The Impact of Childhood Health on Adult Educational Attainment: Evidence from Mandatory School Vaccination Laws

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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 effective in reducing the incidence rates of the targeted diseases. Next, I find sizable and positive effects on educational outcomes as measured by high school completion and years of schooling. The effect on educational attainment is twice as large for non-whites relative to whites.

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I. Introduction

Childhood health, measured as early as age seven, can explain a substantial amount of variation in adult health and human capital outcomes (Blackwell, Hayward, and Crimmins 2001; Case, Fertig, and Paxson 2005; Heckman 2007). As such, economists in recent years have directed much effort towards examining whether the positive correlation between childhood health and subsequent human capital development is causal or borne due to omitted variable biases (Cunha and Heckman 2007; Almond and Currie 2009). 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. The relative dearth of papers on the effects of early childhood health is not due to lack of interest or relevance, but stems in part from the difficulty in identifying plausible "natural experiments" that specifically affect health during early childhood.[2] However, it is important to understand the long-run consequences of early childhood health. Since mortality is much lower during early childhood than in utero or neonatal stages, post-neonatal settings provide an opportunity to investigate the long-run consequences of childhood morbidity. Lower mortality also implies less of a selective attrition problem to affect the composition of survivors (Almond and Currie 2009). In addition, it would be instructive for

[1] Refer to Almond and Currie (2009) for a comprehensive summary of recent findings in the "fetal origins" literature.

[2] In particular, it may not appropriate to examine the effects of post-neonatal child health using the types of quasi-natural experiments used in investigating the long run effects of in-utero environments – which have ranged from exploiting exposure to the 1918 Influenza Pandemic (Almond 2006) to the China famine (Almond et al. 2007). For example, it is difficult to convincingly argue that exposure to famine, once past the exclusive in-utero environment, can be interpreted as a health shock since the child is exposed to many more "moving parts" of her family and society, which in turn may also be affected by famine. One way to tackle this problem is by examining targeted health interventions, such as Bleakley (2008) and Cutler et al. (2011), in which case the challenge becomes finding one with sufficient scale and exogenous variation. Another approach is to conduct randomized experiments, which is usually more feasible in developing countries and necessitates considerable time when trying to examine long-run outcomes, as in Baird et al. (2012).

policy makers to know whether childhood health interventions are as effective as those that occur in earlier stages of life.

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 a unique setting to shed new insight on the question in two ways. First, MSVL cover highly infectious diseases that 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 childhood health interventions that have been studied.[3] I provide suggestive evidence that the timing of MSVL was not driven by disease rates or education policies, and argue that the introduction of MSVL can be interpreted as largely exogenous.

The widespread implementation of MSVL can be explained as a confluence of two main factors. First, few measures in preventive medicine can compare with the impact of vaccines. The success rate of vaccines in providing immunity is high; for example, the effective rate of measles vaccination is estimated to be between 95%-99% (CDC 1977). As a result, 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 U.S., formerly fatal diseases such as polio and diphtheria have now been completely eradicated, and rates of once-universal infectious diseases such as measles and pertussis have dropped by close to 100 percent. Second, with children between ages 5 to 19 being the predominant group affected by such infectious diseases

[3] Bleakley (2008) demonstrate that hookworm eradication in the South increased school attendance, enrollment and literacy. Relatedly, Baird et al (2012) follows up the long-run effects of a randomized deworming experiment in Kenya and find that deworming substantially improved subsequent labor market outcomes. I discuss these papers further in Section V.

– more than 80 percent of measles cases occurred within this age group in 1973 (Orenstein and Hinman 1999) – schools are undoubtedly natural sites for widespread transmission of infectious diseases because of the close contact students have with each other. Soon after the invention of the polio and measles vaccines, states began to require proof of immunizations for children entering school for the first time in order to combat the risk of outbreaks 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 vaccine uptake was very much state-dependent, i.e., 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; Philipson 2000). 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. Children who cannot show proof of vaccination are banned from entering school, leading to the still prevalent saying of "no shots, no school"; in other words, compulsory schooling laws also increased the "bite" of MSVL. For states where

school absenteeism counts towards reimbursement aid, there are even higher incentives to enforce MSVL. Federal subsidization, in addition to coverage by Medicaid and Medicare, enables states to provide vaccines for free or at low costs. State-specific immunization surveys from the 1960s and 70s indicate that vaccine uptake was consistently lowest among minorities and low-income groups. This is consistent with existing literature, which suggests 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 advances (Cutler and Lleras-Muney 2009; Glied and Lleras-Muney 2003). It is thus plausible that children from minority households or lower socioeconomic backgrounds may 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 the likelihood of high school completion by around 2 percentage points and years of schooling by approximately 0.12 years. Interestingly, the impact on non-whites is twice as large as that on whites. I also demonstrate that the impact of MSVL was not driven by education reforms that were triggered by the 1964 Civil Rights Act, such as

desegregation. Moreover, I show that the effect of MSVL increases with the strictness of enforcement and disease coverage, which lends further evidence to the causal link between childhood health and educational attainment.

There are several contributions to this paper. First, I provide evidence that reduced childhood exposure to vaccine-preventable diseases does have long-run consequences for adult human capital outcomes. This finding supports the "cohort morbidity phenotype", a theory first proposed by Finch and Crimmins in their 2004 seminal article in *Science*. "Cohort morbidity phenotype" provides a different but complementary view to the "fetal origins hypothesis". The "fetal origins hypothesis", which was developed by Barker (1990) and has been the focus of much of the existing economic literature, argues that inadequate nutrition in utero "programs" the fetus to have metabolic characteristics that can lead to future chronic health conditions, including cardiovascular disease, hypertension, and type 2 diabetes. The "cohort morbidity phenotype", on the other hand, emphasizes the idea that decreased inflammation from reduced exposure to infectious diseases during early life can lead directly to a decrease in morbidity and mortality resulting from chronic conditions in old age. The results of this paper imply that the magnitude of the impact of decreased exposure to infectious diseases is comparable to those found in the "fetal origins" literature, and even to some targeted education reforms. Second, while the focus on this paper is on the long-run consequences of childhood health, whether MSVL are effective in reducing childhood exposure to infectious diseases is *per se* an important policy question. The results from this study may help inform large-scale vaccination efforts that are ongoing in developing countries. Diseases that MSVL cover have fallen to close to zero rates, but are still endemic in developing countries. For example, measles fatality rates of around 3% are common in developing countries (Wolfson et al. 2009). 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 human capital 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.

II. Mandatory School Vaccination Laws in the United States

II.A. Why MSVL Are Necessary

The economic rationale behind MSVL 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. In other words, the unimmunized child "free-rides" on the herd immunity generated from high immunization rates surrounding her. 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, not to mention the effort required to take a child to receive multiple shots) associated with getting vaccinated 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. When disease rates are low, parents may also be under the impression that shots are no longer necessary. 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.

II.B. The Evolution of School Immunization Laws

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. 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. Similar legislation soon appeared in other states, especially states along the eastern seaboard that were part of the Union and faced more immediate danger from smallpox from a foreign force (Jackson 1969).

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.

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. A landmark case was when 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 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.[4]

[4] 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.

II.C. The Specifics of Modern MSVL

The terminology of MSVL after 1960, which I refer to as 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.[5] Although some states do require immunizations early in life, enforcement does not occur until entry to school – compulsory education makes it logistically possible and convenient for schools to be the site of enforcement. Modern MSVL typically cover a number of childhood illness, including measles, mumps, rubella, diphtheria, pertussis, polio, and tetanus.[6] These diseases were chosen because of their infectious nature (except for tetanus, which is potentially lethal but not infectious) and their health consequences. For example, while measles, mumps, rubella, and pertussis are rarely fatal on their own, they can lead to life-threatening consequences. There could also be serious negative spillover effects on other family members as well – 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. Even without any complications, students who contract any one of these diseases can be expected to be out of school for approximately 3 weeks. I discuss the health implications of contracting childhood infectious diseases further in Section III.

There are different levels of penalty for noncompliance across states as well. The common theme across states 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. In addition, some states consider violation of such

[5] 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.
[6] Smallpox vaccination requirements, which were the foundation of MSVL, have been discarded since the disease has been completely eradicated.

laws as a misdemeanor, while other states impose a fine or even jail sentence for violation for the statute. 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, and 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 in the period of interest.

