circulating. As a result, epidemics that became increasingly severe were reported each summer and fall, and the average age of persons infected increased (Hamborsky et al., 2015; Nathanson and Kew, 2010).

In most cases, patients infected with polio are asymptomatic or experience minor symptoms that resolve in a week (including fever, sore throat, headache or nausea) (Hamborsky et al., 2015; Nathanson and Kew, 2010; Oshinsky, 2006). In some individuals (about one in 150 persons infected), the virus can enter the bloodstream, and then invade the central nervous system, leading to paralysis.[4] The extent and duration of the paralysis differs across individuals; while some people recover completely, others may remain permanently

[4] There are three polio virus subtypes, which differ in their virulence and effect. Poliovirus type 1 was responsible for 80 percent of paralytic cases in the prevaccine period (Nathanson and Kew, 2010).

weak or paralyzed (Hamborsky et al., 2015).

The 1916 outbreak generated substantial fear because it struck higher-income families as much or even more than lower-income families, with seeming random incidence. While polio outbreaks tended to follow seasonal patterns, the geography of outbreaks was unpredictable. Areas that experienced pervasive and widespread viral outbreaks one year might never again see a significant outbreak. The potential lifelong crippling associated with the disease can arise in youth without warning, and a large share of cases in New York City in 1916 occurred among native-born children living in single-family dwellings with clean surroundings and inside toilets (Lavinder et al., 1918).

In attempting to prevent the spread of the epidemic and allay public fear, officials were quick to implement various protocols. Children ages 16 and under were prohibited from leaving New York City for travel unless they produced "... a certificate that the premises occupied by them were free from poliomyelitis, and had been free from this disease since January 1, 1916." This was supplemented by a medical examination of such travelers at the point of departure (Emerson, 1917). In New York City, Health Commissioner Haven Emerson ordered the city streets to be washed with millions of gallons of water each day (Offit, 2005).[5] In addition to flushing streets, public employees enforced sanitary and quarantine regulations. Quarantines were part of the standard set of protocols employed by public health officials during the early 20th century and were widely employed during the 1916 epidemic. New York's State Department of Health recommended particularly harsh measures, ordering individuals diagnosed with poliomyelitis to be quarantined (Paul, 1971). Placards were also placed in front of homes of infected individuals to notify the community

[5] Washing streets with water was not an effective means of sanitation; polio virus can be killed with bleach, but not with plain water nor disinfectants such as alcohols or cresols (World Health Organization, 1999; Hamborsky et al., 2015). Similarly, Philadelphia officials ordered the streets of South Philadelphia washed with 10-million gallons of water each night (Rogers, 1992).

of the public health risk. In at least one case, a child suffering from polio was forcibly removed from his home to a hospital, against the wishes of his parents (Emerson, 1917). Government policy also called for a ban on public gatherings in areas where numerous cases were reported Emerson (1917). In the summer of 1916, New York public health officials barred children from movie theaters and libraries, closed Sunday schools, and banned picnics (The New York Times, 1916b,d; Rogers, 1992). Even though drastic measures were undertaken to control the spread of the disease, hundreds of new infections were reported every week.

As autumn approached, fears that afflicted youths would infect their peers and a belief that quarantines could limit the virus' spread led many school districts to delay the start of the 1916 school year until the pandemic waned. As the Department of Health noted, "The unprecedented virulence and extent of the existing epidemic, and unfamiliarity with the disease, has engendered in the public such a state of mind that concession to public alarm seemed advisable" (Emerson, 1917). New York City schools opened two weeks late (The New York Times, 1916c). Newspaper accounts show numerous other cities nationwide joined New York in postponing the start of school. Philadelphia delayed opening schools until September 18th, and both Washington, D.C., and Fort Wayne schools were not reopened until October 2nd (The Washington Times Company, 1916; Evening Public Ledger, 1916a,b). Evidence from *The Tacoma Times* in Washington, *The Bemidji Daily Pioneer* in Minnesota, and *The Princeton Union* in New Jersey shows school closures occurring in response to where cases of poliomyelitis arose and in rural locations. Lines from these newspapers read: "Seattle has five paralysis cases; school is closed,"[6] "Infantile Crisis closes rural school,"[7] and "Miss Parkander of Cambridge, a young lady about 22 years old,

