The Impact of Childhood Health on Adult Educational Attainment:

Evidence from Mandatory School Vaccination Laws

Dara N. Lee [§]

University of Missouri-Columbia

August 2012

*** PRELIMINARY & INCOMPLETE ***

Abstract

This paper examines the impact of post-neonatal childhood health on adult educational attainment using evidence from mandatory school vaccination laws in the U.S. After the development of a number of key vaccines, states began to require proof of immunization against certain infectious diseases for children entering school. I exploit the staggered implementation of the laws across states to identify both the short-run impacts on child health and long-term effects on educational attainment. First, I show that the mandatory school vaccination laws were very effective in reducing the incidence rates of the targeted diseases. Next, I find sizable and positive effects on educational outcomes as measured by years of schooling and high school completion. The effect on educational attainment is twice as large for non-whites relative to whites.

[§] Email: leedn@missouri.edu.

I. Introduction

Recent research have shown that characteristics measured as early as age seven can explain a substantial amount of variation in adult educational attainment and wages (Heckman 2007). In particular, there has been a growing body of work that demonstrate childhood health is linked to both adult health and human capital outcomes (Blackwell, Hayward, and Crimmins 2001; Case, Fertig, and Paxson 2005). However, whether this link is causal or whether a positive correlation is observed due to omitted variable biases remains an open question.

As such, economists in recent years have directed a great deal of effort towards examining the impact of childhood health on subsequent human capital development (see Almond and Currie 2009 for a more detailed review). The resulting evidence that prenatal and neonatal environments have persistent effects on human capital accumulation seems fairly conclusive.[1] In contrast, there has been considerably less work analyzing the impact of post-neonatal or early childhood settings. Bleakley (2008) demonstrate that hookworm eradication in the South increased school attendance, enrollment and literacy. Relatedly, Miguel and Kremer (2004) find that deworming substantially improved health and school participation among untreated children in both treatment schools and neighboring schools. This paper examines the impact of childhood health on adult human capital outcomes using evidence from modern mandatory school vaccination laws (MSVL) in the United States. MSVL provide two settings that may provide new insight on the question. First, MSVL cover highly infectious diseases that

---

[1] For example, Almond (2006) demonstrate that cohorts *in utero* during the height of the 1918 Influenza Pandemic have reduced educational attainment, increased rates of physical disability, lower income, and lower socioeconomic status. In related work, Almond, Edlund and Palme (2009) examine prenatal exposure to Chernobyl fallout and school outcomes. They find that students born in regions of Sweden with higher fallout performed worse in secondary school. Chay, Guryan, and Mazumder (2009) use racial integration of hospitals to show that improved access to health at very early ages have large, long-term effects on achievement as measured through test performances. Field, Robles, and Torero (2009) find that prenatal iodine supplementation raised educational attainment in Tanzania by half a year of schooling, with larger impacts for girls. Ward (2011) find that school immunization mandates have significant positive benefits for children in-utero in terms of birth weight and adult health.

were prevalent throughout the nation, especially among school-aged children. Second, MSVL target a specific audience, which are children who are entering school for the first time, i.e., children between the ages 5 and 6, and affect every child in the U.S. to this day. The scope of these laws is therefore much larger than previous interventions that have been studied.

Few measures in preventive medicine can compare with the impact of vaccines. Since the development of a number of key vaccines in the first half of the 20th century, incidence rates of preventable diseases have fallen dramatically. In the United States, formerly fatal diseases such as polio and diphtheria have now been completely eradicated. Rates of once-universal infectious diseases, such as measles and pertussis, have dropped by close to 100 percent. Schools are natural sites for widespread transmission of infectious disease because of the close contact students have with each other. Soon after the invention of the vaccines for polio and measles in the 1950s-60s, states began to require proof of immunizations for children entering school for the first time in order to combat widespread transmission in schools. By 1980, all fifty states had compulsory school vaccination laws.

There are compelling reasons to believe, *a priori*, that MSVL made a significant impact. First, immunization surveys administered by the Center of Disease Control (CDC) prior to the implementation of MSVL suggest that parents tend to have their children vaccinated only during epidemics, by which time the children may already have been exposed to the disease and the vaccine would unlikely be effective (CDC 1977). Second, a disease-free school community due to high immunization levels can be thought of as a common good – when morbidity rates decrease, parents may assume vaccinations are no longer necessary. Further, there is considerable anecdotal evidence indicating the rate of uptake of immunizations left room for intervention. For example, when Representative Schofield of Nevada first introduced the mandatory school vaccination bill to the assembly floor in 1971, he motivated the need for the bill by saying, "…some people do not get their kids immunized because they just put it off. This bill would give them a push in the right direction." Third, compulsory school vaccination programs are subsidized by the federal government, and a state's receipt of federal funds is conditional upon its implementation and enforcement of school vaccination regulations. As such, the laws are by-and-large enforced. Children who cannot show proof of vaccination are banned from entering school, leading to the still prevalent saying of "no shots, no school". Federal subsidization also enables states to provide vaccines for free or at very low costs. Children from all socioeconomic backgrounds can thus benefit from MSVL. State-specific immunization surveys from the 1960s and 70s suggest that vaccine uptake was consistently lowest among minorities and low-income groups. Existing literature also provides evidence that improvements in health technologies tend to increase disparities in health across education and income groups, because education and wealth enhances the ability to exploit such technological advances (Cutler and Lleras-Muney 2009; Glied and Lleras-Muney 2003). It is thus plausible that children from minority households or lower socioeconomic backgrounds can benefit more from MSVL.

The results suggest that that childhood health does in fact matter for adult educational attainment. First, I show that MSVL were very effective in reducing morbidity rates of the targeted diseases. In particular, MSVL were responsible for close to half of the drop in the rates of measles, a disease that was close to universal prior to the invention of its vaccine in 1963. As a falsification test, I show that MSVL did not have any effects on the morbidity rates of infectious diseases that were not covered under MSVL. However, I do not find substantive evidence that MSVL affected mortality rates of school-aged children. (I interpret the short-run reduction in morbidity rates as evidence of a "first-stage" relationship, i.e., the health of the affected cohorts as children were improved relative to the control cohorts. Next, I show that MSVL led to a sizable increase in educational attainment of the affected cohorts. Estimates imply that these laws increased years of schooling of the affected cohorts by approximately 0.11 years and the probability of high school completing by 1.8 percentage points. Interestingly, the impact on non-whites is twice as large as that on whites. I also demonstrate that the impact of MSVL increases with the strictness of enforcement and disease coverage, which lends further evidence to the causal link between MSVL and educational attainment. From a policy perspective, this study may help inform large-scale vaccination efforts that are ongoing in developing countries. In addition, while early childhood education interventions such as HeadStart (Garces, Currie, and Thomas 2000) and the Perry Program (Schweinhart et al. 2005) have been shown to be effective in improving adult outcomes, the impact of early childhood health interventions on subsequent human capital development have not been extensively studied. The results of this paper imply that not only are there definitive short-run benefits to vaccination laws, there are also long-term consequences on human capital attainment.

The rest of the paper is organized as follows. Section II discusses the background of MSVL in more detail. Section III describes the data. Section IV sets forth the identification strategy of the paper, reports and discusses the results. Section V provides several robustness checks, and Section VI concludes.

II. The Evolution of Mandatory School Vaccination Laws

The economic rationale behind why MSVL were deemed necessary can be sketched out in a simple "Tragedy of the Commons" (Hardin 1968) argument. Consider a school community where immunization rates are initially high. Although an unimmunized child will not be completely free of risk from contracting an infectious disease, high immunization rates among other students significantly reduces the risk for disease for that child. The unimmunized child may also enjoy the additional benefit of not risking any adverse reactions associated with the vaccine. As disease rates drop, the marginal cost (risk of adverse effects) associated with the vaccine is accentuated, providing further incentive to avoid immunization. Thus, when a child chooses to go unimmunized, it only minimally increases the risk of illness for that child, while the child enjoys the benefit of avoiding the risk of vaccine-induced side effects. If a high enough proportion of children in the school chooses to forego immunization, the level of immunity within the school community may fall below a critical point such that an epidemic will occur. It is therefore argued that MSVL are necessary to maintain a disease-free school environment, even after disease rates have fallen to very low rates as they have in the U.S.