IV.D. Existing Literature on MSVL

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 cross-sectional 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. Chaiken et al. (1987) examine the effect of the introduction of the mumps vaccination before entering school in 1978 in New Jersey. They find that the cohorts in middle school, who would not have been affected by the entry law, were seven times more likely to develop mumps ($p<.001$). However, these studies mainly 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 in identifying causal impacts if the states that choose to enact vaccination laws have other attributes that lead them to have lower incidence rates. To my knowledge, this is the first paper to fully examine the impact of MSVL on a national scale and the long-term consequences on adult human capital outcomes.

III. Conceptual Framework

In order to understand the potential links between childhood health and adult human capital outcomes, it may be helpful to consider a simple conceptual framework. The model presented in this section is largely adapted from Cunha and Heckman (2007): Consider a production function of human capital with a constant elasticity of substitution technology, where h is defined as human capital at the completion of childhood, and there is a 2 period childhood, before age 5 and after age 5.

$$h = A[\gamma I_1^{\phi} + (1-\gamma) I_2^{\phi}]^{1/\phi}, \tag{1}$$

where I_1 represents the investments in human capital in period 1, and I_2 in period 2. h is a two-dimensional measure of human capital representing both cognitive ability and health. As Cunha and Heckman (2007) notes, a growing body of evidence supports that there is complementarity between I_1 and I_2.

The implementation of MSVL can thus be interpreted as a positive shock, μ_s, in period 1 at the time of school entry. In the most basic case, investments are independent of μ_s and hence do not respond to μ_s, so that net investments in the first period are $I_1 + \mu_s > 0$. There will then be two effects of MSVL on subsequent human capital development. First, there may be direct biological effects. The targeted diseases can lead to dangerous complications with long-term negative consequences such as permanent brain damage, behavioral changes, mental retardation, or deafness. About 30% of measles cases develop one or more complications, including

pneumonia, which is the complication that is most often the cause of death in young children. Ear infections occur in about 1 in 10 measles cases and permanent loss of hearing can result. Encephalitis arises in roughly 1/1000 cases, which can lead to mental retardation or death (CDC 2004). Mumps could also lead to similar complications. Pertussis, or whooping cough, is an acute infectious disease that can cause violent coughing lasting up to several weeks, with complications including seizures and brain damage. Polio, diphtheria, and tetanus are considerably more deadly. Polio is a crippling and potentially deadly infectious disease with no cure. Diphtheria is a bacterial respiratory disease that could leads to airway obstruction and deaths in 1 out of 10 people. While tetanus is not an infectious disease, children are particularly susceptible because the bacteria that cause tetanus are found in soil. As many as one out of five people who contracts tetanus dies, and it can take months to fully recover from the disease. In general, the adverse effects of contracting an infectious disease are accentuated in malnourished children or those with compromised immune systems.

Even if complications do not arise, there is growing evidence that childhood exposure to infectious diseases could affect cognitive ability: in recent work, Bloom, Canning, and Seiguer (2012) show that full childhood vaccination for measles, polio, TB, and DPT significantly increases cognitive test scores relative to matched children who received no vaccinations using evidence from the Philippines. Moreover, early life exposures to infectious diseases may have adverse effects on health and well-being into adulthood (Case and Paxson 2009; Costa 2000). Finch and Crimmins (2004) provide evidence that childhood exposures to communicable diseases are associated with later morbidity and mortality in adulthood. In summary, reductions in childhood exposure to infectious diseases through MSVL could directly lead to persistent improvements in health and cognitive ability.

Second, MSVL could lead children to miss less school; typically, a child who contracts measles or one of these diseases (and do not develop complications) are out of school for up to three weeks. Driessen et al. (2009) find measles vaccination in Bangladesh increased school enrollment by around 9.5 percentage points, concentrated among males. They also find measles are often followed by diarrhea, leading to weight loss, and weight for age often does not fully catch up to pre-infection levels over time. Being in a more disease-free, and also less disruptive, environment may also enhance learning. This idea is consistent with Goodman (2012), who uses variation in snowfall to instrument for school absences and finds that school absences negatively impacts student test scores. He interprets this finding as school absences force teachers to expend time getting students on the same page as their classmates, and this effort in coordination of students negatively affects the quality of instructional time.

If investments are not independent of μ_s, then there may be responsive investments in the second period. Assume parent's utility trades off own consumption against their child's human capital: $U_p = U(C, h)$. Their budget constraint is comprised of:

$$Y_p = C + I_1 + I_2/(1 + r)$$

Again, if there is complementarity between childhood stages, then optimal period 2 investments should reinforce μ_s. Hence, given a positive health shock induced by MSVL, parents may in fact seek to increase I_2 and consume less depending on the degree of substitutability between the two periods. Thus, the reduced form impact of MSVL on educational attainment could be interpreted as the combined effects of biology and responsive investment.

Beyond these considerations, note that complementarity between the two periods will imply diminishing marginal productivity of the investment inputs. In other words, other things equal, those with lower level baseline levels of investment will experience a larger effect in h

than those whose baseline levels of investment are high. This may help explain why children from lower socioeconomic and minority backgrounds may benefit more from MSVL. Heckman also points out that "self-productivity" may be generated in such a model, which implies higher levels of capacity in one period create higher levels of capacity in future periods. In particular, in this context where h embodies both health and cognitive ability, this feature of positive "cross-effects" implies that improved health in period 1 leads to higher cognitive ability in period 2. MSVL led to improved health among children by substantially reducing morbidity rates, which could translate into healthier and cognitively-able adolescents.

IV. Data and Identification Strategy

IV.A. Morbidity and Mortality 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. The data are not without issues. First, 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. Second, there are a lot of years with missing data; in particular, the data for polio and diphtheria increasingly patchy after 1970. For all diseases, data missing in between years where data are available are interpolated. Because polio and diphtheria were close to being completely eradicated by 1970, I treat the missing data for polio and diphtheria after the last year for which data are available as zeros. The descriptive

statistics of the morbidity and mortality rates are reported in Panel A of Table 1. Appendix Figure 1 presents the time series graphs of the morbidity rates the seven diseases that are most commonly covered under MSVL, which are measles, mumps, rubella, diphtheria, polio, tetanus, and pertussis, from the years 1960 to 1990 (except for mumps and rubella for which data are only available onwards from 1968 and 1966, respectively).[7] The vertical line on each figure depicts when the vaccine first became publicly available. As it can be seen, the morbidity rates of all seven 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. However, there remained considerable variation to be explained in all diseases, which leads to the question of how much MSVL contributed to the total reduction in the diseases.

Next, the mortality data come 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. There is less of a missing data problem as compared to the morbidity data, but it should be noted that the means of mortality rates among the diseases of interest are already close to zero in the sample years. The descriptive statistics of the mortality rates are reported in Panel A of Appendix Table 1.

IV.B. Adult Outcomes

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 25 to 60 as they would presumably have completed their formal schooling. Table 1 reports the

[7] These numbers are recognized to be vastly underestimated, especially for the less severe diseases such as measles, mumps, and rubella, where cases are not reported to CDC. 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)

summary statistics of key variables. Years of completed schooling are defined by assigning a single number for typical years of education completed using the educational attainment variable in the IPUMS data (or the median number of years if a range is given).[8] High school completion is represented as a binary variable. Annual earnings refer to the total pre-tax wage and salary income for the previous year. Weekly earnings are annual earnings divided by the number of weeks that the respondent reported to have worked during the previous year.

IV.C. The Timing of MSVL

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. Jackson (1969) also has the status of MSVL for most states in 1969, which I use as a cross-validation. 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

[8] Specifically, the years of education is defined as 12 for having graduated high school or completing the GED, for an associate's degree, 16 for a bachelor's degree, 18 for master's degree, 20 for a professional degree, and 21 for a doctorate.

disease. Figure 1 displays the heterogeneous timing of the introduction of modern school vaccination laws. Figure 2 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. I further test this hypothesis in the Section IV.D.