[6] 9/25/1916 issue of *The Tacoma Times*, front page.
[7] 10/18/1916 issue of *The Bemidji Daily Pioneer*, page two.

succumbed to infantile paralysis early Monday morning, and the schools of our neighboring village have closed as a matter of precaution."[8] Even when schools may not have been officially closed, there is evidence that parents worried about sending their children to school. For example, even after the delayed reopening in New York City, worried parents withheld their children from school; up to 200,000 students were absent the first few weeks after schools opened, and the district announced "leniency" for parents who failed to send their children to school (The New York Times, 1916a).[9]

If a significant portion of the student population in 1916 did experience delays in starting school, it may have resulted in individuals acquiring less education relative to those in their individual age group who were not impacted by illness and school closures. Older children who could have worked instead of attending school may have opted to stay in the labor market. In 1910, 22 states had legislated 14 as the minimum age for employment in manufacturing (Moehling, 1999).[10] Around 16.8 percent of males and 5.8 percent of women between the ages of 10 and 15 were active participants of the workforce in 1920, suggesting that many school-age individuals in 1916 would have possessed workforce alternatives to education (Carter and Sutch, 1996). Together, this evidence implies that a notably large portion of youth ages 14 and older had viable and legal employment alternatives available to

[8] 9/07/1916 issue of *The Princeton Union*, page five.

[9] Closing schools in response to outbreaks and parental concern about outbreaks continued to occur throughout the 20th century. Clausen and Linn (1956) report that following an outbreak of polio in the Boston area in July, 1955, officials delayed opening schools for two weeks. Over 80 percent of mothers surveyed in three Boston area communities reported avoiding crowds, and up to 60 percent believed that schools should not have opened on schedule (Clausen and Linn, 1956).

[10] An analysis of these laws by Moehling (1999) shows that state minimum working-age legislation had little effect on youth employment in manufacturing, and that much of the decline in the use of child labor cannot be attributed to these legal restrictions. Furthermore, the laws setting age 14 as the minimum age for manufacturing employment were comparable to much of the state legislation during this period. Lleras-Muney (2002) notes that state laws for the minimum age of a work permit and the legal age for starting and leaving school are not harmonized and are, in fact, complex. However, it is true that the legal age for work permits in 37 states at this time was 14. Only in OH, MI , CA, and SD was the age older, at 15.

them in 1916.[11] Waiting for schools to reopen may have generated a significant opportunity cost, and many individuals may have chosen to enter the workforce rather than wait for schools to reopen.

In addition to affecting older children who may have left school to join the workforce, younger children may be affected by interrupted schooling as well. For example, research into the area of "red shirting" by Deming and Dynarski (2008) suggests that individual students who begin school at an older age reach the legal age of school at a lower level of education and therefore may be more likely to drop out of public education. In addition, there is some evidence that interruptions in schooling at crucial points of development may have long run impacts. Hernandez (2011) suggests that children in third grade experience a pedagogical shift from "learning to read" towards "reading to learn." A failure to develop this proficiency in reading on time appears to inhibit human capital accumulation of students and limits the potential to keep pace with their peers. Lloyd (1978) suggests that students who perform at a lower level than their peers may be more likely to drop out of school, with third-grade academic performance accurately predicting whether an individual would drop out of school nearly 70 percent of the time.