The history of school immunization laws in the United States dates to the era of smallpox vaccination in the 19th century. In 1853 Massachusetts became the first state to require smallpox vaccination for schoolchildren. Similar legislation soon appeared in other states. In 1895, in the face of a widespread smallpox epidemic, Pennsylvania passed a compulsory school vaccination law requiring that all children provide a physician's certificate of vaccination or certified history of previous smallpox infection before being permitted to attend school. The enforcement of this law, which had strong public support throughout the state, was followed by a dramatic reduction in smallpox in the ensuing years (Jackson 1995).

The early successes of school vaccination laws helped lay the foundation for modern immunization statutes, which are the focus of this paper. There were relatively few changes to historical compulsory immunization laws in the United States through the early 1950's. The advent of live virus measles vaccine in 1963 appeared to be the tipping point in pushing states to enact or amend their vaccination laws. Measles vaccination made for an especially compelling case because the epidemiologic link to circulation of the measles virus is children in kindergarten and the first and second grades, meaning measles epidemics tend to originate within these groups. Also, the most infectious period of measles occurs before the appearance of the rash, so students are very likely to spread the virus before they realize they have it. Another relevant concern is that the disease could be carried home to infect other household members. For these reasons, measles was so universal in the pre-vaccine era that it was said to be “as inevitable as death or taxes” (Babbott and Gordon 1954). By 1972, 28 of the states and territories had enacted school immunization laws requiring measles immunization prior to school entry. By 1980, all fifty states had laws requiring that children entering school for the first time provide proof of immunization against certain infectious childhood diseases, including measles, mumps, rubella, diphtheria, pertussis, tetanus, and polio.[2]

Despite the universality of school vaccination laws now, such laws have been and remain controversial. Opponents argue that mandatory vaccination programs are inconsistent with federal constitutional principles of individual liberty and represent an infringement of personal religious beliefs under First Amendment principles. As a result, there were repeated court decisions on the legality of compulsory vaccination laws. Although conflicting legal opinions were given on certain aspects of vaccination requirements, it became an established principle of law that state legislatures may, under certain conditions, require vaccination. The matter was not really settled, however, until the U.S. Supreme Court upheld the constitutionality of the Massachusetts compulsory vaccination law in 1905. The Court ruled that a state had the power, through the legislative process, to pass and enforce compulsory smallpox vaccinations. The question of compulsory vaccination came before the Supreme Court again in 1922. This case

[2] Although a few states do not require the mumps vaccine, almost all measles and rubella vaccine used in the U.S. since 1970 are combined with the mumps vaccine (commonly known as the MMR), implying that most children should be immune to mumps despite MSVL not requiring the vaccination explicitly.

involved the constitutionality of a city ordinance requiring smallpox vaccination as a prerequisite for attendance at school. The Court upheld the ordinance as constitutional, basing its decision on the precedent set by the Supreme Court in 1905. Nonetheless, such laws remain a topic of contention today.[3]

The terminology of modern MSVL indicates that major emphasis is on the requirement that all children be adequately immunized before being allowed to enter school on a permanent basis. There are some exceptions to this rule. For example, statutes in North Carolina and Kentucky require that all children be immunized against diphtheria, tetanus, and polio by age 1. However, it is important to note that although some states require immunizations early in life, enforcement does not occur until entry to school – compulsory education makes it logistically convenient for schools to be the site of enforcement. Modern MSVL typically cover a number of childhood illness, including measles, mumps, rubella, diphtheria, pertussis, tetanus, and polio.[4] These diseases were chosen presumably because of their infectious nature and their health consequences. For example, while measles, mumps, rubella, and pertussis are rarely fatal on their own, they can lead to serious life-threatening consequences such as pneumonia or encephalitis. In particular, if a pregnant mother contracts rubella, the probability of still birth increases by 30 percent and the child may be born with congenital rubella syndrome, which entails a range of serious incurable illnesses. Without any complications, students who contract one of these diseases are out of school for approximately 3 weeks.

There are different levels of penalty for noncompliance across states as well. Some states consider violation of such laws as a misdemeanor, while other states impose a fine or even jail

[3] In particular, a small but heated minority have been opposing school vaccination laws in recent years because they believe that vaccinations can lead to autism.

[4] Smallpox vaccination requirements, which were the foundation of MSVL, have been discarded since the disease has been completely eradicated.

sentence for violation for the statute. The common theme across these states, however, is that MSVL require compliance from parents of children entering public, parochial, or private schools for the first time, and children who are not sufficiently immunized are barred from entering school. As mentioned in the previous section, states have incentives to enforce these rules, both because it is costly to deal with epidemics, and also because a state's receipt of federal funds depends on its enforcement of such regulations. All school immunization laws grant exemptions to children who are physician-certified to be susceptible to adverse effects from the vaccine. Virtually all states also grant religious exemptions for persons who have sincere religious beliefs in opposition to immunization; however, the percentage of parents who choose to exempt their children from vaccinations using this route is negligibly small.

The literature on the effectiveness of school immunization laws is surprisingly sparse and is concentrated entirely in the medical and epidemiological fields. The long-term consequences on human capital accumulation, in particular, have yet to be examined. While such laws are acknowledged in the medical and epidemiological fields to be effective in reducing infectious disease rates (Hinman et al., 2002; Jackson 1969; Orenstein and Hinman, 1999; Orenstein et al, 2005), their impact has never been fully investigated. Robbins et al. (1981) show a strong correlation between states with high incidences of measles and states that do not have comprehensive mandatory school immunization laws. A 1977 study by CDC demonstrated that states with compulsory school immunization laws in 1973 had a 50 per cent lower incidence of measles than those without such laws. However, these studies rely on cross-sectional data to show that states that have mandatory school vaccination laws have lower number of cases of infectious diseases, which may be problematic if the states that choose to enact vaccination laws have other attributes that lead them to have lower incidence rates. As I discuss further in Section

IV, this paper attempts to circumvent that issue by using a differences-in-differences approach with state fixed effects to control for unobservable characteristics, as well as including a host of state-year variables that could potentially affect the outcome variable.

III. Data

The empirical analysis of this paper is divided into two main portions. I first examine the impact of MSVL on contemporaneous health outcomes, measured by morbidity and mortality rates. Next, I explore whether there are long-term effects on the human capital development of the affected cohorts.

The morbidity data are from the National Notifiable Disease Surveillance System (NNDSS) database at the Center for Disease Control. The data include the number of reported cases for certain diseases from each state between the years 1960 and 1990. Unfortunately, the data are not available broken down by age group. However, since these diseases predominantly occur among school-aged children, the morbidity rates should still be representative of incidence rates of the target population. Figure 1 presents the time series graphs of the morbidity rates the six diseases that are most commonly covered under MSVL, which are measles, mumps, rubella, diphtheria, polio, and pertussis, from the years 1960 to 1990 (except for mumps, for which data are only available from 1968 onwards).[5] The vertical line on each figure depicts when the vaccine first became publicly available. As it can be seen, the morbidity rates of all six diseases were on a decline since 1960. The most striking figure is perhaps that of measles, the most endemic disease in the pre-vaccine era. After the invention of the measles vaccine in 1963, measles fell precipitously and rapidly.