IV.D. Identification Strategy

I use a differences-in-differences approach to identify the short-run and long-term impacts of MSVL. The identification strategy exploits the staggered timing of the introduction of MSVL. The validity of the approach rests upon the case that the timing of MSVL was independent of the error term, conditional on observables; more specifically, the timing should not be correlated with changes in education policies that could directly affect educational attainment. This is not a trivial assumption: the 1960s and 1970s in the U.S. witnessed a host of landmark education reforms, including school desegregation, the introduction of Head Start, and Title I grants. Further, hospital desegregation following the 1964 Civil Rights Act improved health care access for blacks. For example, Chay et al. (2008) find that hospital desegregation led to substantial improvements in black neonatal mortality rates. The larger effect I find of MSVL on non-whites could thus also be confounded.

I address these concerns in several ways. First, I provide evidence that the timing of MSVL was driven primarily by historical factors, rather than reasons related to socioeconomic factors or state differences in education policies. Second, I control for a number of school quality measures in certain specifications, which should help capture any state-level varying policy attitudes towards education. Third, I present several robustness and falsification tests to ensure the effects observed are due to MSVL and not other contemporaneous programs.

IV.D.1. Timing of Modern MSVL

Jackson (1969) argues that the timing of modern MSVL was in fact driven primarily by whether the state already had a smallpox immunization law in place. He notes that the states to first pass modern MSVL were mainly east of the Mississippi River, especially those along the eastern seaboard. These states were also the first of the Union and faced more immediate danger from the introduction of smallpox from a foreign force, and hence tend to already have legislation for compulsory smallpox vaccination before the advent of modern MSVL. Unsurprisingly, it was easier for a state that already had a smallpox vaccination law to add other immunization requirements to it. Although other states recognized the importance of enacting school immunization mandates, writing a completely new law on compulsory immunization proved to be difficult in some states, leading to the staggered timing across states, although all states implemented MSVL by 1980. Jackson (1969) also observed that states with large populations, especially those with dense urban population would have more compelling reasons to pass MSVL, although he does not provide empirical evidence for his hypotheses.

I examine the correlation between the timing of MSVL and a host of state characteristics using a Weibull duration model, with the dependent variable equal to the number of years after 1963 (the first year the measles vaccine was publicly licensed) that the state implements a school immunization law for measles. The predictors included in the model are whether the state has a historical smallpox immunization law, and the following covariates from 1963: log measles rate, the pupil-teacher ratio, relative teacher pay, log average expenditures per student, percent urban, percent black, log population, percent of population under 5, between 5 and 17, 45 and 64, and over 65. The coefficients are presented in Table 2. As it can be seen, the only coefficient that is statistically different from zero is that on whether the state has a historical mandate for smallpox

vaccination – states that require smallpox vaccination for school entry are considerably more likely to pass measles immunization mandates sooner. The only other covariate that comes close to becoming statistically significant is the percent of population between 5 and 17, which is consistent with the anecdotal evidence that states with larger school population have stronger incentives to enact MSVL. The coefficients on the education variables and of other state characteristics are not statistically differentiable from zero. Since whether a state has a smallpox law is determined largely by geographic factors, this test provides some evidence that MSVL could be interpreted as plausibly exogenous.

V. Regression Results

V.A. Morbidity and Mortality

I begin by examining the impact of MSVL on childhood health as measured by morbidity and mortality 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. As discussed earlier, while some states introduced MSVL for all diseases at once, other states implemented coverage for different diseases at different times. In this section, I consider the timing for the specific disease when examining the impact on incidence rates.

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 density of the number of disease cases in state s in year t, d_{st}, is therefore:

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

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, and the percent of population between 5 and 17. γ_s and δ_t are the state and year fixed effects, respectively. I also include state-specific time trends in certain specifications.

The estimates of α_1 for the six most targeted diseases are reported in the top panel of Table 3. 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. The inclusion of mumps in the vaccination schedule led to a reduction of 41 percent in mumps, which accounts for approximately the same percent of the overall reduction in mumps. However, the magnitude of the effect falls substantially when including state-specific time trends. Overall, it appears that MSVL also led to a significant decline in rubella, diphtheria and polio. Somewhat surprisingly, there were no statistically significant effects on pertussis or tetanus, but this could be masked by the widespread resistance to the pertussis vaccine due to public anxiety (CDC 2004).

As a falsification test, I also include several diseases that were not covered under compulsory immunization mandates 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 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.[9] 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. Finally, I include an event study of the impact on measles rates in Figure 3. There is a clear and sharp discontinuous drop in measles after the mandatory school vaccination schedule included measles, which lends support to the hypothesis that MSVL led to a substantial decline in measles incidence rates. I present similar graphs using the introduction of when measles became mandated on hepatitis B and meningitis as falsification tests, and there is no visible impact of mandating the measles vaccine on either disease.

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 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-

[9] 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.

aged children, so even before vaccines for those diseases were invented, mortality rates due to these diseases were 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 seven 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 0.02 per 100,000 over the entire sample period (1968-1988), and 0.04 from 1968-1970. (The incidence rates for the other targeted diseases are under 0.01.) 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 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 Appendix Table 1 depicts, there was a negative but not statistically significant effect on the mortality rate of measles, for either the 5-14 cohort or the 25-34 cohort. There are no discernible impacts on the mortality rates of hepatitis, chickenpox, or meningitis, for either cohort. The results suggest the role school vaccination laws played on childhood health was on reducing morbidity rather than mortality.

V.B. Adult Educational Attainment

There could be a number of channels through which a positive shock to childhood health could lead to increased educational attainment, as explored through the conceptual framework introduced in Section III. First, there could be a direct biological effect on cognitive ability and health. Second, children may miss less school and also learn better when there are fewer disruptions from outbreaks. Third, there could be responsive investments from parents – parents

may reinforce the positive shock on health by investing more in their children's human capital. The second part of the analysis examines the reduced form impact on adult human capital outcomes, focusing mainly on educational attainment as measured by years of schooling and probability of high school completion. The empirical strategy is analogous to before. I employ a differences-in-differences strategy to compare the education outcomes of children who were "treated" by MSVL versus those who were not, relative to individuals in other states. More specifically, an individual is considered to be "treated" if MSVL has been implemented in her birth state by the time she turns 5, the youngest age at which children enter formal schooling in U.S. The impact is therefore identified by comparing the mean terminal educational attainment of the treated versus untreated cohorts in a state, relative to the that in other states where MSVL have yet to be passed. I define the treatment group in a state as all individuals who were younger than 5 in the year of MSVL took effect, and the control group as those who were older than 12 in the state. Individuals between the ages 6 and 12 when MSVL began in that state are omitted from the sample: even though MSVL targeted children entering school for the first time, there could be positive spillover effects on the rest of the grades in elementary school. In addition, while all states began MSVL by mandating vaccinations for first time school entrants, some states eventually amended such laws to cover the rest of the school population. Hence, cohorts between ages 6 and 12 are not included as they may not form an appropriate control group. Finally, I base the analysis using state of birth as the state identifier, which is arguably be a more appropriate proxy than state of residence for the status of MSVL at age 5.

The estimating equation for examining adult human capital outcomes is:

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

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 compulsory school vaccinations have been implemented in state of birth j of the individual belonging to birth year cohort b at age 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_{ijby}– gender and race. Z_{jb} includes a set of state-specific demographic, economic, and education controls associated with the birth cohort at age 5, including log disposable income per capita, unemployment rate, pupil-teacher ratio, relative teacher pay, and expenditure per pupil in public schools.[10] ε_{ijby} is the usual error term. Standard errors are clustered by state of birth to allow for serial correlation within state.

I report the regression results from estimating Equation (3) in Table 4. I first use the high school completion as the dependent variable, estimated as a linear probability model (Panel A), and the second measure of educational attainment I use is the years of schooling. Column 1 of Panel A 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. In Column 3, I include a placebo dummy which turns on which is set to unity if MSVL were introduced in the

[10] 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.

individual's state of birth before the individual entered high school. Since MSVL affected first time school entrants, individuals entering high school should not be affected. I also include state-specific quadratic time trends in Column 4.