3 Data and Empirical Methodology

Using the 1916 poliomyelitis epidemic as a natural experiment, this paper examines the effects that epidemiological induced panics and large-scale school closures have on the educational outcomes of school-age children. We rely on two primary data sources to analyze the effect of the polio epidemic on educational attainment. The U.S. Public Health Reports

[11] A sizable literature on the effects of compulsory schooling laws suggests that educational attainment is also affected by increases in the legal age of school exit, increases in the age at which children can legally work, and decreases in the maximum age of school entrance. For a full discussion, see Angrist and Krueger (1992); Margo and Finegan (1996) and Lleras-Muney (2002).

provide data on reported polio cases at the state level in 1916 (U.S. Surgeon General and U.S. Public Health Service, 1916) and the Integrated Public Use Microdata Series (IPUMS) of the 1940 Census provides information on individual educational attainment and other characteristics (Ruggles et al., 2010). [12]

We measure 1916 polio pandemic exposure by reported infections at the state level, so that our main identifying assumption is that people who were school age in 1916 would be exposed in their state of birth.[13] This assumption would be violated if children and adolescents migrated between states prior to 1916 epidemic. While we can only speculate as to the number of children who moved across states during childhood, we do know that in 1940, 77 percent of people were residing in the same state in which they were born. Further, migration would bias the treatment effect towards zero if migration prior to the pandemic was not systematically correlated with polio morbidity. Equation (1) represents the reduced form empirical regression used to study the effects of the 1916 pandemic on educational attainment:

$$Y_{i,b,s,a} = \boldsymbol{\alpha_b} + \boldsymbol{\kappa_s} + \Sigma_j \beta_j * Polio_b * AgeBin_{a,j} + \boldsymbol{X_b} * \boldsymbol{\gamma_a} + \epsilon_{i,b,s,a} \tag{1}$$

$Y_{i,b,s,a}$ denotes educational outcome for individual i, born in state b, residing in state s in 1940, and born in age cohort a. The variables $\boldsymbol{\alpha_b}$, $\boldsymbol{\kappa_s}$, and $\boldsymbol{\gamma_a}$ denote state of birth, state of residence in 1940, and age cohort fixed effects. State of birth fixed effects control for factors common across persons born in the same state, and state of residence fixed effects control for factors that are shared among persons residing in the same 1940 enumeration state. Common shocks shared across birth year cohorts, such as WWI, are controlled for

[12]By 1940, the educational attainment of most children who were school-age during the polio epidemic should have been complete.

[13]Using state of birth to proxy for pandemic exposure is not ideal but is the most precise measure of exposure given that the Census does not report more disaggregated information about birthplace.

using birth year fixed effects. In the full specification, we also include state level economic and demographic controls for 1916 state of birth.[14] These controls are denoted by $\boldsymbol{X_b}$ and include manufacturing wage earners per capita, doctors per capita, education expenditures per capita, ln manufacturing wages per earner, and ln population. Interacting these controls with age cohort fixed effects allows the effect of these state-level characteristics on educational attainment to vary across different age cohorts. We want to compare the effect of polio on the educational attainment of cohorts who are likely in school with the effect of cohorts from the same birth state who are slightly older and not likely to be in school. Thus, the main variables of interest are the interactions between the state polio case rate in 1916 per 10,000 population ($Polio_b$), and the age specific cohort bins ($AgeBin_{a,j}$). These interactions allow the state-level treatment effect of the pandemic to vary across birth year cohorts. Identification of these coefficients arises from variation in treatment intensity across birth cohorts from the same birth state. Finally, $\epsilon_{i,b,s,a}$ denotes a heteroskedastic error term clustered at the state of birth level.

In order to test whether the pandemic influenced the educational attainment of exposed cohorts, we match a sample of white males born between 1895 and 1905 (who were between the ages of 11 and 21 during the pandemic) with the 1916 polio morbidity rate in their state of birth. We restrict the sample to males since they entered the workforce as permanent participants, and we exclude blacks to limit potential measurement error in educational attainment, access to education, and other potentially unobserved confounding factors. Table 1 reports summary statistics for the primary sample.

Our main specification consists of four pooled birth-year cohorts consisting of individuals born between 1895 and 1905. In order to test our hypothesis that children of different

[14]We thank Adriana Lleras-Muney for providing these data.

ages may have been differentially impacted by the polio pandemic based on their labor market alternatives, we bin them into three age groups: ages 17-18 (born in 1898), ages 14-17 (born between 1899 and 1901), and ages 11-14 (born between 1902 and 1905).[15] We include indicator variables for each age bin in the regression, and interact each age bin with the polio morbidity rate. The excluded reference cohort consists of people born between 1895 and 1897, who form a plausibly untreated group since they would have been between the ages of 18 and 21 during the pandemic and likely not in school.[16] Since the cohort of persons born in 1898 may have included both school-aged and non-school-aged individuals, we also separately include an indicator variable for individuals born in 1898 (and its interaction with the polio morbidity rate) in the analysis.