[5] These numbers are recognized to be vastly underestimated. For example, before licensure of the measles vaccine, the average number of measles cases reported was in excess of 500,000, a small fraction of the estimated 4 million cases occurring annually (Bloch et al., 1985)

The mortality data are from the National Vital Statistics System (NVSS), which are available for years 1968-1988. These data contain case counts summarized by age group, state and year. To examine to impact on adult outcomes, I use the 1990 and 2000 1-percent IPUMS Integrated Public Use Series (Ruggles et al. 2004). I focus on individuals between the ages 30 to 60 as they would presumably have reached their final educational attainment. The birth cohorts are restricted to those between 1931 and 1970, which allows the use of states that passed MSVL later as control states. Table 1 reports the summary statistics of key variables.

I collect the data on the mandatory school vaccination laws based on a number of sources. First, I trace the statutes regulating school immunizations in each state. Then I determine when the state enacted or amended the statute to include measles, which I define to be the beginning of modern school vaccination era (in the sense that some states had old immunization laws regarding smallpox). I separately request the information from the department governing the statutes in each state, which is usually the state health department, for the history of the statutes. Finally, I am able to verify the introduction of these laws in each state based on newspaper articles. Unsurprisingly, given the widespread impact and consequences of such “no shots, no school” laws, they were highly publicized to ensure parents take heed to have their children fully immunized before the beginning of school in September. In most states, the enactment of MSVL included the core five diseases (measles, diphtheria, pertussis, tetanus, and polio) in the same year. In states where enactment is staggered by disease, I use the first year that the measles vaccine was required because it was the most endemic disease. Figure 2 displays the heterogeneous timing of the introduction of modern school vaccination laws. Figure 3 shows the average rate of measles in the immediate three years in the pre-vaccine invention era.

Interestingly, there does not appear to be too much of a correspondence between states that had the highest measles rates and states that enacted the laws the earliest.

IV. Identification Strategy and Results

IV.A. The Impact on Morbidity

I begin by examining the impact of MSVL on morbidity rates. If children were already fully immunized by the time they enter school, the immunization laws would not have an effect on morbidity rates. I look at the impact on the targeted communicable diseases, and I also use several diseases that vaccines were not available for, and hence not covered under MSVL, at the time as falsification checks. The dependent variables here are incidence rates of the six most commonly covered vaccine-preventable diseases under school vaccination laws, which are measles, mumps, rubella, diphtheria, polio, and pertussis. Since the distribution of the data is very much skewed to the right with some zero counts, the regressions are estimated using a Poisson specification, adjusted for population.

The identification strategy is a simple differences-in-differences approach that exploits the staggered timing of the introduction of the mandatory school vaccination laws. The density of the number of disease cases in state *s* in year *t*, d_{st}, is:

$$P(d_{st}|.) = \frac{e^{-\mu_{st}}\mu_{st}^{d_{st}}}{d_{st}!} \quad (1)$$

Where the conditional mean, $\mu_{st} = E[d_{st}|.]$, is assumed to have the following exponential form,

$$\mu_{st} = p_{st}\exp\{\alpha_0 + \alpha_1 MSVL_{st} + X_{st}\alpha_2 + \gamma_s + \delta_t\} \quad (2)$$

The exposure variable, p_{st}, is the population of state *s* in year *t*, $MSVL_{st}$ is a dummy variable indicating whether state *i* has begun mandating proof of immunizations for the particular disease for children entering school for the first time by year *t*, and X_{st} is a row vector of state-year characteristics including the percentage of state population under the poverty line, inflation-adjusted disposable income per capita, unemployment rate. γ_s and δ_t are the state and year fixed effects, respectively.

The estimates of α_1 for the six most targeted diseases are reported in the top panel of Table 2.[6] Robust standard errors clustered by state are reported. There is a large and statistically significant reduction of 45 percent reduction in measles due to the vaccination laws, and the estimate is statistically significant at the 1 percent level. From the invention of the measles vaccine in 1963 to 1990, measles fell by approximately 99 percent. The school vaccination laws can therefore account for close to half of that drop. There is smaller reduction in mumps of around 17 percent, which account for approximately the same percent of the overall reduction in mumps. MSVL also led to a decrease in rubella of 33 percent, and a decrease in pertussis by 38 percent. There is an insignificant drop in diphtheria and polio. This may be because the voluntary uptake of polio vaccine was much more dramatic given its fatal consequences (XXX). Further, diphtheria, while once fatal, was already greatly controlled with the invention of sulfa drugs earlier in the century. By the time MSVL were enacted, both polio and diphtheria had already dropped to very low levels. These results are also consistent with Ward (2011), who shows that immunization laws had a large negative impact on MMR incidence rates.

As a falsification test, I also include several diseases that were not covered under the mandatory school vaccination laws during the period of interest. If states that enacted MSVL were concurrently increasing efforts towards child health or improving school environments, then the reduction in the targeted diseases could be a reflection of those efforts rather than the enactment of vaccination laws. If that were the case, we should expect to see a drop in other communicable diseases as well. I therefore use several other contagious diseases that were not

[6] I am currently working with the CDC to obtain data for tetanus and data regarding the other diseases that extend further back in time.

covered under vaccination laws because they were not yet available at the time. For example, meningitis is a communicable bacterial disease that affects school-age children but the vaccine for meningitis was not available until the 1980s.[7] Similarly, hepatitis B and salmonella are infectious diseases that were not covered under the laws. In the bottom panel of Table 2, we can see that MSVL basically had no effect on the three control diseases. Overall, the results imply that the vaccination laws were successful in reducing morbidity rates of the targeted diseases, especially in measles.

IV.B. The Impact on Mortality

Next, I briefly examine the impact of vaccination laws on disease mortality rates, using the same empirical strategy as the previous section. Mortality data are available only from 1968 - 1988. By the late-60s, mortality due to most of these childhood diseases had been reduced to close to zero already. Measles, mumps, rubella, and pertussis are not usually fatal for school-aged children, so even before vaccines for those diseases were invented, mortality rates due to these diseases were very low. Also, the uptake for the polio vaccine was rapid and the fatal nature of diphtheria was already much ameliorated with the invention of sulfa drugs. Among the six targeted diseases, the only disease that would be meaningful to study within the timeframe (and for which data are available) is measles, where the mean incidence rate for 5-14 year olds was 0.11 per 100,000 over the entire sample period (1968-1988), and 0.25 from 1968-1970. (The incidence rates for the other targeted diseases are under 0.05) Again, I choose several other communicable diseases which were not covered under the immunization laws to perform falsification checks. Since the mortality data are broken down by age group as well, I am able to use 25-34 year olds as a second control group. Presumably any action caused by the mandatory

[7] Varicella (Chickenpox) would have made an excellent falsification test as it is a common childhood disease but the vaccine was not invented until the 1990s. Unfortunately the CDC did not collect the state-year counts for varicella until the 1980s.

vaccination laws should be concentrated among school-aged children, although there could be some positive spillover effects on adults who live in the same household. As Table 3 depicts, there was a negative effect on the mortality rate of measles, for the 5-14 cohort, but not the 25-34 cohort (although the two estimates are not statistically different from one another). There are no discernible impacts on the mortality rates of hepatitis, chickenpox, or meningitis, for either cohort. The mean rates of these three diseases (per 100,000) 5-14 year olds are 0.42, 0.74, and 1.36, respectively. The results provide suggestive evidence that school vaccination laws helped reduce measles mortality rates among school-aged children. Nonetheless, the main impact of the laws was to reduce morbidity rather than mortality rates.

IV.C. The Impact on Adult Education

Finally, I turn my attention to adult educational attainment. There are several channels through which educational attainment would be affected. First, innate productivity could have been affected. As discussed in Section II, infectious diseases can lead to dangerous complications with long-term negative consequences such as permanent brain damage, behavioral changes, mental retardation, or deafness (such complications arise in roughly 1/1000 cases). The adverse effects of the diseases are more severe in persons with compromised immune systems, such as in malnourished children. As seen in Section IV.A, MSVL led to much lower morbidity rates and presumably healthier, more productive children. Second, MSVL could increase the returns to educational investment, for example, a relatively disease-free school environment could lead to students learning better. Further, students who contract any one of these diseases are usually out of school for 3 weeks. So a student who contracts 3 diseases during his or her time in school would be out of school for more than 2 months, which could plausibly have long-term negative consequences on educational attainment. Third, one can imagine a model where parents have a fixed amount of resources, divided between their own consumption and human capital investments in the child. MSVL effectively reduces the price of investment, and could potentially increase the parents' investment in the child's human capital.