The results in Columns 1 to 3 indicate that MSVL increased the probability of high school completion by around 1.9 percentage points, and the years of schooling by 0.12 years, and. The placebo dummy in both Panels A and B are close to zero and statistically insignificant (and the null hypothesis that the two estimates of *MSVL* and *Placebo* are equal can be rejected at the 1 percent level.) However, the inclusion of state-specific time trends brings the magnitude of the estimate down substantially, although the coefficient remains statistically different from zero.[11]

V.B.I. Interpretation of Results

The results found in this section seem to be sizeable but not unreasonable when compared to other large-scale education or health circumstances. Among the "fetals origins" literature, Almond (2006) demonstrate that cohorts *in utero* during the height of the 1918 Influenza Pandemic had 0.75 fewer years of schooling and 6 percent lower high school graduation rate. In addition, the cohorts who were more affected by the pandemic had 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. Field, Robles, and Torero (2009) find that prenatal iodine supplementation raised

[11] However, including state-specific time trends may not be the most appropriate specification in this case for several reasons. First, as Wolfers (2006) notes, imposing panel-specific trends may pick up not only different preexisting trends across states, but also differences in the evolution of educational attainment subsequent to the adoption of MSVL. Second, educational attainment was trending in a very non-linear fashion during the period of interest (where it was on an upward trend for birth cohorts up until around 1950, decreased until 1965, and rose again to a peak for cohorts born in 1970). Adding a time trend may hence swamp any effects of the policy.

educational attainment in Tanzania by half a year of schooling, with larger impacts for girls. Further evidence from developing countries demonstrate malaria interventions targeted towards children increase cognitive test scores and educational attainment (Clarke et al. 2009, Lucas 2010, Cutler et al. 2010). Driessen et al. (2009) find measles vaccination in Bangladesh increased school enrollment by around 9.5 percentage points, concentrated among males. 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.

Among the somewhat more limited literature on early childhood health environments, Bleakley (2008) finds that hookworm eradication increased school enrollment by approximately 20 percent and literacy by 13 percent. Further, children with higher exposure to the eradication campaign were more likely to be literate and earn higher incomes as adults, and increased years of schooling of blacks by around 0.10. Baird et al. (2012) follows up on the long-run effects of a randomized experiment consisting of deworming of school-aged children in Kenya, and find that deworming increased mean hours of work by 12% and substantive impact on earnings.[12]

The estimates found in this paper are smaller in magnitude but still comparable to large scale early education interventions. Garces, Thomas and Currie (2001) find that whites who attended Head Start are around 20 percent more likely to complete high school and 28 percent more likely to attend college than siblings who did not attend. Campbell and Ramey (1994) examine the long term impact of the Carolina Abecedarian Project and find that children who received the preschool treatment had higher average test scores and were twice as likely to still be in school at age 21. Relatedly, the Perry Preschool program has been demonstrated to increase

[12] The short-run results of this randomized experiment were reported in Miguel and Kremer (2004), where they find deworming increased school participation and attendance.

test scores, high school completion and adult earnings. Temple et al provide evidence that another pre-school enrichment program, Chicago Child-Parent Centers (CPC), reduced high school dropout by 24%, and the size of the effect grows with the time children spent in the program. However, these effects are not scaled by dollar amounts. A more detailed cost-benefit analysis may potentially reveal that MSVL as being more cost-effective than such education programs, which tend to be costly and therefore also unable to benefit a large population.

As discussed in Section III, there could be a number of mechanisms that improved childhood health induced by MSVL could lead to higher educational attainment. One contributing factor could be that children were missing less school due to contracting fewer infectious diseases. There are a number of studies that examine more time spent in school lead to improved academic outcomes. For example, Pischke (2007) exploits variation in instructional time created by the German “short school years” of 1966 and 1967 and finds that the shorter school years (13 fewer weeks of instruction each year) were associated with a small increase in grade repetition in primary school and a decrease in enrollment in more advanced secondary school tracks. Fitzpatrick et al. (2011) exploits quasi-random variation in the timing of test taking to measure the average effect of an additional day between tests, and find robust statistically significant test score gains for additional time spent in school. Similarly, Hansen (2008) exploits changes in the number of school days missed due to inclement weather and also finds that more time spent in school before tests improves student performance on state-wide exams. Unfortunately, these papers focus on test scores rather than longer term education outcomes, so it is not possible to perform a back-of-the-envelope calculation to see how missing three weeks of

school would affect educational attainment.[13] Nonetheless, the results are qualitatively consistent – if children are missing fewer days of school because of vaccine protection, their academic performance may improve and potentially lead to higher educational attainment.

V.C. Adult Wages and Labor Market Outcomes

Next, I investigate the impact of MSVL on 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 signaling model.

The results are reported in Table 5. It appears that on average, MSVL increased labor force participation (estimated as a linear probability model) as well as weeks worked. Next, I explore the impact of MSVL on log wages and occupational standing measures. Occupational standing measures exhibit a marked improvement, but this could be driven by the fact that individuals who are not in the labor force are included in the sample (as they are assigned zeros). While there is a positive impact on measures of occupational standing, the coefficient of wages is not statistically different from zero. However, the lack of result could be masked by women not in the labor force or by individuals near retirement. Hence I examine the effects by gender, restricted to ages 30 to 55, by gender in Panels B and C. While MSVL increased labor force participation for both genders, there is indeed a more obvious impact on wages for males, but less for females.

[13] There are a number of papers that investigate how school entry age affects educational outcomes. However, the results from those papers are not appropriate for use in this exercise because there may be multiple interacting effects associated with such laws, as discussed in Bedard and Dhuey (2007).

V.D. Heterogeneous Effects by Race

According to surveys 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 examine whether there are heterogeneous effects of mandatory school vaccination laws by race. If non-minority parents were already vaccinating their children before compulsory immunization, then it is conceivable that mandatory school vaccination laws benefit students from minority backgrounds more. The results in Table 6 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.[14] This result is also consistent with Cunha and Heckman (2007), who have documented from a variety of intervention studies that ability gaps in children from different socioeconomic groups can be reduced if remediation is attempted at early ages. Further, the remediation efforts that appear to be most effective are those that supplement family environments for disadvantaged children.

VI. Robustness Checks

The primary threat to the identification strategy is that states that implement MSVL may also be carrying out other programs that could potentially affect health and educational attainment. Although I control for educational inputs in the full specification of the education regressions, they may not fully capture concurrent programs and hence lead to spurious results. In particular, hospital and school desegregation began after the 1964 Civil Rights Act. As Almond et al. (2008) detailed, hospital desegregation happened fairly rapidly between 1964 and

[14] If we accept these results at face value, they would imply MSVL were responsible for roughly half of the increase in educational attainment among non-white birth cohorts born between 1945 and 1975.

1965. School desegregation occurred at a more gradual pace – complicating matters further is that school desegregation occurred across districts within states at various paces (Cascio et al. 2010), so it is difficult to directly control for using state-level data. In addition to desegregation efforts, other programs that could potentially have confounded the results in this paper include Head Start, a federal program which began as part of the "War on Poverty" in 1965 and provided public preschool program for disadvantaged children.

I present several robustness checks to confirm the validity of the results on educational attainment. The first attempts to capture the impact of desegregation. I examine the impact of MSVL on high school completion for segregated states, non-segregated states, and for non-whites in all states. In Column 1 of Table 7, I look at the impact of MSVL and also include an indicator for nonwhite cohorts who enter school for the first time after the 1964 Civil Rights Act (as well as the relevant double interaction terms).[15] The results are revealing – although desegregation did increase high school completion rates substantially for non-whites relative to whites, the impact of MSVL remains significant, and we still observe a larger impact on non-whites relative to whites. I turn to examine the impact of MSVL in non-segregated states. If it were the case that the results were confounded by desegregation efforts, then we should not see an effect of MSVL in non-segregated states. As it can be seen in Column 2, the effect of MSVL still holds (although the effect for whites is smaller). Finally, I look at the impact for non-whites only, for all states. Since the

Nonetheless, the interaction terms in Table 6 are only imprecise proxies, and one may remain concerned that the aforementioned programs or other state reforms are not sufficiently controlled for. I further address this concern in two ways. First, I exploit the degree of penalty for

[15] To the extent the "War on Poverty" and HeadStart occurred after 1965, fixed effects for birth cohorts should help absorb some of its effects.

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 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 9, 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.

VII. 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. I show that school immunization laws have played a key role in reducing vaccine-preventable diseases in the U.S., thus improving the childhood health of the affected cohorts, and the same cohorts eventually achieved higher levels of educational attainment. The results also suggest that compulsory school vaccination laws deserve their position among the roster of large-scale health interventions in the last century. Previous work has already proven childhood immunization as being extremely cost-effective. Coffield et al. (2001) ranked childhood immunization as the most cost-effective service among thirty clinical preventive services. Zhou et al. (2001) estimated that for every dollar invested in childhood vaccination, $5.8 are saved in direct medical costs, and the savings rise to $17.7 when indirect benefits (such as parents taking time off) are included. The results from this paper imply the

previous estimates may be downward biased and savings would even be higher when accounting for the long-run benefits on education. However, more work remains on investigating the precise mechanisms through which childhood health improves adult human capital outcomes.