4 Results

In our analysis, we run six different regressions, reported in Table 2. Columns (1)-(3) report results from estimating equation (1) with the level of educational attainment as the dependent variable. Column (1) includes fixed effects for state of residence in 1940, state of birth, and birth year. Column (2) also includes the full set of fixed effects and Census region x age-cohort trends to control for potential underlying geographic trends common across cohorts born in different areas of the country, and column (3) replaces the Census region trend with flexible state of birth economic and demographic controls interacted with age cohort dummies. Columns (4)-(6) present estimates for the same specifications with

[15]For our formal specification, we decided to limit the sample to persons ages 11-21 because birth cohorts close in temporal proximity are less likely to violate this assumption than cohorts which are spread further apart as it is unlikely that unobserved economic, demographic, and environmental conditions have changed radically over a short period, and the empirical model assumes that the treated cohorts have similar unobserved characteristics relative to the reference cohort.

[16]We choose a three-year reference cohort rather than a single-year reference cohort to reduce the likelihood of arbitrarily selecting a single-year reference cohort with unobserved characteristics that could make comparisons between treated and untreated cohorts invalid.

the dependent variable measured as the natural logarithm of educational attainment, which may resolve issues arising from the fact that education cannot take non-zero values. All coefficient results discussed refer to the most restrictive specifications, (3) and (6), unless otherwise noted.

Results presented in Table 2 confirm our hypothesis that the polio pandemic of 1916 had different effects on educational attainment for children of different ages. School-aged children who were old enough to have labor market alternatives (those who were between ages 14 and 17), and who were living in areas more affected by the pandemic had lower educational attainment than similarly-aged children living in areas with lower polio morbidity rates. This result is robust even in our models with the the most restrictive controls, and suggests that a one-standard-deviation increase in the polio morbidity rate per 10,000 persons (reported as 4.42 in Table 1), results in persons aged 14-17 having around 0.07 fewer years of educational attainment on average. This effect is equivalent to every fourteenth person in the cohort receiving one fewer year of education relative to the reference cohort.[17] The results from columns (4), (5), and (6) provide further evidence suggesting that the 1916 polio pandemic had adverse affects on educational attainment on children of working age. We find that a one percent increase in the polio morbidity rate would lead to approximately a 6 percent reduction in average educational attainment for the cohort.[18]

In contrast, the pandemic of 1916 did not statistically significantly affect the educational attainment of younger individuals who were unable to legally work in most states;

[17]To get this value, divide one by the marginal effect for an average person in the cohort.

[18]Given that some individuals born in 1902 may have been 14 years old in the fall of 1916, we estimate an alternative specification where these individuals were included in the cohort of persons between 14 and 17, and results do not significantly change. In general, results are robust to defining age bins differently. Given our bin definition may be somewhat arbitrary, we present results from regressions with single-year *age x polio* interactions in the appendix, as well as results from a regression where age-bins span two years. Both tables in the appendix show similar results to those reported in Table 2.

the estimated coefficient on the interaction between polio morbidity and the age bin for persons born between 1902 and 1905 is not statistically different than zero in any of the six specifications. Relative to individuals born before 1898, the educational attainment of people born in that year was not affected by polio morbidity rates.[19]