The estimating equation for examining adult educational attainment is:

$$S_{ijby} = \alpha_j + \delta_b + \gamma_y + \beta MSVL_{jb} + X_{ijb}\theta + Z_{jb}\rho + \varepsilon_{ijby} \quad (3)$$

where S_{ijby} is the adult educational attainment measure for individual i in state j belonging to year of birth cohort b, observed in Census year y. $MSVL_{jb}$ is a dummy variable indicating whether the individual belongs to the treated cohort b in state of birth j, i.e, $MSVL_{jb}$ equals unity indicates dummy indicating whether MSVL were implemented in state of birth j by the time the individual belonging to birth year cohort b turned 5. β is then the coefficient of interest – it assesses whether MSVL causes a deviation from a state's mean of educational attainment relative to other states where such laws have yet to be implemented. α_j and δ_b are the state of birth and birth cohort fixed effects. γ_y represents Census year fixed effects. Since I am identifying the final completed years of education, the sample consists of individuals of ages 25-60. For the same reason, I include only two (time-invariant) individual characteristics in X_{ijbr}– gender and race. While all states that had compulsory immunization laws for first time school entrants, some states had different requirements for the rest of the school population. As such I omit those who were between ages 6 and 12 in the year of enactment since the impact on these cohorts may not be clear-cut. Z_{jb} includes a set of state-specific demographic, economic, and education controls associated with the birth cohort at age 5, including the inflation-adjusted disposable income per capita, unemployment rate, pupil-staff ratio, inflation-adjusted teacher salaries and inflation-adjusted expenditure per pupil in public secondary schools.[8] ε_{ijby} is the usual error term.

Table 4 summarizes the results. I first use the number of years of completed schooling as the dependent variable. Column 1 reports the estimate on *MSVL* with only the fixed effects and no additional controls. Column 2 adds on the state-year and individual gender and race controls. A binary variable denoting whether the individual completed high school is used as the dependent variable in Columns 3 and 4. The results suggest a consistent story – MSVL increased educational attainment by approximately 0.10 years, and increased the probability of high school completion by around 1.8 percentage points. This seems to be a sizeable but not unreasonable effect when compared to other large-scale education programs. For example, Acemoglu and Angrist (2000) find using the 1950-1980 Censuses that "men born in states with a child labor law that required 9 years in school before allowing work ended up with 0.26 more years of school completed than those born in states that required 6 or fewer years." Hinrich (2010) shows that increased exposure to the National School Lunch Program increased educational attainment of 0.36 for females and close to a year of males. Field, Robles and Torero find a large effect of in utero iodine on treated children, who attain an estimated 0.35 – 0.56 years of additional schooling.

IV.D. Heterogeneous Impact by Race

According to the U.S. Immunization Survey, which was conducted by CDC in cooperation with the Bureau of the Census from 1965 and 1985, immunization levels were consistently lower among poverty and minority groups (CDC 1977, Orenstein et al. 1978). It would be instructive to

[8] Most of the education data were kindly shared by Card and Krueger (1992). The rest were obtained from *Historical Trends: State Education Facts, 1969 to 1989*, published by the National Center for Education Statistics (NCES), and the rest were from various years of the *Digest of Education Statistics*, also published by NCES. Data from a few missing years are linearly interpolated.

examine whether there are heterogeneous effects of mandatory school vaccination laws by race. If non-minority parents were already vaccinating their children before compulsory school attendance, then it is conceivable that mandatory school vaccination laws benefit students from minority backgrounds more. The results in Table 5 confirm this hypothesis, where I include an interaction term of *MSVL* and a dummy for *Non-white*, as well as fixed effects for race. The results imply that the vaccination laws had roughly twice as large an impact on non-whites than whites in terms of educational attainment.

IV.E. The Impact on Labor Market Outcomes

The final set of dependent variables I investigate includes adult labor force participation, hours, wages and occupational standing measures. There are two potential channels through which MSVL could impact adult wages. First, MSVL could have increased innate productivity of the affected cohorts through improving childhood health, which may in turn be reflected in higher wages. Second, MSVL increased educational attainment, which could also increase adult wages through a human capital model.

The results are reported in Table 6 and 7. I first explore the impact of MSVL on labor market participation. The results in Columns 1 and 2 of Table 6 imply that on average, MSVL increased labor force participation, although that effect is primarily reflected in the white population.[9] Both the reported number of weeks worked last year and the usual hours of work worked per week last year increased by approximately by 0.5. It appears that overall, MSVL increased labor force participation on both the extensive and intensive margins. The effect on non-whites is less clear: the impact on labor force participation is close to zero. And although the sign on the estimate of MSVL on weeks worked for non-whites is positive, it is not statistically significant. However, MSVL did lead to the usual number of hours worked to increase for non-whites by 0.77 hours, an estimate which is statistically significant at 1 percent.

[9] I estimate this as a linear probability model. Using a Probit model gives similar results.

Next, I explore the impact of MSVL on wages and occupational standing measures (Table 7). Because there are a fair amount of zeros reported in the income measure, I use a Tobit specification left-censored at zero for estimation purposes.[10] I calculate weekly wages based on the reported number of weeks worked and the total wage and salary income annual income in the previous year. Hourly wages are the constructed weekly wages divided by the reported number of hours per week that the respondent usually worked in the previous year. The results in Table 7 imply that on average, the school vaccination laws increased weekly wages by around 5 percent and hourly wages by 3 percent.[11] The impact for non-whites is approximately twice as large. The impact is also reflected in measures of occupational standing – the coefficient of MSVL on the occupational income score is 0.26 (a 1 percent increase), while that on the Duncan socioeconomic index by 0.57 (a 1.4 percent). The increase in wages is more than what the standard (10-percent) returns to education estimate would predict. Taken at face value, the results imply that school vaccination laws increased not only educational attainment, but also the returns to education.

V. Robustness Checks

The primary threat to the identification strategy is that states that implement MSVL may also implement other practices that could potentially affect educational attainment. Although I control for educational inputs in the full specification of the education regressions, they may not fully capture concurrent programs that could lead to spurious results. In this section I present several robustness checks to confirm the validity of the results on educational attainment.

The first test I implement exploits the degree of penalty for violating MSVL. As discussed in Section II, states uniformly bar children who cannot show proof of immunizations from entering school. However, on top of that, there are also varying levels of penalties ranging

[10] These are true zeros in the sense that the individual did not report an occupation, reported zero weeks of work as well as zero annual income wages. I replace the log wages variables with zeros for these individuals.
[11] The estimates from using an OLS model and not replacing the log values with zeros for the individuals who did not work are very close to zero, which implies the impact may have been more on the intensive margin.

from monetary fines to threat of a criminal offense across states. If MSVL were the driving force behind the gain in education, we should expect to see states that have stricter laws gain more in education. Table 8 confirms this. I divide the gradient of penalty into three categories –no fines, monetary fines, and monetary fines and misdemeanor charges (which could include jail time). Using no fines as the base category, I include interaction terms of MSVL with the other two categories. As it can be seen, the degree of penalty matters. As the penalty for violating MSVL increases, the magnitude of the effect of MSVL becomes larger.