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Figures and Tables

Figure 1 – Timing of Mandatory School Vaccination Laws

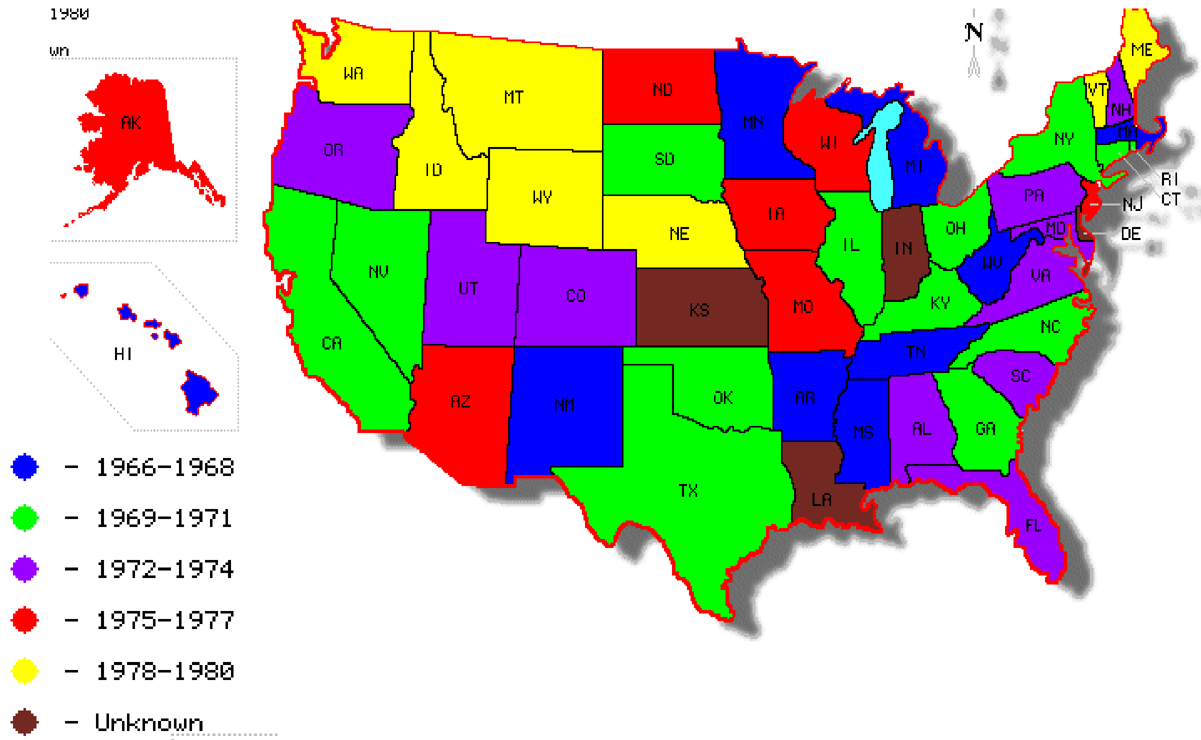


Figure 2 – Pre-vaccine Measles Rate by Percentile

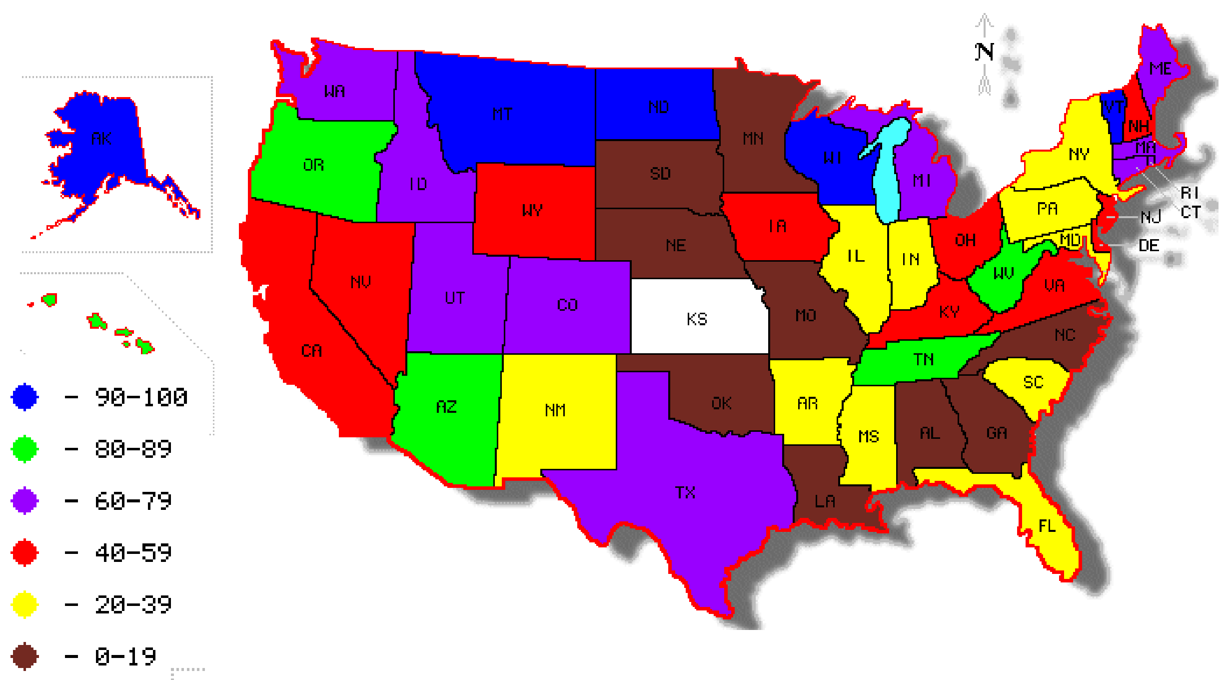


Table 1 – Descriptive Statistics of Key Variables

Panel A - Morbidity Rates, 1960-1990	Mean	s.d.
Measles	67.70	152.91
Mumps	24.64	49.19
Rubella	11.92	22.70
Diphtheria	0.17	0.46
Pertussis	3.27	6.15
Tetanus	0.12	0.14
Polio	0.12	0.45
Hepatitis B	6.14	5.32
Meningitis	2.80	3.27
Salmonella	13.03	11.08

Panel B - Educational Attainment, Ages 25-60	Mean	s.d.
Years of completed schooling	13.46	2.50
High School Completion	0.86	0.34
Labor Force Participation	0.84	0.36
Weeks worked last year	39.22	19.83
Weekly Wages (in 2000$)	709.60	1229.42
Occupational Income Score	25.52	12.49
Duncan Socioeconomic Index	40.62	25.98
Non-white	0.10	0.31
Male	0.49	0.50

- Panel A: Rates are calculated as the number of cases per 100,000 population.
- Underlying data in Panel A are from the CDC National Notifiable Disease Surveillance System.
- Underlying data in Panel B are from the IPUMS 1990 and 2000 1-percent samples.