4.1 Robustness Checks

To check the robustness of our results, we perform a series of placebo tests to test whether polio morbidity at the state level is spuriously correlated with unobserved factors that affect educational attainment. In the first analysis, we select a sample of persons who would have already completed school by the fall of 1916. In this falsification test, we compare the educational attainment of those born between 1884 and 1892 to persons born between 1893 and 1895. These persons would have been ages 18 to 32 during the pandemic, so should not have their educational attainment affected by polio morbidity rates in 1916. Results from the placebo test are reported in Table 3. Specifications (1), (2), and (3) report the effect of increased cohort exposure to the pandemic on years of education. These results suggest that persons born between 1893 and 1894 in areas with greater morbidity had slightly less educational attainment relative their peers born between 1895 and 1897, but this negative effect is smaller than in the main specification and becomes statistically insignificant once controls for local economic conditions are added. Specifications (4), (5), and (6) report the effect of increased cohort exposure to 1916 polio morbidity on log years of education. Unlike specifications (1) through (3), these tests find no statistically significant effect on the 1893/1894 cohort. Overall, the falsification test fails to find any consistent effect of increased pandemic exposure and educational attainment in post-schooling cohorts.

[19] The results are robust to the merging of the 1898 cohort with the reference cohort.

We also perform an additional regression that includes younger cohorts born between 1906 and 1916. Results are reported in Table 4. In our primary specification, we exclude these children from the sample because the 1916 pandemic affected primarily young children, who may have had educational attainment interrupted because of the disabling effect of polio. This complicates the treatment effect of the pandemic and makes it difficult to make claims regarding the school closures as a causal channel. Furthermore, this multifaceted treatment effect makes finding an appropriate control cohort for comparison more difficult. Comparing young cohorts to persons already out of school would likely violate the comparability assumption made earlier. The unobserved institution, political, and economic factors likely differ substantially between these two populations. The results presented in Table 4 include pre-school age cohorts, but these populations would have had a much higher rate of polio infection, in addition to being affected by parental behaviors such as red-shirting. If parents of five year old children in the fall of 1916 decided to postpone their enrollment until 1917, these children would have reached the legal work age one grade earlier than their peers, which may have ultimately affected their educational attainment. If anything, the inconsistent results reported in Table 4 suggest that polio may have increased educational attainment for the youngest cohorts and had no affect on the others, leading us to conclude that excluding younger children from our test is appropriate when looking at schooling as a causal channel and preserving the comparability of cohorts close in time.

5 Conclusions

The first major polio epidemic in the United States struck in the summer of 1916 and persisted into the fall. With over 23,000 cases of polio diagnosed, the epidemic tested the nascent system of public health departments. Officials engaged in a variety of measures to stem the outbreak, including quarantines, washing streets, and closing public schools. In this paper, we examine the effect of public school closures on educational attainment. Our results show that children of legal working age living in areas with higher rates of polio infection had lower educational attainment than similarly aged children living in states with lower infection rates. This result, which is strong, robust and consistent across specifications, does not hold for age groups who were not of legal working age, nor does it hold for slightly older children who had already completed their secondary schooling. Our results suggest that a one-standard-deviation increase in the number of polio cases reported in a person's birth state resulted in the person having around 0.07 fewer years of educational attainment on average – an effect which is equivalent to every fourteenth person in the cohort receiving one fewer year of education relative to the reference cohort.

We consider this number to be an upper bound to the plausible effect on school closures in the modern era on educational attainment for two reasons. First, our measure combines the indirect effect of school closures on educational attainment with the direct effect of having polio (and missing school) on educational attainment. While 90 percent of polio cases were in younger children, we cannot completely eliminate the direct effect on educational attainment given available data. Second, it is probably the case that the opportunity cost of remaining in school today is much lower (given increases in returns to schooling over the past 100 years) than in 1916. Nevertheless, results suggest that there is a long-run cost when schools are closed as a response to disease outbreaks.