The second robustness check utilizes the evolution of the coverage of diseases by state. In Section IV, I simply use the first year the measles vaccine became mandatory as a condition for school entrance, since measles was the disease most affected by the laws. In more than half the cases, this is also the same year the rest of the diseases became required. However, other states which implemented immunization requirements in different years. For example, New York began mandating vaccinations for polio in 1967, measles in 1969, rubella in 1970, diphtheria, pertussis, and tetanus in 1972, and mumps in 1977. The intuition behind this test is that if MSVL were the reason for the change in educational attainment, we may expect higher disease coverage to lead to larger gains in schooling. I exploit the within- and across- state variation in the number of diseases covered under MSVL to examine this. In the first two columns of Table 8, the independent variable of interest is the count of diseases that vaccinations are required for under MSVL associated with the birth cohort at age 5. (As an example, for individuals born in New York, the number of diseases variable is 0 for cohorts born before 1963, 1 for cohorts born between 1963 and 1964, 2 for cohorts born between 1965 and 1966, 6 for cohorts born after 1967, and 7 for cohorts born after 1972.) The coefficients imply as the number of diseases covered under MSVL increases by one, the years of schooling increases by 0.015, and the probability of high school graduation by 0.27 percentage points. However, one may be concerned that the number of diseases may not affect schooling linearly. In Columns 3 and 4 of Table 8, I include fixed effects for the number of diseases covered instead (where the omitted category is no diseases covered). It appears the critical number of diseases to affect educational outcomes is five. In almost all states, the first five diseases for which immunizations become mandatory are polio, diphtheria, pertussis, tetanus, and measles. Both exercises provide supporting evidence that MSVL were indeed the driving mechanism behind the change in educational attainment.

VI. Conclusion

The relationship between health and human capital is one that has received much interest from labor economists in recent years. This paper sheds light on how childhood morbidity affects adult educational attainment. While the main impact on health likely rest on the invention of the vaccines, the staggered timing of the enactment of MSVL enables a more in-depth analysis of both the short-run impact on morbidity and long-term effects on adult educational attainment. The results suggest that compulsory school vaccination laws deserve their position among the roster of large-scale health interventions in the last century. The laws led to both a significant decline in morbidity rates of the covered diseases, and a sizeable increase in educational attainment. The next step is to perform a cost-benefit analysis. However, all signs point to school vaccination laws being very cost-effective, especially when taking into account the long-run benefits on education.

References

Almond, Douglas. 2006. "Is the 1918 Influenza Pandemic Over ? Long-term Effects of In Utero Influenza Exposure in the Post-1940 U . S . Population." *Journal of Political Economy* 114 (4): 672-712.

Almond, Douglas, and Janet Currie. 2010. "Human Capital Development before Age Five." *Handbook of Labor Economics* 4B (November 2009): 1315-1486.

Bleakley, Hoyt. 2007. "Disease and Development: Evidence from Hookworm Eradication in the American South." *Quarterly Journal of Economics* 122 (1): 73-117.

Bloch, Alan B, Walter A Orenstein, Harrison C Stetler, Steven G Wassilak, W Robert, Kenneth J Bart, Cecil D Kirby, et al. 1985. "Health Impact of Measles Vaccination in the United States." *Pediatrics* 76 (4): 524-532.

Center for Disease Control: Measles Surveillance Report No. 9, 1972. Atlanta: CDC, Issued August 1973.

Center for Disease Control and Prevention. 1977. "Measles – United States." *Morbidity and Mortality Weekly Report* 26:101-109.

Center for Disease Control and Prevention. 1978. "Measles and School Immunization Requirements – United States." Morbidity and Mortality Weekly Report 27: 303-4.

Chay, KY, and Jonathan Guryan. 2009. "Birth cohort and the black-white achievement gap: The roles of access and health soon after birth." *NBER Working Paper 15078*.

Cutler, David, and Adriana Lleras-muney. 2010. "Understanding Differences in Health Behaviors by Education." *Journal of Health Economics* 29 (1): 1-28.

Field, Erica, Omar Robles, and Maximo Torero. 2009. "Iodine Deficiency and Schooling Attainment in Tanzania." *American Economic Journal Applied Economics* 1 (4): 140-169.

Gee, L., Sowell, R. F. Jr. 1975. "A School Immunization Law is Successful in Texas." *Public Health Report* 90: 21-24.

Hinrichs, Peter. 2010. "The Effects of the National School Lunch Program on Education and Health." *Journal of Policy Analysis and Management* 29 (3) (January): 479-505.

Jackson, C L. 1969. "State Laws on Compulsory Immunization in the United States." *Public health reports* 84 (9) (September): 787-95.

Middaugh, J P and Zyla, L D. 1978. "Enforcement of School Immunization Law in Alaska." *Journal of the American Medical Association* 239: 2128-2130.

Miguel, Edward, and Michael Kremer. 2004. “Worms: Identifying Impacts on Education and Health in the Presence of Treatment Externalities.” *Econometrica* 72 (1): 159-217.

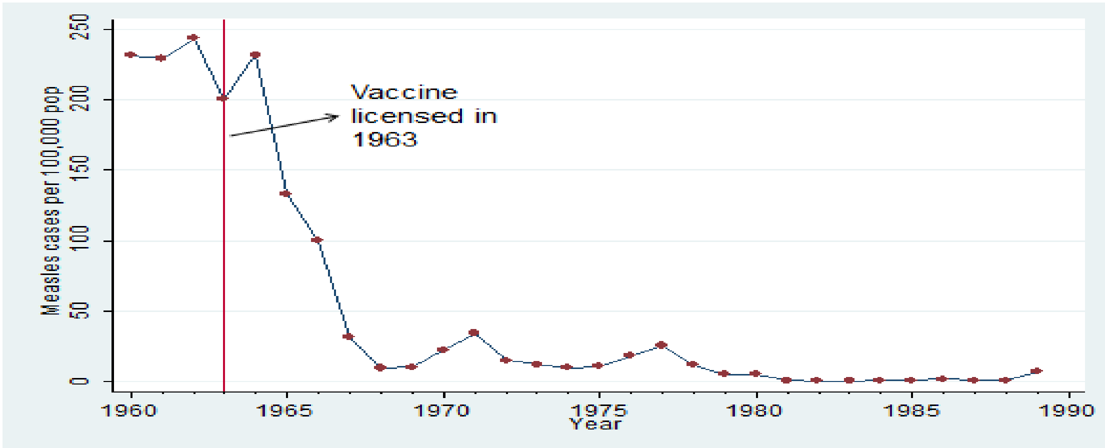
Orenstein, W a, and a R Hinman. 1999. “The Immunization System in the United States - the Role of School Immunization Laws.” *Vaccine* 17 Suppl 3 (October 29): S19-24.

Orenstein, Walter A, Neal A Halsey, Gregory F Hayden, Donald L Eddins, J Lyle, John J Witte, John F Modlin, Stephen R Preblud, Phillip I Nieburg, and R Alan. 1978. “Current Status of Measles in the United States, 1973-1977.” *The Journal of Infectious Diseases* 137 (6): 847-853.

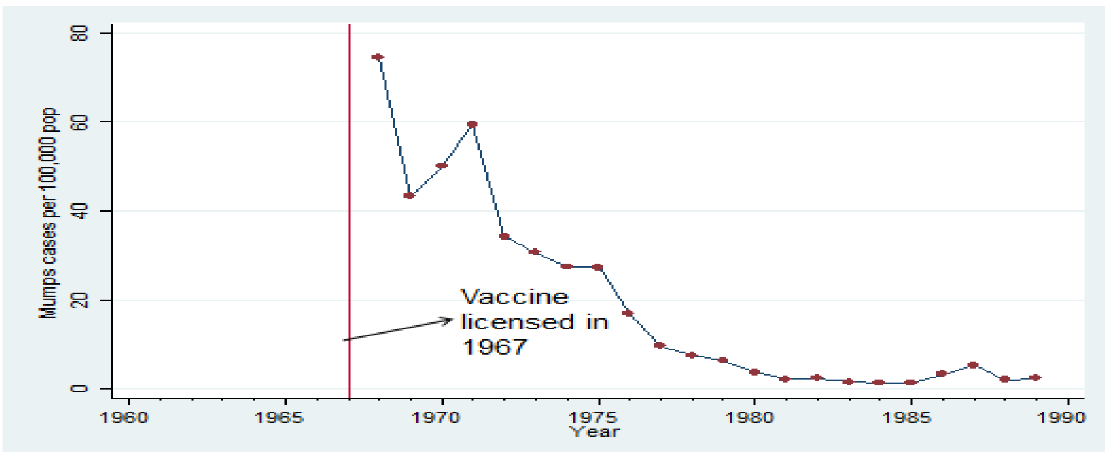
Ward, Courtney. 2011. “The Long-Term Economic Effects of School Immunization Mandates: Does Prenatal Exposure to State School Immunization Policy Impact Health and Well-Being in Later Life?” Dalhousie University Department of Economics Working Paper.