Table 2 – Maximum Likelihood Weibull Duration Model Estimates of the Relationship Between State Characteristics and the Introduction of MSVL

Covariates based on 1963 Levels	Coefficient
Log (Average of Measles Rate, 1960-1963)	-0.200
	(0.208)
1(Smallpox Vaccination Law in Place)	1.493**
	(0.721)
Pupil-Teacher Ratio	-0.028
	(0.157)
Relative Teacher's Pay	-0.035
	(1.324)
Average Adult Educational Attainment	-0.343
	(3.163)
Log Disposable Income per capita (in 2000 $)	-2.610
	(5.122)
Percent in Metro Area	0.046
	(0.042)
Unemployment Rate	0.023
	(0.195)
Percent of population under 5	0.262
	(0.564)
Percent of population between 5-17	0.670
	(0.412)
Percent of Population between 45-64	0.178
	(0.455)
Percent of Population over 65	0.520
	(0.430)
Percent Black	-0.018
	(0.050)
Log(Population)	-0.018
	(0.050)
Sample Size	49

* significant at 10% ** significant at 5% *** significant at 1%

- 1963 is the first year the measles vaccine became licensed to the public

Table 3 – The Impact of MSVL on Morbidity

	Diseases covered under MSVL					
	Measles		Mumps		Rubella	
MSVL	-0.448***	-0.420**	-0.418***	-0.253*	-0.258*	-0.413***
	(0.164)	(0.214)	(0.151)	(0.147)	(0.155)	(0.156)
Time trends		✓		✓		✓
Obs	1,578	1,578	1,150	1,150	1,095	1,095

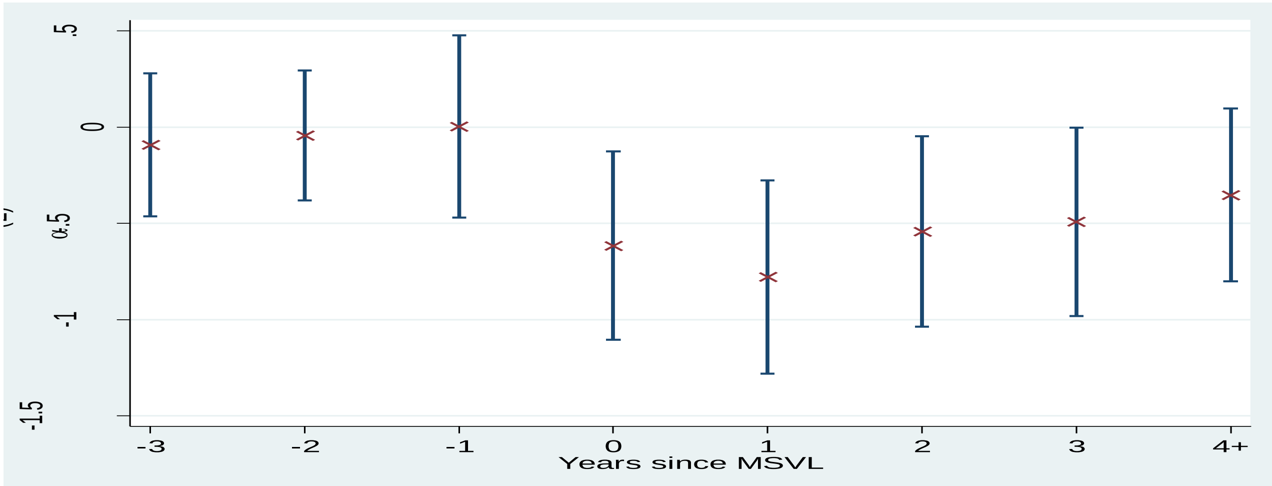
	Diseases covered under MSVL					
	Pertussis		Tetanus		Diphtheria	Polio
MSVL	-0.123	0.120	-0.073	0.050	-1.531***	-0.568***
	(0.180)	(0.121)	(0.066)	(0.061)	(0.618)	(0.230)
Time trends		✓		✓		
Obs	1,500	1,500	1,561	1,561	1,486	1,532

	Diseases not covered under MSVL					
	Hepatitis B		Meningitis		Salmonella	
MSVL	-0.012	-0.100	-0.043	0.018	-0.042	-0.062
	(0.161)	(0.079)	(0.124)	(0.082)	(0.079)	(0.064)
Time trends		✓		✓		✓
Obs	1,215	1,215	1,348	1,348	1,483	1,483

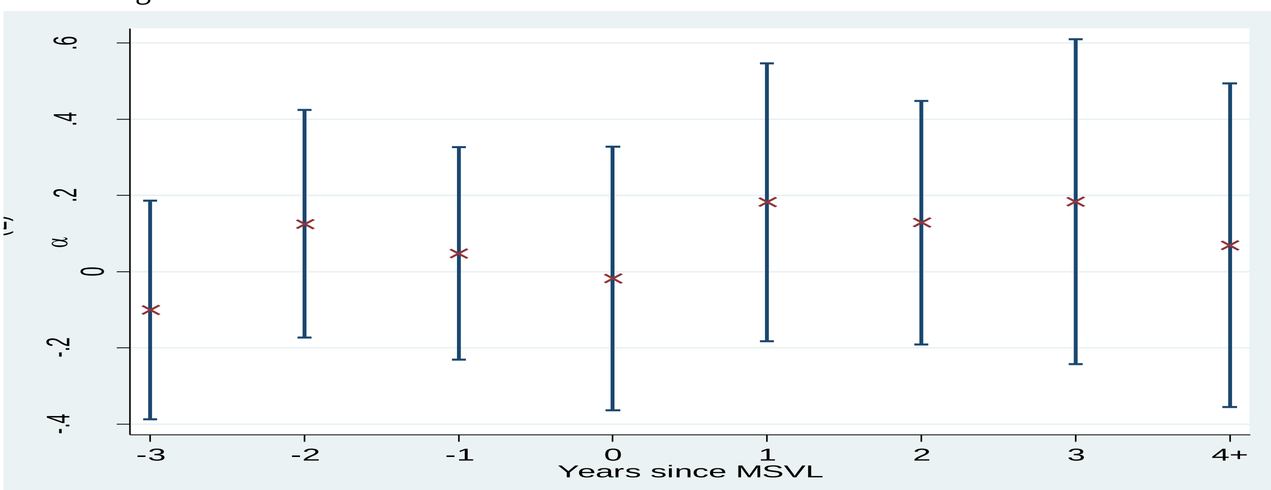
- Regressions are estimated as Poisson models with population as the exposure variable.
- Standard errors presented in parentheses are clustered by state.
- All regressions include fixed effects for state and year.
- Underlying data in Panel A are from the CDC National Notifiable Disease Surveillance System.

Figure 3 – The Impact of MSVL on Measles, Hepatitis B, and Meningitis

A. Measles



B. Meningitis



C. Hepatitis

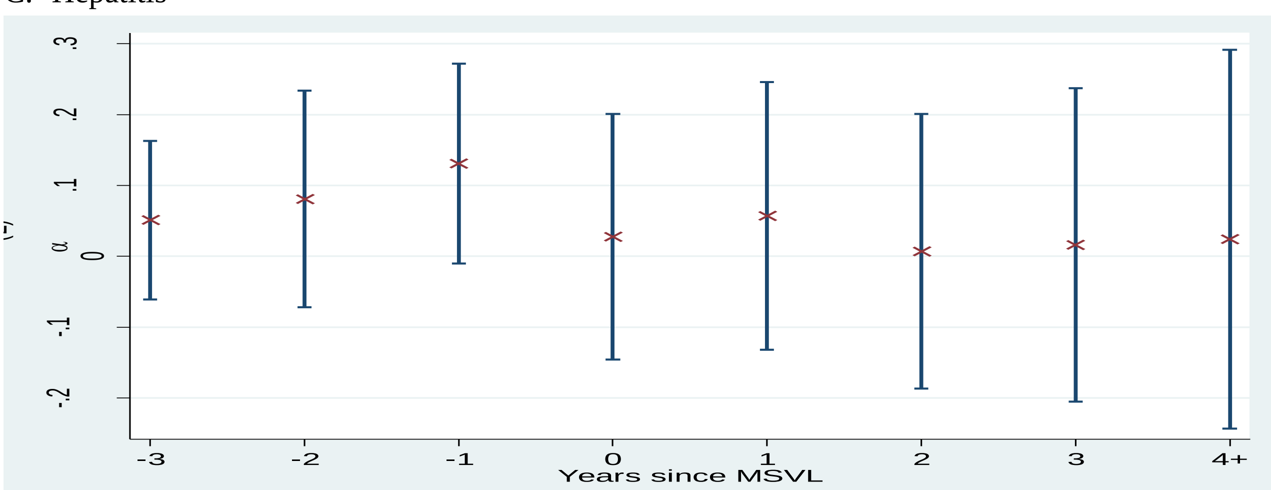


Table 4 – The Impact of MSVL on Adult Educational Attainment

	(1)	(2)	(3)	(4)
Panel A		High School Completion		
MSVL	0.0205**	0.0190**	0.0195***	0.0079**
	(0.0082)	(0.0077)	(0.0069)	(0.0039)
Placebo			-0.0008	
			(0.0031)	
State controls		✓	✓	✓
Time trends				✓

	(1)	(2)	(3)	(4)
Panel B		Years of Schooling		
MSVL	0.1288**	0.1224**	0.1177**	0.0370*
	(0.0626)	(0.0608)	(0.0546)	(0.0219)
Placebo			0.0089	
			(0.0210)	
State controls		✓	✓	✓
Time trends				✓

- Standard errors presented in parentheses are clustered by state of birth.
- All regressions include fixed effects for race, gender, 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.
- State controls include pupil-staff ratio, relative teacher's pay, inflation-adjusted disposable income per capita, unemployment rate, and percent of population between 5 and 17 associated with the birth cohort at age 5.
- Underlying data are from the IPUMS 1990 and 2000 1-percent samples. # of observations = 1,640,634.