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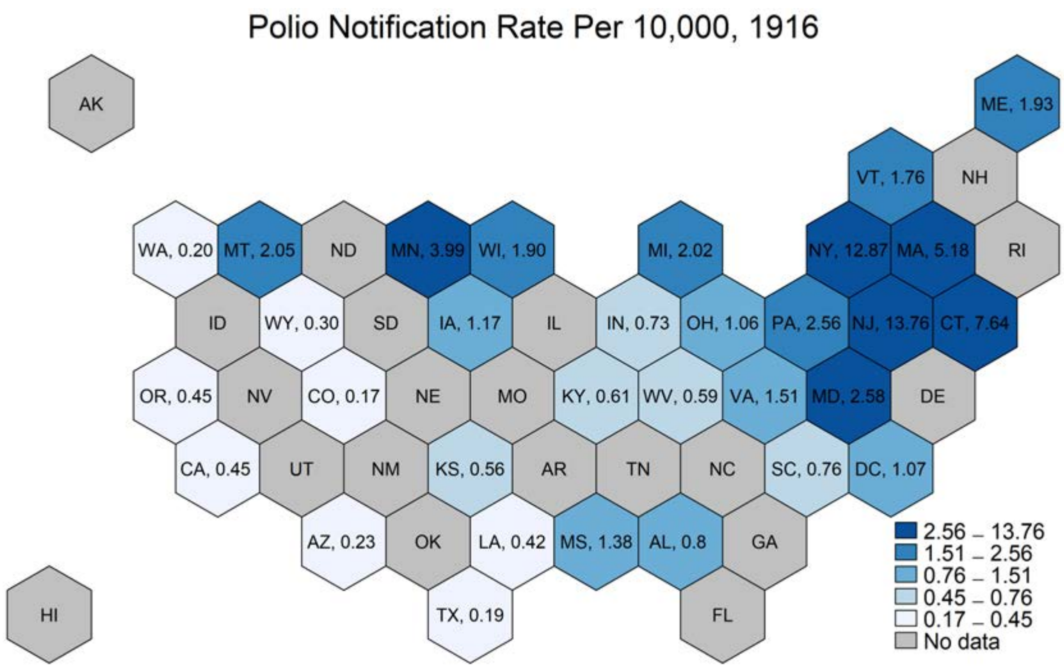

Figure 1: Map of 1916 Polio Morbidity. Source: Public Health Reports 1916

Table 1: Summary statistics

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**N**
Age in 1916	15.837	3.171	11	21	56,238
Years of Education	9.255	3.302	0	17	56,238
Polio Cases 1916 per 10,000	3.59	4.42	0.17	13.76	56,238
Mfg Wage Earners/Pop, 1916	0.086	0.045	0.02	0.199	56,097
Doctors/Capita, 1916	0.001	0	0.001	0.002	56,097
Education Expenditures/Capita, 1916	62.111	19.884	14.359	126.338	56,097
Mfg Wage Per Wage Earner, 1916	7,781.363	993.579	4,840.915	12,095.155	56,097
Population, Census Imputed, 1916	4,400.316	2,988.118	173.15	9,856.607	56,097

Table 2: Effect of 1916 Pandemic on Educational Attainment in 1940, Main Specification

	(1)	(2)	(3)	(4)	(5)	(6)
	Years Education			Ln Years Education		
Polio * Born 1898	-0.001	-0.001	0.001	-0.001	-0.001	0.002
	(0.007)	(0.007)	(0.008)	(0.001)	(0.001)	(0.001)
Polio * Born 1899-1901	-0.013***	-0.014***	-0.016***	-0.012***	-0.013***	-0.014***
	(0.005)	(0.006)	(0.005)	(0.001)	(0.001)	(0.001)
Polio * Born 1902-1905	-0.009	-0.011	-0.007	-0.010	-0.013**	-0.006
	(0.007)	(0.007)	(0.008)	(0.001)	(0.001)	(0.001)
Birth Cohort FE	Yes	Yes	Yes	Yes	Yes	Yes
State 1940 FE	Yes	Yes	Yes	Yes	Yes	Yes
Birth state FE	Yes	Yes	Yes	Yes	Yes	Yes
Census region cohort trend	No	Yes	No	No	Yes	No
Lleras-Muney controls	No	No	Yes	No	No	Yes
Reference cohort	1895-97	1895-97	1895-97	1895-97	1895-97	1895-97
N	56,238	56,238	56,097	56,238	56,238	56,097
R^2	0.066	0.066	0.066	0.079	0.079	0.079

All standard errors are clustered by state of birth. Lleras-Muney controls are controls interacted with age cohort dummies. These variables include 1916 state level manufacturing wage earners per capita, doctors per capita, education expenditures per capita, ln manufacturing wages per earner, and ln population.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3: Placebo Test: Cohorts Ages 18 to 32 in 1916