Figure 1 – Morbidity Rates of Communicable Diseases Covered by Mandatory School Vaccination Laws, 1960-1990

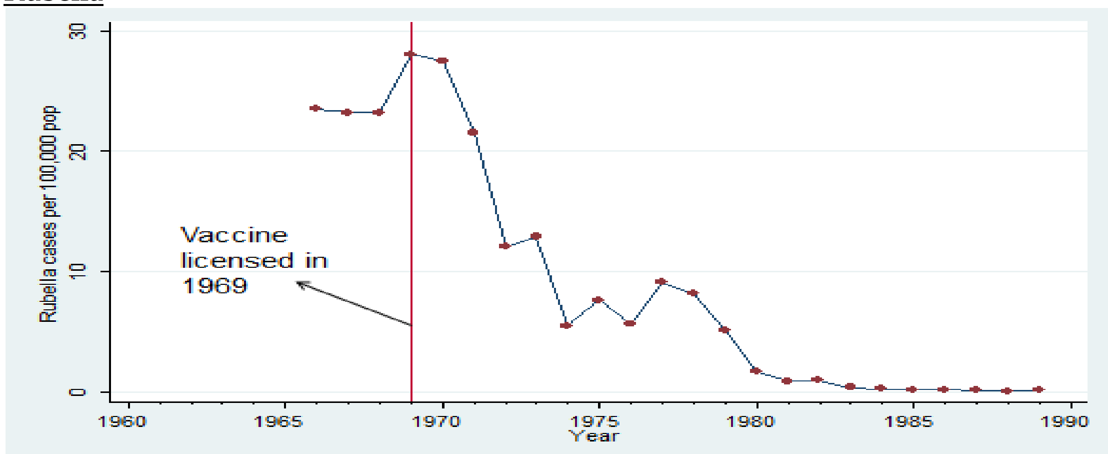
Measles



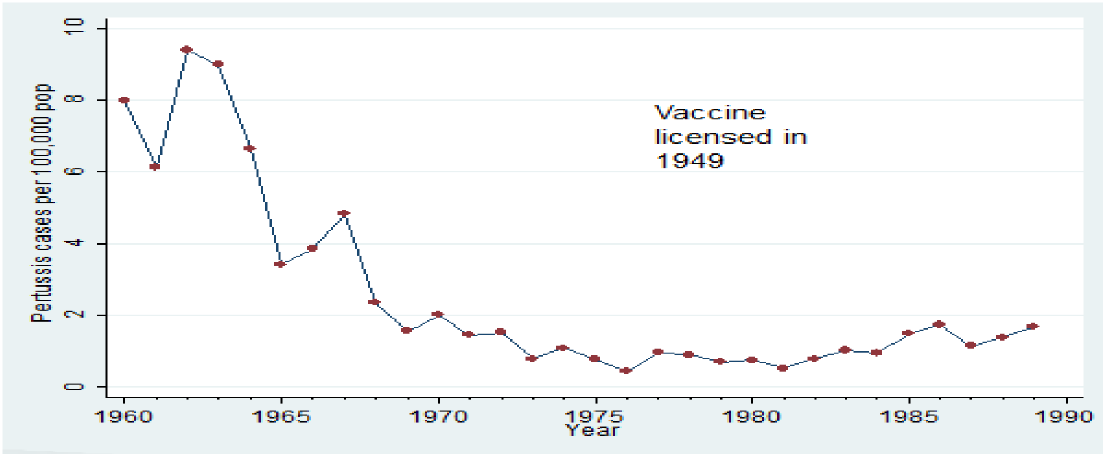
Mumps



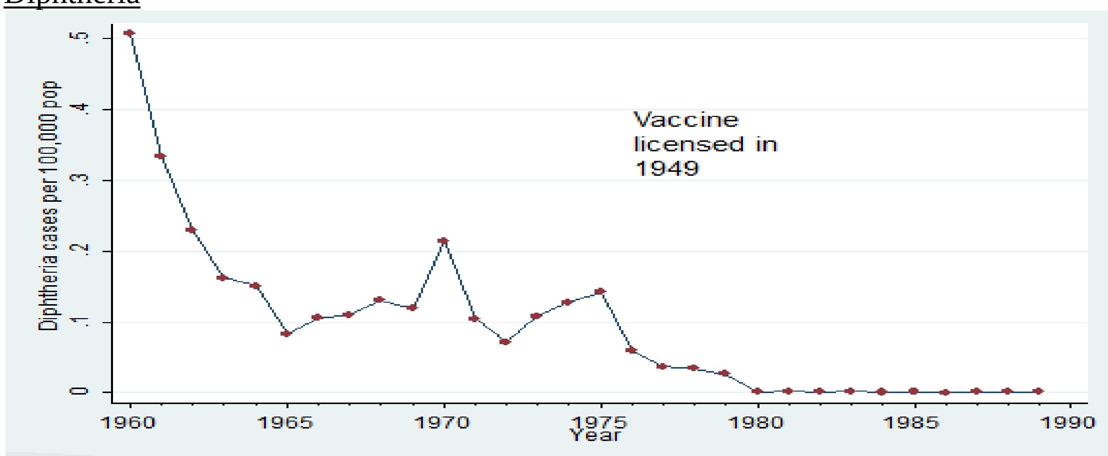
Rubella



Pertussis



Diphtheria



Polio

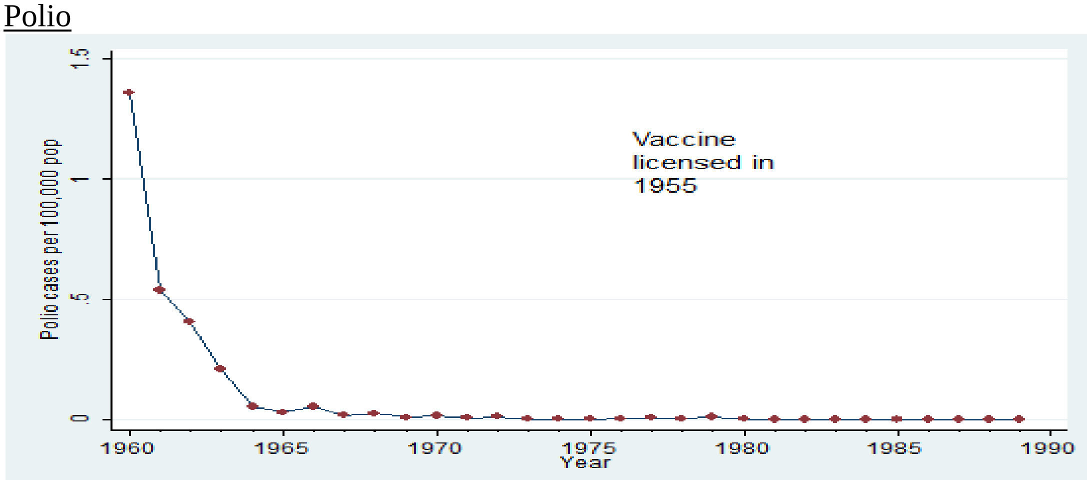


Figure 2 – Timing of Mandatory School Vaccination Laws

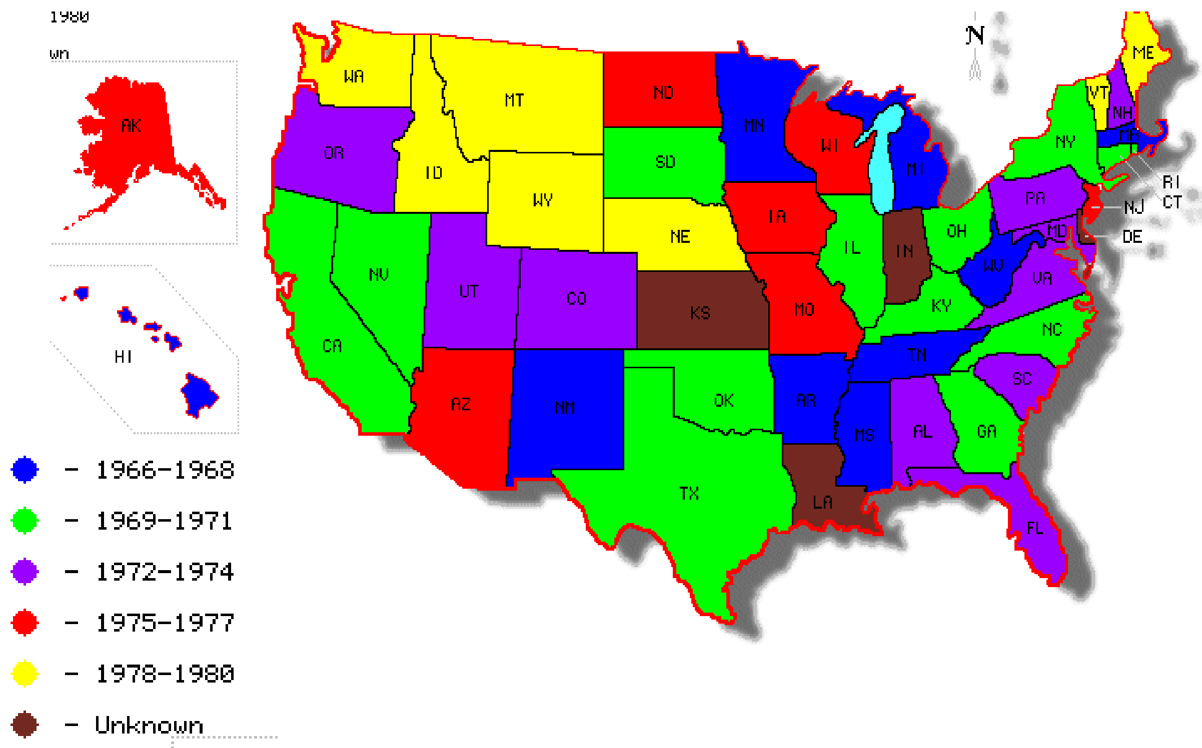


Figure 3 – Pre-vaccine Measles Rate by Percentile

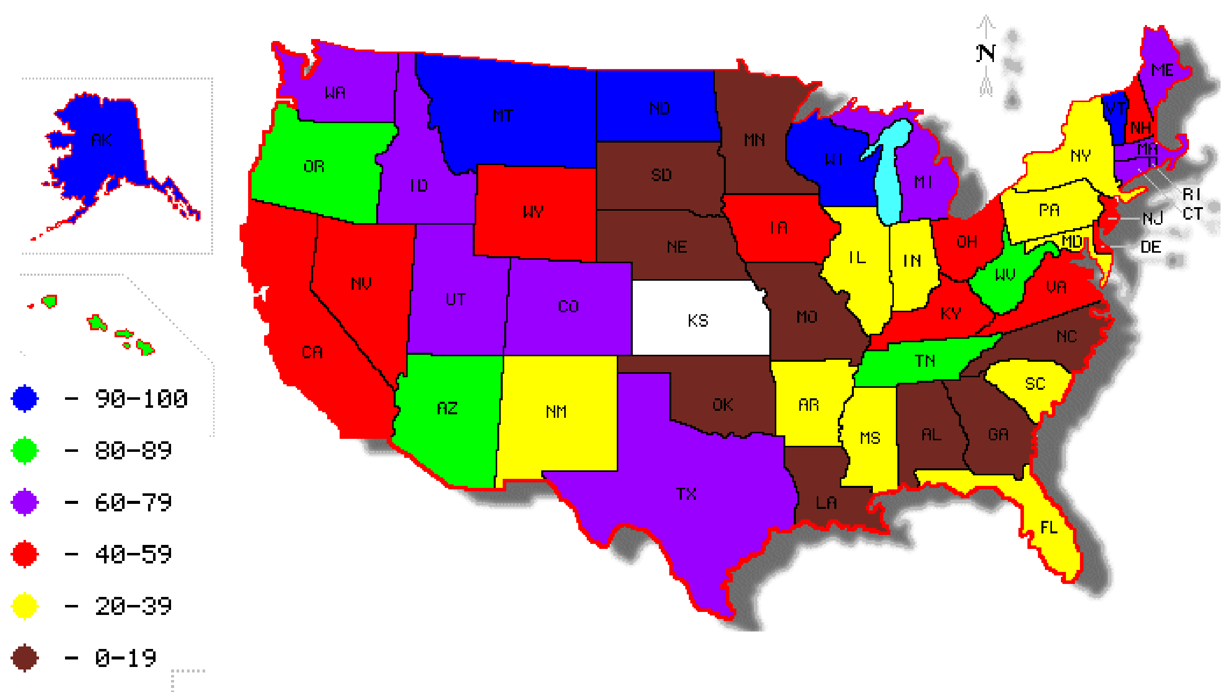


Table 1 – Summary Statistics

Panel A - Morbidity Rates, 1960-1990	Mean	St.Dev.
Measles	67.70	152.91
Mumps	24.64	49.19
Rubella	11.92	22.70
Pertussis	3.27	6.15
Diphtheria	0.12	0.44
Polio	0.10	0.45
Hepatitis B	6.14	5.32
Meningitis	2.80	3.27
Salmonella	13.03	11.08

Rates are calculated as the number of cases per 100,000 population.

Panel B - Educational Attainment, Cohorts born between 1931 and 1970	Mean	St.Dev.
Years of completed schooling	13.46	2.50
High School Completion	0.86	0.34
Weekly Wages	633.38	1138.55
Occupational Income Score	25.52	12.49
Duncan Socioeconomic Index	40.62	25.98
Non-white	0.10	0.31

Table 2 – Short-Run Effects: The Impact of Mandatory School Vaccination Laws on Morbidity

	Diseases covered under MSVL					
	Measles	Mumps	Rubella	Pertussis	Diphtheria	Polio
MSVL	-0.448***	-0.174**	-0.329**	-0.385**	-0.084	-0.236