Table 5 –The Impact of MSVL on Labor Market Outcomes

	Labor Force Participation	Weeks Worked	Occupational Income Score	Socio-economic Index	Log Annual Wages	Log Weekly Wages
MSVL	0.0098**	0.5577***	0.4094***	1.0396***	0.0039	0.0018
	(0.0038)	(0.1840)	(0.1226)	(0.3108)	(0.0122)	(0.0104)
Obs	1,616,980	1,616,980	1,616,980	1,616,980	1,263,278	1,263,278
			Males (30-55)			
MSVL	0.0075**	0.3081*	0.3891*	1.2580***	0.0182	0.0226*
	(0.0029)	(0.1793)	(0.1963)	(0.4172)	(0.0115)	(0.0116)
Obs	613,845	613,845	613,845	613,845	514,267	514,267
			Females (30-55)			
MSVL	0.0167**	0.7477	0.5540**	1.0110*	-0.0122	-0.0086
	(0.0074)	(0.4521)	(0.2172)	(0.5266)	(0.0155)	(0.0126)
Obs	648,100	648,100	648,100	648,100	477,217	477,217

- 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.
- The following controls are included: age, age-squared, dummies for farm households, metro area, marital status, number of children, as well as pupil-staff ratio, relative teacher's pay, inflation-adjusted disposable income per capita, unemployment rate, and percent of population
- Underlying data are from the IPUMS 1990 and 2000 1-percent samples.

Table 6 – Heterogeneous Effects by Race: The Impact of Mandatory School Vaccination Laws on Adult Outcomes

	Years of Schooling	High School Completion
MSVL	0.1023*	0.0126*
	(0.0582)	(0.0070)
Non-white * MSVL	0.1294**	0.0421***
	(0.0631)	(0.0101)
Effect on Non-whites	0.2316***	0.0547***
	(0.0819)	(0.0116)

Males, Ages 30-55	Labor Force Participation	Log Weekly Earnings	Occupational Income Score
MSVL	0.0083**	0.0083**	0.2811**
	(0.0037)	(0.0037)	(0.1166)
Non-white * MSVL	0.0087**	0.0087**	0.7969***
	(0.0037)	(0.0037)	(0.1479)
Effect on Non-whites	0.0171***	0.0171***	1.0780***
	(0.0048)	(0.0048)	(0.1651)

- 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.
- The following controls are included: age, age-squared, dummies for farm households, metro area, marital status, number of children, as well as pupil-staff ratio, relative teacher's pay, inflation-adjusted disposable income per capita, unemployment rate, and percent of population between 5 and 17 associated with the birth cohort at age 5.
- Underlying data are from the IPUMS 1990 and 2000 1-percent samples.

Table 7 – Are Results Confounded by Desegregation?

Sample:	High School Completion Segregated States	 Non-Segregated States
	(1)	(2)
MSVL	0.0370***	0.0103**
	(0.0067)	(0.0051)
MSVL * Non-white	0.0139*	0.0107*
	(0.0084)	(0.0055)
Post-Civil Rights Act * Non-white	0.0383***	
	(0.0125)	
Obs	542,523	1,012,523

- Standard errors presented in parentheses are clustered by state of birth.
- All regressions include fixed effects for race, gender, 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.
- State controls include pupil-staff ratio, relative teacher's pay, inflation-adjusted disposable income per capita, unemployment rate, and percent of population between 5 and 17 associated with the birth cohort at age 5.

Table 8 – The Effect of MSVL on Educational Attainment, by Degree of Penalty

	High School Completion	Years of Schooling
MSVL	0.0063	0.0367
	(0.0071)	(0.0562)
MSVL * fine	0.0286**	0.1713**
	(0.0140)	(0.1084)
MSVL * (fine + misdemeanor charge)	0.0563***	0.3640***
	(0.0127)	(0.0764)

- Standard errors presented in parentheses are clustered by state of birth.
- All regressions include fixed effects for race, gender, 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.
- 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.
- Underlying data are from the IPUMS 1990 and 2000 1-percent samples. # of obs = 1,600,622

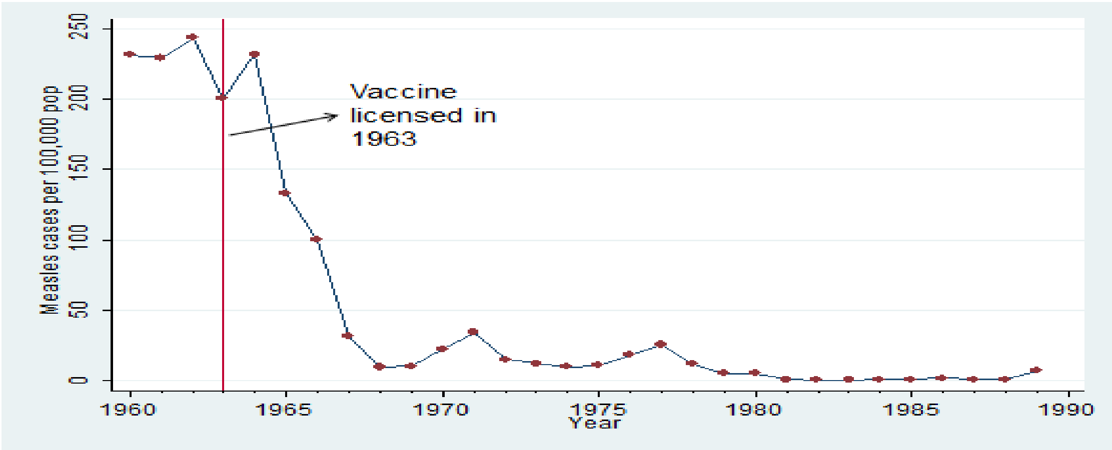
Table 9 – The Effect of MSVL on Educational Attainment, by Degree of Disease Coverage

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

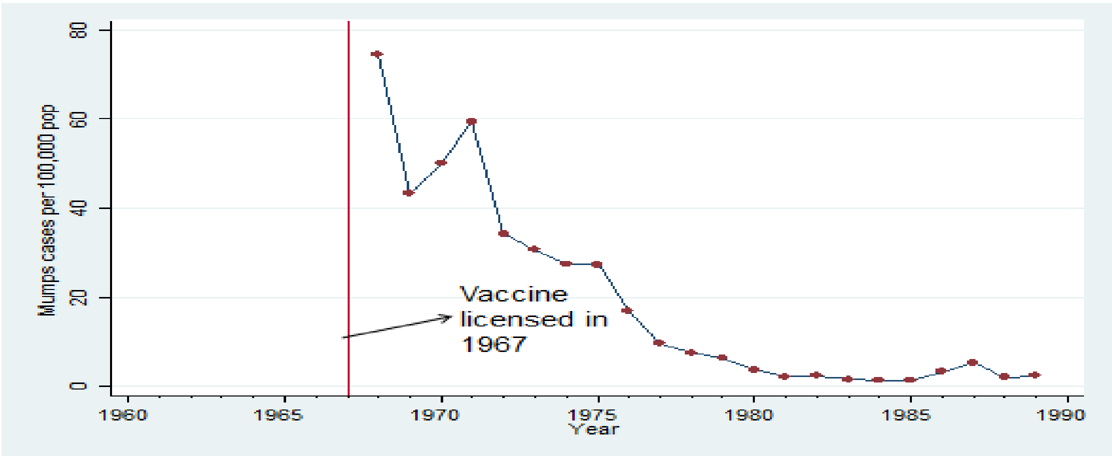
- Standard errors presented in parentheses are clustered by state of birth.
- All regressions include fixed effects for race, gender, year of birth, state of birth, and Census yea
- Number of diseases covered represent the number of diseases vaccinations are required for entering school before age of 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.
- State controls include pupil-staff ratio, relative teacher's pay, inflation-adjusted disposable income per capita, unemployment rate, and percent of population between 5 and 17 associated with the birth cohort at age 5.
- Underlying data are from the IPUMS 1990 and 2000 1-percent samples. # of obs = 1,600,622