	(1)	(2)	(3)	(4)	(5)	(6)
	Years Education			Ln Years Education		
Polio * Born 1893 - 1894	-0.006**	-0.007**	-0.010*	-0.003	-0.004	-0.006
	(0.044)	(0.045)	(0.092)	(0.005)	(0.006)	(0.011)
Polio * Born 1890 - 1892	0.004	0.001	-0.001	0.006**	0.003	0.001
	(0.045)	(0.037)	(0.076)	(0.005)	(0.004)	(0.008)
Polio * Born 1887 - 1889	-0.000	-0.004	-0.009	0.003	-0.001	-0.007
	(0.055)	(0.049)	(0.119)	(0.006)	(0.005)	(0.013)
Polio * Born 1884 - 1886	0.003	-0.002	0.001	0.009*	0.003	0.004
	(0.092)	(0.083)	(0.113)	(0.008)	(0.007)	(0.012)
Birth cohort FE	Yes	Yes	Yes	Yes	Yes	Yes
State 1940 FE	Yes	Yes	Yes	Yes	Yes	Yes
Birth state FE	Yes	Yes	Yes	Yes	Yes	Yes
Census region cohort trend	No	Yes	No	No	Yes	No
Lleras-Muney controls	No	No	Yes	No	No	Yes
Reference cohort	1895-97	1895-97	1895-97	1895-97	1895-97	1895-97
N	59,422	59,422	59,291	59,422	59,422	59,291
R^2 a	0.064	0.064	0.064	0.075	0.075	0.075

All standard errors are clustered by state of birth. Lleras-Muney controls are controls interacted with age cohort dummies. These variables include 1916 state level manufacturing wage earners per capita, doctors per capita, education expenditures per capita, ln manufacturing wages per earner, and ln population.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Effect of 1916 Pandemic on Educational Attainment, Younger Cohort Interactions

	(1)	(2)	(3)	(4)	(5)	(6)
	Years Education			Ln Years Education		
Polio * Born 1914 - 1916	0.011	0.013*	0.016***	0.009	0.009	0.012**
	(0.084)	(0.079)	(0.053)	(0.009)	(0.009)	(0.007)
Polio * Born 1908 - 1910	0.008	0.006	0.014**	0.008	0.008	0.015**
	(0.071)	(0.085)	(0.074)	(0.008)	(0.009)	(0.009)
Polio * Born 1906 - 1908	0.004	0.001	0.006	0.007	0.007	0.008
	(0.077)	(0.092)	(0.102)	(0.008)	(0.010)	(0.011)
Birth cohort FE	Yes	Yes	Yes	Yes	Yes	Yes
State 1940 FE	Yes	Yes	Yes	Yes	Yes	Yes
Birth state FE	Yes	Yes	Yes	Yes	Yes	Yes
Census region cohort trend	No	Yes	No	No	Yes	No
Lleras-Muney controls	No	No	Yes	No	No	Yes
Reference cohort	1911-13	1911-13	1911-13	1911-13	1911-13	1911-13
N	71,303	71,303	71,124	71,303	71,303	71,124
R^2	0.0683	0.0684	0.0684	0.0763	0.0763	0.0764

All standard errors are clustered by state of birth. Lleras-Muney controls are controls interacted with age cohort dummies. These variables include 1916 state level manufacturing wage earners per capita, doctors per capita, education expenditures per capita, ln manufacturing wages per earner, and ln population.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6 Appendix

Table A.1: Effect of Pandemic on Educational Attainment, Single Birth Year Interactions