	(0.164)	(0.088)	(0.176)	(0.182)	(0.061)	(0.380)
Obs	1416	1014	1013	1409	1486	1486

	Diseases not covered under MSVL		
	HepB	Meningitis	Salmonella
MSVL	-0.076	-0.064	-0.012
	(0.126)	(0.107)	(0.086)
Obs	1164	1307	1483

- Regressions are estimated using a Poisson specification with population as the exposure variable
- Standard errors presented in parentheses are clustered by state
- All regressions include state and year fixed effects, as well as state-specific controls for the percentage of state population under the poverty line, inflation-adjusted disposable income per capita, and unemployment rate

Table 3 – Short-Run Effects: The Impact of of Mandatory School Vaccination Laws on Mortality

5-14 y.o.s	Measles	Hepatitis	Chickenpox	Meningitis
MSVL	-0.730*	0.043	0.045	0.025
	(0.402)	(0.291)	(0.173)	(0.160)
25-34 y.o.s	Measles	Hepatitis	Chickenpox	Meningitis
MSVL	-0.626	0.169	-0.144	-0.038
	(1.179)	(0.295)	(0.611)	(0.134)

- Log Rates are estimated using a Poisson specification with population of the age group as the exposure variable
- Standard errors presented in parentheses are clustered by state
- All regressions include state and year fixed effects, as well as state-specific controls for the percentage of state population under the poverty line, inflation-adjusted disposable income per capita, and unemployment rate.