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

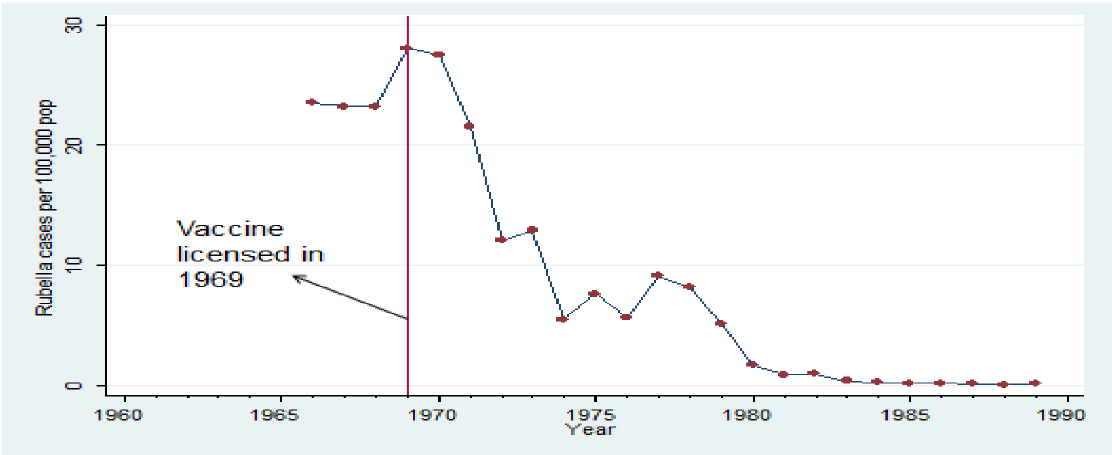
Measles



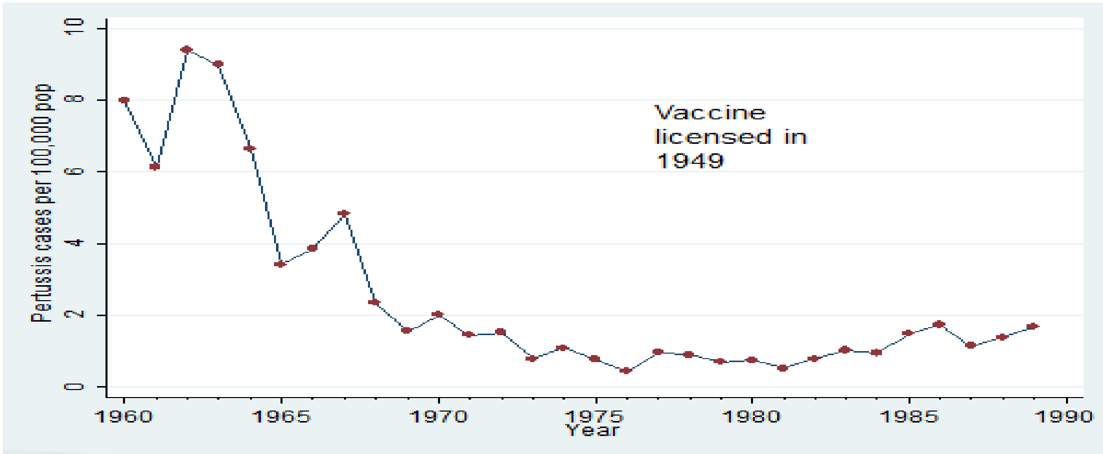
Mumps



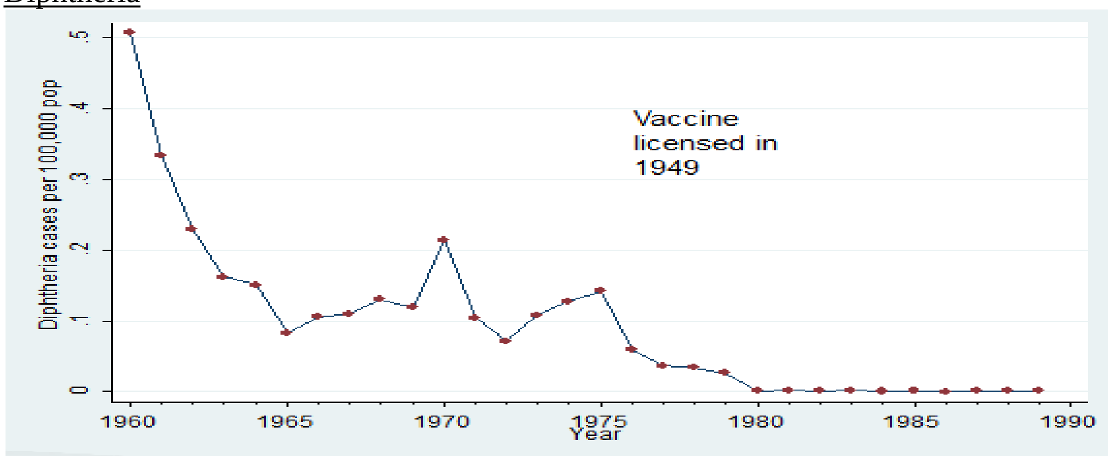
Rubella



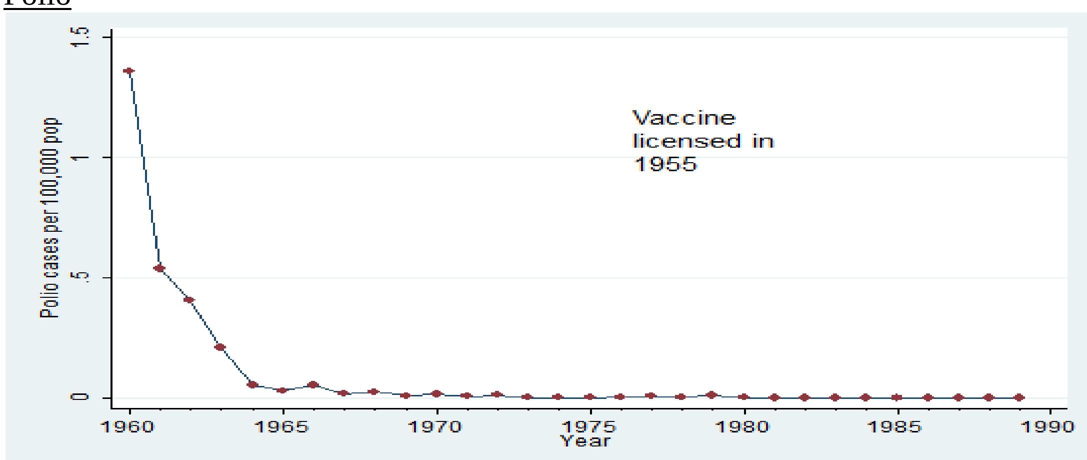
Pertussis



Diphtheria



Polio



Appendix Table 1 – The Impact of MSVL on Childhood Mortality

Panel A: Mortality Rates, 1968-1988

Age Group:	5-14		25-34	
	Mean	s.d.	Mean	s.d.
Measles	0.0166	(0.0626)	0.0029	(0.0253)
Mumps	0.0047	(0.0292)	0.0003	(0.0046)
Rubella	0.0049	(0.0351)	0.0006	(0.0077)
Pertussis	0.0008	(0.0114)	0.0001	(0.0018)
Diphtheria	0.0072	(0.0501)	0.0014	(0.0271)
Polio	0.0015	(0.0183)	0.0033	(0.0314)
Hepatitis	0.0554	(0.1529)	0.3318	(0.3241)
Meningitis	0.1825	(0.2760)	0.1574	(0.2850)
Chickenpox	0.1041	(0.2061)	0.0291	(0.1556)

Panel B: The Impact of MSVL on Mortality

5-14 y.o.s	Measles	Hepatitis	Chickenpox	Meningitis
MSVL	-0.730	0.016	-0.060	-0.054
	(0.462)	(0.237)	(0.155)	(0.115)

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)

- Regressions are estimated using a Poisson model 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.