	(1)	(2)	(3)	(4)	(5)	(6)
	Years Education			Ln Years Education		
Polio * Born 1898	-0.001	-0.001	0.001	-0.001	-0.002	0.002
	(0.007)	(0.007)	(0.008)	(0.001)	(0.001)	(0.001)
Polio * Born 1899	-0.011***	-0.011***	-0.008*	-0.010***	-0.011***	-0.007
	(0.006)	(0.006)	(0.010)	(0.001)	(0.001)	(0.001)
Polio * Born 1900	-0.001	-0.002	-0.007**	0.001	0.000	-0.005
	(0.007)	(0.008)	(0.006)	(0.001)	(0.001)	(0.001)
Polio * Born 1901	-0.012***	-0.013***	-0.015**	-0.013***	-0.014***	-0.015***
	(0.008)	(0.008)	(0.010)	(0.001)	(0.001)	(0.001)
Polio * Born 1902	-0.004	-0.005	-0.008*	-0.004	-0.005	-0.008*
	(0.007)	(0.008)	(0.009)	(0.001)	(0.001)	(0.001)
Polio * Born 1903	-0.002	-0.003	0.003	-0.005	-0.007	-0.001
	(0.012)	(0.012)	(0.014)	(0.001)	(0.001)	(0.001)
Polio * Age 11/12, Born 1904	-0.006*	-0.008*	-0.001	-0.006	-0.008*	0.002
	(0.007)	(0.008)	(0.007)	(0.001)	(0.001)	(0.001)
Polio * Age 10/11, Born 1905	-0.006	-0.008	-0.008	-0.006	-0.009*	-0.007
	(0.012)	(0.011)	(0.013)	(0.001)	(0.001)	(0.001)
Birth cohort FE	Yes	Yes	Yes	Yes	Yes	Yes
State 1940 FE	Yes	Yes	Yes	Yes	Yes	Yes
Birth state FE	Yes	Yes	Yes	Yes	Yes	Yes
Census region cohort trend	No	Yes	No	No	Yes	No
Reference cohort	1895-97	1895-97	1895-97	1895-97	1895-97	1895-97
Lleras-Muney controls	No	No	Yes	No	No	Yes
N	56,238	56,238	56,097	56,238	56,238	56,097
R^2	0.066	0.066	0.066	0.079	0.079	0.079

All standard errors are clustered by state of birth. Lleras-Muney controls are controls interacted with age cohort dummies. These variables include 1916 state level manufacturing wage earners per capita, doctors per capita, education expenditures per capita, ln manufacturing wages per earner, and ln population.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A.2: Effect of 1916 Pandemic on Educational Attainment, Two Year Bin Interactions

	(1)	(2)	(3)	(4)	(5)	(6)
	Years Education			Ln Years Education		
Polio * Born 1898-1899	-0.007**	-0.008**	-0.005	-0.007**	-0.008**	-0.003
	(0.005)	(0.005)	(0.008)	(0.001)	(0.001)	(0.001)
Polio * Born 1900-1901	-0.009**	-0.010*	-0.015***	-0.008*	-0.009*	-0.013**
	(0.006)	(0.007)	(0.006)	(0.001)	(0.001)	(0.001)
Polio * Born 1902-1903	-0.004	-0.005	-0.004	-0.006	-0.007	-0.006
	(0.007)	(0.007)	(0.010)	(0.001)	(0.001)	(0.001)
Polio * Born 1904-1905	-0.008	-0.010	-0.006	-0.008	-0.010*	-0.003
	(0.009)	(0.008)	(0.008)	(0.001)	(0.001)	(0.001)
Birth cohort FE	Yes	Yes	Yes	Yes	Yes	Yes
State 1940 FE	Yes	Yes	Yes	Yes	Yes	Yes
Birth state FE	Yes	Yes	Yes	Yes	Yes	Yes
Census region cohort trend	No	Yes	No	No	Yes	No
Reference cohort	1895-97	1895-97	1895-97	1895-97	1895-97	1895-97
Lleras-Muney controls	No	No	Yes	No	No	Yes
N	56,238	56,238	56,097	56,238	56,238	56,097
R^2	0.0657	0.0657	0.0658	0.0790	0.0791	0.0790

All standard errors are clustered by state of birth. Lleras-Muney controls are controls interacted with age cohort dummies. These variables include 1916 state level manufacturing wage earners per capita, doctors per capita, education expenditures per capita, ln manufacturing wages per earner, and ln population.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$