5-14 y.o.s	Measles	Hepatitis	Chickenpox	Meningitis
Vaccination Law	-0.730* (0.402)	0.043 (0.291)	0.045 (0.173)	0.025 (0.160)

25-34 y.o.s	Measles	Hepatitis	Chickenpox	Meningitis
Vaccination Law	-0.626 (1.179)	0.169 (0.295)	-0.144 (0.611)	-0.038 (0.134)

Log Rates are estimated using a Poisson specification with population of the age group as the exposure variable

Standard errors clustered by state

Table 4 – Long-Run Effects: The Impact of Mandatory School Vaccination Laws on Educational Attainment

	Years of Schooling		High School Completion	
MSVL	0.1031** (0.0581)	0.1036*** (0.0412)	0.0186** (0.0076)	0.0181*** (0.0065)
State of Birth FE	x	x	x	x
Year of Birth FE	x	x	x	x
Controls		x		x
Obs	1,600,622	1,600,622	1,600,622	1,600,622

- Standard errors presented in parentheses are clustered by state of birth.
- MSVL = 1 if law passed before age of 5 in state of birth. 5-12 y.o.s in year of enactment omitted from sample.
- Controls include the inflation-adjusted disposable income per capita, unemployment rate, pupil-staff ratio, inflation-adjusted teacher salaries and inflation-adjusted expenditure per pupil in public secondary schools associated with the birth cohort at age 5

Table 5 – Long-Run Effects: Heterogeneous Impact of Mandatory School Vaccination Laws on Adult Educational Attainment, by Race

	Years of Schooling	High School Completion
MSVL	0.0996** (0.0432)	0.0133*** (0.0066)
Non-white * MSVL	0.1308** (0.0589)	0.0438*** (0.0134)

- Standard errors presented in parentheses are clustered by state of birth.
- MSVL = 1 if law passed before age of 5 in state of birth. 5-12 y.o.s in year of enactment omitted from sample.
- All regressions include fixed effects for race, year of birth, state of birth, and Census year.
- Controls include the inflation-adjusted disposable income per capita, unemployment rate, pupil-staff ratio, inflation-adjusted teacher salaries and inflation-adjusted expenditure per pupil in public secondary schools associated with the birth cohort at

Table 6 – Long-Run Effects: The Impact of Mandatory School Vaccination Laws on Labor Force Participation

	Labor Force Participation		Weeks Worked		Usual Hours worked Per Week	
MSVL	0.0115** (0.0052)	0.0129** (0.0053)	0.4788*** (0.1857)	0.5298** (0.2098)	0.5158*** (0.1661)	0.4267*** (0.1680)
Non-white * MSVL		-0.0089* (0.0052)		-0.3255 (0.2759)		0.3468 (0.2139)
Effect of MSVL for Non-whites		0.0041 (0.0071)		0.2043 (0.3074)		0.7735*** (0.2405)

- Standard errors presented in parentheses are clustered by state of birth.
- All regressions include fixed effects for race, year of birth, state of birth, and Census year.
- MSVL = 1 if law passed before age of 5 in state of birth. 5-12 y.o.s in year of enactment omitted from sample.
- Controls include the inflation-adjusted disposable income per capita, unemployment rate, pupil-staff ratio, inflation-adjusted teacher salaries and inflation-adjusted expenditure per pupil in public secondary schools associated with the birth cohort at age 5.

Table 7 – Long-Run Effects: The Impact of Mandatory School Vaccination Laws on Wages and Occupational Standing Measures

	Tobit			
	Log Weekly Wages		Log Hourly Wage	
	(1)	(2)	(3)	(4)
MSVL	0.0533**	0.0674**	0.0321**	0.0273*
	(0.0240)	(0.0332)	(0.0154)	(0.0149)
Non-white * MSVL		0.0480		0.0214
		(0.0351)		(0.0165)
Effect of MSVL for Non-whites		0.1154***		0.0487**
		(0.0448)		(0.0206)

	OLS			
	Occupational Income Score		Socioeconomic Index	
	(5)	(6)	(7)	(8)
MSVL	0.2630***	0.2720**	0.5717**	0.5835**
	(0.0980)	(0.1245)	(0.2914)	(0.2965)
Non-white * MSVL		0.7785***		2.5120***
		(0.1558)		(0.3978)
Effect of MSVL for Non-whites		1.0505***		3.0955***
		(0.1719)		(0.4290)

- Standard errors presented in parentheses are clustered by state of birth.
- All regressions include fixed effects for race, year of birth, state of birth, and Census year.
- MSVL = 1 if law passed before age of 5 in state of birth. 5-12 y.o.s in year of enactment omitted from sample.
- Controls include the inflation-adjusted disposable income per capita, unemployment rate, pupil-staff ratio, inflation-adjusted teacher salaries and inflation-adjusted expenditure per pupil in public secondary schools associated with the birth cohort at age 5.

Table 8 – Robustness Check: Effect of Mandatory School Vaccination Laws on Educational Attainment, by Degree of Penalty

	Years of Schooling	High School Completion
MSVL	0.0367	0.0063
	(0.0562)	(0.0071)
MSVL * fine	0.1713**	0.0286**
	(0.1084)	(0.0140)
MSVL * (fine + misdemeanor charge)	0.3640***	0.0563***
	(0.0764)	(0.0127)
State of Birth FE	x	x
Year of Birth FE	x	x
Controls	x	x
Obs	1,600,622	1,600,622

- Standard errors presented in parentheses are clustered by state of birth.
- MSVL = 1 if law passed before age of 5 in state of birth. 5-12 y.o.s in year of enactment omitted from sample.
- Fine indicates the penalty for failing to comply with MSVL in that state is a monetary fine. (Fine + misdemeanor) indicates the penalty for failing to comply with MSVL in that state is a monetary fine and a misdemeanor charge which can result in jailtime.
- Controls include the inflation-adjusted disposable income per capita, unemployment rate, pupil-staff ratio, inflation-adjusted teacher salaries and inflation-adjusted expenditure per pupil in public secondary schools associated with the birth cohort at age 5

Table 9 – Robustness Check: Effect of Mandatory School Vaccination Laws on Educational Attainment, by Degree of Disease Coverage

	Years of Schooling	High School Completion	Years of Schooling	High School Completion
Number of Diseases Covered	0.0153*	0.0027**		
	(0.0085)	(0.0013)		
One disease covered			-0.0531	-0.0098
			(0.0899)	(0.0098)
Two diseases covered			-0.0170	-0.0016
			(0.0759)	(0.0063)
Three diseases covered			-0.0501	-0.0081
			(0.0624)	(0.0085)
Four diseases covered			-0.1005	-0.0121
			(0.0810)	(0.0099)
Five diseases covered			0.1911**	0.0248**
			(0.0850)	(0.0154)
Six diseases covered			0.1087*	0.0184*
			(0.0628)	(0.0102)
Seven diseases covered			0.0852*	0.0170**
			(0.0454)	(0.0084)
State of Birth FE	x	x	x	x
Year of Birth FE	x	x	x	x
Controls	x	x	x	x
Obs	1,600,622	1,600,622	1,600,622	1,600,622

- Standard errors presented in parentheses are clustered by state of birth.
- Number of diseases covered represent the number of diseases vaccinations are required for entering school before age of 5 in state of birth
- x diseases covered = 1 if law passed before age of 5 in state of birth and law mandates vaccinations for x number of diseases.
- Controls include the inflation-adjusted disposable income per capita, unemployment rate, pupil-staff ratio, inflation-adjusted teacher salaries and inflation-adjusted expenditure per pupil in public secondary schools associated with the birth cohort at age 5